Reoperations on Thoracic Aorta and Aortic Root: Surgical Technique and Pitfalls

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Abstract

Keywords

- ascending aorta
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- reoperation
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- myocardial protection
- extracorporeal membrane oxygenator
- circulatory arrest

Repeat operations involving the aortic root, ascending aorta, and arch (proximal aorta) are technically challenging. These procedures are associated with higher operative mortality and morbidity. A dedicated surgical team with special skill set is essential to manage these complex patients. Redo root and proximal aortic procedures can be done with acceptable risk in most patients with attention to details involving the surgical procedure, patient selection, and perioperative management.

Elective primary repair of aortic root, ascending aorta, and proximal arch can be done with low operative mortality.¹ Crawford et al published one of the earliest article in 1985. In their series, redo surgery was done on the root and proximal aorta in 59 patients with early mortality of 17%.² Multiple published reports have shown that redo procedures involving the aortic root and proximal aorta carry higher mortality.^{2–5} Short-term mortality with reoperations has improved with more experience in doing the procedure and better surgical techniques in redo coronary artery bypass grafting⁶ and redo aortic valve replacement (AVR).⁷ This has shown to be true with redo surgery involving the aortic root and proximal aorta.⁸ A robust surveillance program is essential after any aortic aneurysm surgery. Routine surveillance either with computed tomography angiography (CTA), magnetic resonance imaging (MRI), or echocardiography at specified intervals can detect the problem sooner.⁹ In our center, we follow all our patients following acute type A dissection repair with a contrast CTA at 3, 6 to 9 months, and annually for 5 years if the CTA shows stability of the remnant false and true lumen. If there is any increase in the size of false lumen, we follow all the patients at a shorter interval, every 6 months. Elective aneurysm repair patients are followed up with contrast CTA at

6 months for a year and annually after that if stable. Aneurysms without rupture or dissection are also followed up using a standard protocol.

Patient Presentation and Evaluation

Patients are referred with a new diagnosis of enlarging aneurysm of unresected segment, pseudoaneurysm (►Fig. 1), degenerated autograft (►Fig. 2), new dissection, graft infection, or aortic valve pathology. Some patients are selected from our aortic clinic surveillance program. We will routinely obtain a CTA of the chest and include abdomen and pelvis if needed. Obtain an echocardiogram, preferably a transesophageal echocardiogram (TEE) to assess the myocardial function, aortic valve, and other valve pathologies (►Fig. 3). Stable patients with no emergent need for surgery will have coronary angiogram, pulmonary function testing, and carotid duplex scans to assess their risk for surgery. CTA is probably the most valuable diagnostic test as it will guide us to plan the correct surgery. After all the testing is done, operative risk assessment is done. Society of Thoracic Surgeons risk calculator does not have a risk model for aneurysm surgery and EuroSCORE I and EuroSCORE II can be used to guide the decision-making process but are not

Fig. 1 Pseudoaneurysm of the aortic root with prior stentless valve root replacement for endocarditis.

well validated for aneurysm surgery alone. As such there is no calculator to assess the risk of aneurysm surgery, either primary or redo.¹⁰

Surgical Planning

Review the CTA to assess the proximity of the aorta, right ventricle (RV), and coronary grafts to the sternum to avoid catastrophic sternal re-entry. CTA can also help make a decision about cannulation options for cardiopulmonary bypass (CPB) and cerebral protection strategies. We routinely place an arterial pressure monitoring line (A-line) in the right radial artery and a femoral artery. Right radial pressure line is essential to monitor perfusion pressure if right axillary/subclavian artery is used for CPB. We place a femoral A-line to be used in case of emergent access for arterial cannulation for CPB, intraaortic balloon pump (IABP) placement, and in most cases to have a reliable arterial pressure measurement during and after CPB as the radial A-line will

Fig. 2 Enlarged pulmonary autograft with functioning mechanical aortic valve done at second surgery for aortic insufficiency.

Fig. 3 Transesophageal echo of the aortic root pseudoaneurysm and failed stentless valve for endocarditis.

be inaccurate in some patients with prolonged CPB run. Pulmonary artery catheter and central venous catheters are placed in all patients. After general endotracheal anesthesia is achieved, temperature sensing urinary catheter, external defibrillation pads (ZOLL Medical Corporation; Chelmsford, MA), and cerebral oximetry monitors (Somanetics Corporation, part of Covidien; Troy, MI) are placed. TEE probe is inserted and comprehensive evaluation is done. CPB lines are divided and prepared. Peripheral cannulation is done at this time if CPB institution and/or circulatory arrest is planned prior to redo sternotomy. CPB prior to sternotomy is done in cases of sternum adherent to the RV, coronary grafts, aortic graft, or pseudoaneurysm. Heparin is administered to achieve an activated clotting time (ACT) of more than 480 seconds. Intravenous infusion of aminocaproic acid is used in all patients. Arterial and venous cannulation options for CPB are described in the next section. Previous sternotomy incision is reopened and sternal wires are cut but not removed. Further dissection is done at the xiphoid and suprasternal notch. Sternum is divided using an oscillating saw with previous sternal wires in place along the posterior table and removed after dividing the sternum. This may help avoid injury to underlying structures. Sharp and blunt dissection is done to dissect the aorta, right atrium (RT), prior grafts if present, prior to administration of heparin to minimize bleeding when central cannulation is planned.

CPB and Cannulation Options

Arterial and venous cannulation options for CPB depend on the extent of the aortic involvement and procedure planned.

Arterial Cannulation

1. Central aortic cannulation is done if there is no concern for sternal re-entry and distal ascending aorta is available for cannulation and cross-clamping. Any standard cannula can be used for cannulation of the distal ascending aorta or transverse arch. Our preference is to use a Bio-

Medicus NextGen Femoral Arterial Cannula (Medtronic, Inc., Minneapolis, MN). Use serial dilations over the wire technique with TEE guidance to make sure the wire is in the descending aorta.

2. Right axillary artery cannulation is done when ascending aorta is not suitable for cannulation, hypothermic circulatory arrest is required to perform the procedure, or clamping of the ascending aorta is not safe due to aneurysm or calcified aorta. Axillary artery is exposed with a small incision vessel loop passed around it. Heparin is administered and a partial occlusion clamp is placed. Artery is opened with knife and scissors to accommodate a 10-mm graft. We use a 10-mm Vascutech graft (Terumo Heart, Inc., Ann Arbor, MI) to sew to the axillary artery using a 5-0 polypropylene suture. Graft is trimmed to appropriate length and a (3/8) × (3/8) connector with a three-way stopcock is attached. The other end of the connector is attached to the arterial side of the CPB circuit. The three-way stopcock is useful to deair the circuit. Antegrade cerebral perfusion during systemic circulatory arrest is made simpler with right axillary artery cannulation using the existing circuit, details will be discussed in the next section.
3. Innominate artery cannulation is done when redo sternotomy can be done safely and patient has an adequate sized innominate artery without any calcification or dissection. Direct cannulation can be done with standard cannula, but we prefer to sew a 10-mm graft similar to axillary arterial graft with a partial clamp in place.
4. Femoral arterial cannulation is rarely done for redo aneurysm surgery except in emergency crash on bypass situation. The reason not to use femoral cannulation routinely in this setting is due to significant atherosclerosis and/or dissections involving the descending aorta. When it is done, we use a Bio-Medicus NextGen Femoral Arterial Cannula (Medtronic, Inc.). Using micropuncture technique and serial dilations over the wire technique with TEE guidance to make sure the wire is in the proximal descending aorta.
5. Direct cannulation of the ascending aorta/aneurysm is done at times when axillary, innominate, and femoral arteries are not accessible due to atherosclerosis or dissection. We have a "Y" limb in the arterial circuit and use one limb to go on bypass. Use the second limb with balloon tipped catheters for antegrade cerebral perfusion during circulatory arrest.

Venous Cannulation for CPB

1. Central cannulation using standard two-stage or a three-stage cannula via right atrium if sternotomy can be done safely.
2. Central bicaval cannulation when surgery involves mitral or tricuspid valves. Any standard cannula, either metal tipped or wire reinforced can be used.
3. Percutaneous venous cannulation is done when CPB is instituted prior to sternotomy or if central cannulation cannot be done safely, for example, when coronary grafts are present on the RA. Common femoral vein is accessed

with micropuncture kit and ultrasound guidance. TEE is used to make sure the wire is in the superior vena cava (SVC). We use a LivaNova 23/25 Fr RAP-200-150 Femoral Venous Cannula (LivaNova PLC, London, UK) with serial dilation over the wire.

After cannulation and achieving ACT of more than 480 seconds, CPB is started and flow rate of more than 2.2 L/M2 is maintained. A right superior pulmonary vein vent is placed and directed into left ventricle (LV) for venting. If longer CPB and ischemic times are anticipated, we also place a coronary sinus catheter for cardioplegia delivery. We routinely use warm blood perfusion via coronary sinus catheter at the end of the procedure prior to removal of aortic clamp. Carbon dioxide is infused into the pericardial well prior to opening the aorta and until aorta is closed to minimize air entrapment in the LV cavity. Neo-Synephrine is used as needed to maintain adequate perfusion pressure. Patients are cooled to ~32°C degrees if no systemic circulatory arrest is planned. If circulatory arrest is planned, then cool to 26 to 28°C. Never cool or rewarm too fast. In general, we keep the temperature gradients below 10°C and never rewarm above 37°C.

Myocardial Protection

After achieving CPB, ascending aorta is dissected and clamped if safe clamping is feasible. Cold Custodial HTK Solution (Essential Pharmaceuticals, LLC, Durham, NC) cardioplegia is delivered into aortic root if there is no aortic insufficiency. If aortic insufficiency is present, aorta is opened and directly delivered into main coronary ostia with balloon tipped soft catheters. Standard dose we use is 20 mL/kg for initial dose. If aorta cannot be clamped and circulatory arrest is needed, cerebral circulation is first established and then cardioplegia is delivered as mentioned earlier. Subsequent doses are usually around 500 mL at 60 to 90 minutes interval. Subsequent doses are delivered via coronary ostia or coronary sinus catheter. Myocardial protection can be a challenge if patient has a patent left internal mammary artery. If it is easily identified, we place a soft clamp to occlude it. If the pedicle is not identified then resort to cooling the patient to 28°C and use continuous cold blood perfusion via coronary sinus catheter. Also, use topical cooling with cold water/ice slush. During rewarming and closure of the aorta, continuous warm pump blood is infused via coronary sinus catheter for controlled reperfusion and deairing of the coronaries.

Cerebral Protection

Cerebral oximetry is monitored in all patients. We use selective antegrade cerebral perfusion exclusively and rarely use retrograde SVC perfusion for brain protection. After achieving desired systemic temperature, CPB pump is turned off and most of the blood is drained into the reservoir. External cooling of the head is done with ice packs. Aorta is transected just below the innominate artery and origins of head vessels visualized to make sure there is no dissection.

Antegrade cerebral perfusion with cold pump blood at a rate of 10 to 15 mL/kg/min is started. This can be achieved in many different ways. Our preferred approach is to clamp the innominate artery at the origin if there is no significant calcification and if clamping is not feasible, we place a balloon tipped coronary sinus catheter and inflate the balloon. Start unilateral perfusion at 10 to 15 mL/kg/min and monitor right radial A-line pressure to keep between 40 and 60 mm Hg. If we notice significant change in the cerebral oximetry on the left side, left carotid is clamped or a coronary sinus catheter is placed into the lumen and the balloon inflated. This usually pressurizes the left carotid and immediate improvement in cerebral oximetry is seen. If the oximetry does not come up to baseline, cold blood perfusion of left carotid is performed through the catheter. Rarely ever left subclavian perfusion is necessary. In cases where central aortic cannulation or femoral cannulation is used for CPB and circulatory arrest is required, we use coronary sinus catheters inserted into innominate and left carotid arteries for perfusion. After satisfactory cerebral and myocardial protection is established, we proceed with distal anastomosis to transverse arch or proximal descending aorta. Location of the distal anastomosis depends on the extent of the aneurysm or dissection. Simplest of all the arch reconstructions is the hemiarch type anastomosis and usually takes less than 20 to 30 minutes of arrest time. A straight Vascutec graft (Terumo Heart, Inc.) of appropriate size is used for hemiarch replacement and if total arch replacement is done, we use a multiple branched graft (► Fig. 4). We reinforce the anastomosis with Teflon strip externally and frequently spray a thin layer of BioGlue (CryoLife, Inc, Kennesaw, GA). Clamps or the catheters in the head vessels are removed, the arch and graft are deaired. Cross-clamp is placed on the new aortic graft below the anastomosis and whole body perfusion is performed and generally systemic rewarming is also started at this time.

Fig. 4 Complete arch replacement via clam-shell approach for dissection with three prior sternotomies for valve surgery and descending aortic replacement. CPB, cardiopulmonary bypass.

Aortic Root Reconstruction

Aortic root is often involved in redo surgeries after prior surgery on the ascending aorta.⁹ Assessment of the pathology of the root is important. CTA, TEE, and MRI are valuable diagnostic tests. Also, it is important to know details of the previous surgeries. If the sinus of Valsalva (SOV) is not dilated and aortic valve functioning well, a straightforward end-to-end anastomosis between the graft and sinotubular junction (STJ) is all that is needed. If the SOV is normal and aortic valve is stenotic or incompetent, then a separate AVR and proximal anastomosis to STJ are done. When SOV is dilated and valve is abnormal, patient will need a root replacement with a valve conduit of mechanical or bioprosthesis with coronary reimplantation. In most patients this can be a Bentall procedure where the coronary buttons are directly implanted on to the sinus portion of the new graft (we routinely use Vascutec Valsalva graft; Terumo Heart, Inc.). If the root is extremely enlarged, coronary buttons cannot be mobilized adequately to do a tension-free anastomosis (► Fig. 5). In this situation, a Cabrol modification is a safer procedure. An 8- or 10-mm Dacron graft is anastomosed to left main ostium and the other end anastomosed to the right coronary artery (RCA) ostium, create a side-to-side anastomosis to the ascending aortic graft along the greater curvature.¹¹ If the RCA button is calcified, or difficult to dissect, or damaged during dissection, a short vein graft to proximal RCA is a better option (► Fig. 6). There have been reports of new Dacron grafts with prefabricated coronary side branches, may diminish the complexity involved in Bentall procedures.¹² In patients with annular abscess or pseudoaneurysm of aortic root, a homograft as root replacement may be the best option. We generally avoid using homograft in young patients due to early failures and

Fig. 5 Dilated root with displaced coronaries after a failed Ross procedure and subsequent mechanical aortic valve replacement. RCA, right coronary artery.

Fig. 6 Completed root reconstruction with modified Cabrol graft to left main and vein graft to right coronary artery (RCA).

difficult reoperations. In most patients, we use Teflon felt and BioGlue to reinforce and minimize bleeding.

Pitfalls and Bailout Strategies

Reoperative proximal aortic and root surgery is a complex procedure and fraught with pitfalls that could be fatal. Many of them are potentially avoidable with proper planning, preparation, and attention to details. Few of the common problems encountered are listed below.

1. **Re-entry problems:** Review the preoperative CTA for graft location, pseudoaneurysms, RV, and aortic proximity to sternum. If injury is highly likely, go on peripheral bypass prior to opening the sternum. If an injury to RV or aorta occurs during sternotomy, have an assistant hold pressure to tamponade the bleeding and quickly go on femoral bypass. This is the reason to always have a femoral A-line placed which can be used for arterial access for emergent CPB. If a coronary graft is injured during sternotomy, an intracoronary shunt placement can avoid catastrophic myocardial ischemia.
2. **Cerebral protection:** If selective antegrade perfusion is not feasible, cool the patient to $<20^{\circ}\text{C}$ and use retrograde cerebral perfusion via SVC cannulation. When using unilateral antegrade perfusion and contralateral cerebral oximetry, values decrease simply clamping the carotid or placing a balloon tipped catheter may normalize the values. If just placing a balloon catheter does not correct the problem, start perfusion through the catheter.

3. **Coronary ischemia:** Always pay attention to myocardial protection during surgery and redose cardioplegia as necessary. Topical and systemic cooling can be helpful. Placing a retrograde catheter directly into coronary sinus via right atriotomy can minimize RV ischemia. Avoid doing a direct coronary implantation into the graft if it cannot be adequately mobilized to do a tension and kink-free anastomosis. A Cabrol modification is better option for left main in this situation. RCA button is harder to dissect and can result in injury in redo situation. Best option for RCA when left main is not a problem is bypassing the proximal RCA with a short vein graft (**Fig. 6**). Myocardial ischemia can occur in a delayed fashion also. Best way to manage immediate postoperative myocardial ischemia is to return to operating room and correct the problem. If you suspect coronary kinking or obstruction, urgent coronary bypass is more expedient than redoing the root.¹² If this problem occurs in a delayed fashion, coronary stenting can be an option for kinked or narrowed coronaries.¹³
4. **Bleeding:** Many of these patients have significant coagulopathy after CPB and blood component replacement in a timely fashion can stop bleeding. Use of reinforcement material, especially in the root and topical coagulation agents is also helpful. In patients with diffuse bleeding, even after correction of coagulopathy, recombinant activated factor VII at half dose ($45\text{ }\mu\text{g/kg}$) would usually control the bleeding. It can be repeated again. If there is significant bleeding from the root, a Cabrol patch (graft material or bovine pericardium) is sewn to isolate the root and ascending aorta. An 8- or 10-mm graft is sewn to this patch and the other end is anastomosed to RA to divert the blood into RA.¹¹ In almost all cases, bleeding will stop within 24 hours and the graft will be thrombosed. When there is oozing, despite all efforts, it is best to pack the mediastinum and place a negative pressure wound dressing. Most bleeding will stop with rewarming and correcting the coagulopathy within 12 to 24 hours.
5. **Failure to wean from CPB:** This can happen with poor myocardial protection or very long ischemic times in patients with prior myocardial dysfunction. It can happen with coronary button issues after AVR or root replacement. Even when this pathology is corrected, prolonged ischemia may lead to pump failure and failure to wean. Starting inotropes can resolve the problem in many patients. If inotropes are not sufficient, IABP should be placed. When there is more severe LV dysfunction and IABP is not sufficient, a temporary left ventricular assist device (LVAD) would be needed. This can be achieved with existing arterial cannula and a 34-Fr apical cannula in the LV apex for best drainage or a cannula in the pulmonary vein. When there is biventricular failure with or without oxygenation issues, central venoarterial extracorporeal membrane oxygenator (ECMO) is the best option. In its simplest version, existing venous and arterial cannulas can be left behind and connected to an ECMO circuit.¹⁴ If prolonged support is anticipated, we prefer to sew a graft to the ascending aorta or use the existing subclavian graft

for arterial outflow and place a femoral venous cannula for venous drainage. We often place a LV apical vent as well for LV decompression and to avoid pulmonary edema. With the use of coated circuit for ECMO and temporary LVAD, systemic anticoagulation can be avoided for 24 to 48 hours.

Conclusion

Complex reoperations on the proximal aorta and aortic root can be done safely with acceptable mortality. More and more complex procedures are being done with improved outcomes. This may be due to increasing experience, improved technology, and better care of the patients in the perioperative period. Team approach to manage these patients is essential for good outcomes and a robust surveillance program is essential for a successful thoracic aortic program.

References

- 1 Lima B, Williams JB, Bhattacharya SD, et al. Individualized thoracic aortic replacement for the aortopathy of bicuspid aortic valve disease. *J Heart Valve Dis* 2011;20(04):387–395
- 2 Crawford ES, Crawford JL, Safi HJ, Coselli JS. Redo operations for recurrent aneurysmal disease of the ascending aorta and transverse aortic arch. *Ann Thorac Surg* 1985;40(05):439–455
- 3 LeMaire SA, DiBardino DJ, Köksoy C, Coselli JS. Proximal aortic reoperations in patients with composite valve grafts. *Ann Thorac Surg* 2002;74(05):S1777–S1780, discussion S1792–S1799
- 4 Estrera AL, Miller CC III, Porat E, et al. Determinants of early and late outcome for reoperations of the proximal aorta. *Ann Thorac Surg* 2004;78(03):837–845, discussion 837–845
- 5 David TE, Feindel CM, Ivanov J, Armstrong S. Aortic root replacement in patients with previous heart surgery. *J Card Surg* 2004;19(04):325–328
- 6 Sabik JF III, Blackstone EH, Houghtaling PL, Walts PA, Lytle BW. Is reoperation still a risk factor in coronary artery bypass surgery? *Ann Thorac Surg* 2005;80(05):1719–1727
- 7 Potter DD, Sundt TM III, Zehr KJ, et al. Operative risk of reoperative aortic valve replacement. *J Thorac Cardiovasc Surg* 2005;129(01):94–103
- 8 Girardi LN. Reoperative repair of the aortic root and ascending aorta. *Tex Heart Inst J* 2011;38(06):680–683
- 9 Iribarne A, Keenan J, Benrashid E, et al. Imaging surveillance after proximal aortic operations: is it necessary? *Ann Thorac Surg* 2017;103(03):734–741
- 10 Hernandez-Vaquero D, Díaz R, Pascual I, et al. Predictive risk models for proximal aortic surgery. *J Thorac Dis* 2017;9(Suppl 6):S521–S525
- 11 Cabrol C, Pavie A, Gandjbakhch I, et al. Complete replacement of the ascending aorta with reimplantation of the coronary arteries: new surgical approach. *J Thorac Cardiovasc Surg* 1981;81(02):309–315
- 12 Shahriari A, Eng M, Tranquilli M, Elefteriades JA. Rescue coronary artery bypass grafting (CABG) after aortic composite graft replacement. *J Card Surg* 2009;24(04):392–396
- 13 Marino M, Cellini C, Tsiopoulos V, et al. A case of myocardial infarction effectively treated by emergency coronary stenting soon after a Bentall-De Bono aortic surgery. *Cardiovasc Revasc Med* 2010;11(04):263.e5–263.e9
- 14 Ramaiah C, Babu A. ECMO cannulation techniques. In: Firshtenberg M, ed. *Extracorporeal Membrane Oxygenation – Advances in Therapy*. Chap. 4 Rijeka: INTECH; 2016