Aortic Root Replacement with a Composite Valved Conduit

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Currently there are several operative techniques in use around the world to address aortic root pathologic problems. These include valve-sparing aortic root replacement, stentless porcine aortic root replacement, pulmonary autograft root replacement, and composite valved graft conduits (CVG) housed with either a mechanical or in some cases a bioprosthetic valve. The CVG root replacement is the most time tested of all options and was first described by Bentall and DeBono in 1968. Since then there have been many published series that have extended out beyond 20 years that demonstrate the efficacy of this approach. The indications for aortic root replacement include aneurysmal disease, aortic dissection when the primary tear occurs in the aortic root or with concomitant aortic valve disease or aneurysmal disease, and invasive aortic valve endocarditis that involves the aortic root. Most commonly aortic root replacement is performed for aneurysmal disease that stems from a degenerative process or is secondary to a genetic abnormality that predisposes to proximal aortic dilation as in Marfan syndrome, Loeys–Dietz syndrome, Ehlers–Danlos syndrome vascular-type (type IV), familial aortic aneurysm or dissection syndromes, and aneurysm associated with bicuspid aortic valve.

Abnormal aortic root and ascending aortic dimensions have been determined based on patient age and body size. Accrual of large amounts of echocardiographic and cross-sectional imaging data from normal individuals has allowed the development of regression formulas and nomograms to define abnormal aortic dilation. For example, an individual 18 to 40 years old will have an average aortic diameter at the sinus level equal to 0.97 + (1.12 × BSA [m²]) (cm). The upper limit of normal is 2.1 cm/m² for the sinus segment in most adults. The aorta is pathologically dilated if its diameter exceeds the norm for a given age and body surface area (BSA). It is defined as an aneurysm if its diameter is 50% greater than the norm.

There remains some debate as to what the indication for operative intervention should be based on maximal orthogonal diameter alone without consideration of other clinical factors like aortic valve pathologic complications. Clearly, there are cohorts of patients with aortic root and ascending aortic aneurysms that are at higher risk of an aortic catastrophe (dissection, disruption, or sudden death) than others, like patients with a bona fide connective tissue disorder or family history of aortic dissection. Moreover, surgeon experience with aortic root replacement operations varies widely. High volume centers have tended to generate the best results, and consequently, are justified in intervening earlier when it can be demonstrated that the risk of operative intervention is lower than the risk of the pathologic problem itself managed medically over a period of time. Guidelines based on the collective issues have been established by the community of thoracic aortic surgeons around the world. A reasonable trigger point for a patient with a degenerative aneurysm is when the measured diameter is 50% larger than the predicted diameter for that patient based on age and body surface area. That threshold is often lowered for patients with connective tissue disorders to a diameter that is 30% larger and to 40% for patients with bicuspid aortic valve dysfunction.

The advantages of utilizing a mechanical CVG strategy for aortic root replacement are its long-term durability and its ease of implant relative to many of the other root replacement techniques. The disadvantages of a mechanical CVG include the need for long-term anticoagulation and the inherent risk of embolic events that exceeds the risk of other root replacement options.

Aortic root replacement with a CVG has become a fairly standardized operation. The aim of this article is to provide some insight of the technical nuances of performing a safe and efficient aortic root replacement.
Operative Technique

Figure 1 Anatomy of the aneurysmal aortic root. This figure features a typical large ascending aortic aneurysm that begins in the sinus segments and terminates in the proximal aortic arch with typical displacement of the heart into the left chest. The pulmonary artery is displaced leftward, and the superior vena cava (SVC) is displaced rightward.
Figure 2 Circulation management. Arterial cannulation is typically via the distal ascending aorta except for cases involving aortic dissection or significant calcified/atheromatous disease of the arch at which time a silo graft can be sewn to the distal right subclavian artery and cannulated. The right atrium is drained with a dual-staged venous cannula through the appendage, and a superior vena caval cannula is placed when using retrograde cerebral perfusion. Myocardial protection is imparted using antegrade, cold blood, potassium-enriched cardioplegia for induction and maintained with continuous retrograde cardioplegia augmented with intermittent antegrade direct ostial right coronary artery cardioplegia for additional right ventricular protection. Ventricular septal myocardial temperature is monitored with a needle probe and is maintained between 7 and 10°C with this strategy. A centrifugal pump is used for cardiopulmonary bypass, and a left ventricular vent is placed via the right superior pulmonary vein to help clear blood from the field during root reconstruction. Patients are not systemically cooled unless there are plans for an open distal aortic anastomosis or aortic arch reconstruction.

Arch reconstruction is performed under deep hypothermic circulatory arrest (HCA) using a protocol that includes neurocerebral monitoring with electroencephalography and cerebral oximetry. Patients are cooled to electrocerebral silence for greater than 4 minutes (core temperature ranging from 14 to 20°C). Barbiturates and benzodiazepines are avoided so that electroencephalography changes are reflective of brain cooling or ischemia rather than pharmacologic changes. Isoflurane is delivered via the cardiopulmonary bypass circuit for general anesthesia. Lidocaine, magnesium, mannitol, and methylprednisolone are also administered as adjuncts for neurocerebral protection with deep hypothermia. Either retrograde (RCP) or antegrade cerebral perfusion (ACP) is utilized in all open arch cases depending on the predicted period of HCA required for arch reconstruction (RCP for HCA < 20 minutes, ACP for HCA > 20 minutes). RCP is delivered using the cardioplegia circuit via a stopcock attached to the SVC drainage catheter. Cold blood is administered at a rate of 200 to 350 mL/min for a right internal jugular venous pressure of 20 to 25 mmHg. ACP is delivered via the primary cardiopulmonary bypass circuit either through the right subclavian arterial access limb or through direct ostial cannulation of the right and left carotid arteries using balloon-tipped catheters once the arch is opened. ACP is delivered at a rate to maintain bilateral carotid pressures of 50 mmHg as measured by the pressure lines mounted within the balloon-tipped catheters. LV = left ventricle, RCP = retrograde cerebral perfusion, SVC = superior vena cava.
Operative dissection of the aortic root. The ascending aorta is transected just above the sinotubular junction. From the right side of the posterior aspect of the ascending aorta, the fatty tissues adherent to the right pulmonary artery (PA), the main PA, and the noncoronary and left coronary sinuses are divided with electrocautery dissecting the aorta away from the right pulmonary artery (RPA) and main PA. The line of dissection follows the border of the RPA and main PA as they abut the aorta, allowing the aortic and peri-aortic tissues to fall away from the RPA and main PA rather than the other way around. This initial dissection of the RPA and main PA off of the aortic root is the key to the dissection of all aortic root cases, but it is particularly important to be very meticulous with this part of the dissection in reoperative cases. a. = artery; SVC = superior vena cava.
Figure 4  Tailoring coronary buttons. Coronary buttons are created sharply with 3 to 5 mm of aortic cuff associated with each coronary ostia, leaving the superior-most aspect of the aorta at the coronary os initially intact to the level of the sinotubular junction to serve as a manipulating handle for the button before completion of its orthotopic transfer and anastomosis to the new root.
Implanting the prosthesis: the annular anastomosis. Utilizing a gelatin-impregnated polyester graft with a prefabricated "sinus of Valsalva" housed with either a mechanical or a bioprosthetic valve has several advantages over straight tube grafts for root replacement. These advantages are certainly realized in the setting of a reoperative root replacement when dense peri-aortic scar tissue limits dissection and mobility of the coronary buttons. The dilated, "sinus" segment of the graft (above the valve) permits easier apposition of the coronary buttons to the graft and facilitates orthotopic coronary transfer precluding the need for a Cabrol-modification of the left main coronary’s attachment. The valved conduit with a sewing cuff that is rigid is most securely implanted using an intra-annular horizontal mattress suture technique that incorporates a cuff of aorta at the annular interface that serves as a gasket between the pledgets of the mattress sutures and the valve sewing cuff. Sutures are passed from the aorta adjacent to the annulus exiting into the left ventricular outflow tract just below the anatomic annulus or hinge point of the removed native valve.
Orthotopic coronary button transfer. Coronary buttons are fashioned with a 3- to 5-mm cuff of aorta around the coronary ostia. The main coronary arteries are freed up through the fat planes around the vessels dividing epicardial tissues that create a continuity of the peri-arterial tissues to surrounding structures (eg, the pulmonary arterial trunk and right pulmonary artery). A breadth of peri-arterial fat and soft tissues are left in continuity with the coronary arterial trunks to provide some support and to prevent kinking on button transfer to the newly implanted root. Each coronary button anastomosis is completed with running 5-0 polypropylene suture. Great care is taken to ensure that the polyester graft material is intussuscepted within the aortic cuff of the button to maintain direct apposition of the polyester graft to the button’s intimal surface to facilitate optimal healing and a hemostatic suture line. No felt material is utilized with this technique. a. = artery.
Figure 7  Heterotopic coronary artery transfers (modified Cabrol technique). In the current era, it is unusual to have a problem with adequate mobilization of the left coronary artery to warrant coronary transfer via a separate graft (modified Cabrol technique) because of the new prefabricated sinus segment grafts that are available for root replacement. These grafts have a broader sinus segment that will often reach even a difficult, scarred left main coronary artery. We prefer orthotopic button positioning over alternative routes. Rarely, it may still be necessary to use an additional conduit to facilitate optimal left main coronary blood flow and to ensure that there is no kinking or flattening of the left main coronary artery with its transfer to the new root. This may occur in cases of extensive scarring (eg, the multiple reoperative setting) or with endocarditis that has destroyed the left main coronary ostium. In these cases an intervening conduit may be required. For noninfective cases, either a large-caliber (≥5 mm) saphenous vein from the thigh or a polyester graft (typically 8 mm) is an acceptable conduit. For endocarditic cases that require resection of a portion of the left main coronary button, vein graft is optimal. In most cases these conduits to the left main coronary artery have a better lie when brought posterior to the aorta adjacent to the right pulmonary artery with the anastomosis to the aortic graft either positioned along the lateral wall adjacent to the superior vena cava or brought 270° around the aortic graft to its anterior aspect. A typical beveled end-to-side anastomosis is optimal to create a hood in the shape of a cobra head. a. = artery.
Figure 8 Distal aortic anastomosis with a clamp. When the distal ascending aorta is neither dilated nor diseased with calcified or friable atheromata, it is reasonable to complete the distal reconstruction with an aortic cross-clamp in place. Depending on the length of the ascending aorta that is replaced, the distal aspect of the valved conduit can be cut to an appropriate length and anastomosed to the clamped distal ascending aorta. In cases where there is considerable length between the aortic root and the distal anastomosis, a separate graft distinct from the root graft can be used for the distal aortic anastomosis to allow for beveling of both the distal aspect of the root graft and the proximal aspect of the aortic graft to re-create the natural curvature of the ascending aorta as it emanates from the root and heads through the arch (typically 120°). Regardless, care should be taken to fashion these anastomoses in such a way that prevents kinking of the graft(s) along either the lesser curve of the arch or the posterior aspect of the mid ascending aortic graft. The graft-to-distal aortic anastomosis is completed with a running 4-0 polypropylene suture, and again, care is taken to intussuscept graft into native aorta to ensure graft onlay onto aortic intima. This helps facilitate a hemostatic suture line. No felt material is necessary with this technique.
Hemi-arch reconstruction. In most cases when aortic root replacement with a valved conduit is required, there is concomitant disease of the ascending aorta. Generally, I prefer to complete proximal aortic reconstructions with an open distal anastomosis and hemi-arch reconstruction as a routine, particularly when there is dilation of the distal ascending aorta or when there are calcified or friable atheromatous changes to the aorta in this area. Open reconstruction ensures a higher quality distal anastomosis and helps prevent embolization of debris or atheromatous disease from the arch into either carotid artery.

The hemi-arch anastomosis is completed with a separate graft than that used for root reconstruction. The arch graft is beveled with the tongue positioned at the distal lesser curve to re-create the normal curvature of the lesser curve of the arch. This anastomosis is similarly completed with a running 4-0 polypropylene suture, and the graft is intussuscepted into the arch to ensure apposition with the aortic intima. No felt material is utilized with this approach.
Conclusions

Aortic root replacement with a CVG is a durable operation with broad applicability. The tenets of this operation like most open heart procedures start with good myocardial and neurocerebral protection. From a technical standpoint, meticulous attention to the dissection of the aortic root and to creating each anastomosis with a small amount of intussusception of graft edge into the native aorta distally or with each coronary button promotes hemostasis and a durability of these anastomoses. Biologic glues or felt materials are unnecessary when the techniques described above are utilized, and eliminating or at least minimizing the use of these adjuncts can significantly impact the degree of difficulty of any subsequently required cardiac operation in a patient’s future and may actually promote better anastomotic durability.

Reference