Aneurysms involving the ascending aorta and aortic root can be repaired with low operative risk. Operations such as composite valve-graft root replacement or valve-sparing root reconstruction carry expected mortality <4% with few perioperative complications. However, reoperative surgery on the ascending aorta continues to be quite challenging for cardiac surgeons. The mortality for these complex reconstructions is routinely 3 times higher than with elective surgery and often associated with substantial morbidity.

The earliest report on patients undergoing reoperations on the ascending aorta was reported by Dr. Stanley Crawford and coworkers in 1985. They reported their experience with 59 patients undergoing 67 reoperative procedures. Myocardial failure, stroke, and preoperative hemorrhage occurred at an astounding rate. The 30-day mortality was 17%.

Since that original report, surgeons with a particular interest in aortic disease have reduced dramatically the risk of these hazardous reoperations. Advancements in myocardial and cerebral protection, improvements in graft technology, and an evolution in surgical technique and postoperative critical care have allowed experienced aortic centers to perform these operations with expected outcomes not dramatically different from elective aortic root surgery. Excellent long-term survival and freedom from further surgery can be anticipated for a majority of patients.
Operative Technique

Figure 1 In patients who have undergone previous cardiac surgery and now require an operation for an aneurysm of the tubular ascending aorta or root, safe sternal reentry is the most critical step in a successful outcome. A preoperative computed tomographic (CT) scan or magnetic resonance imaging (MRI) scan is strongly suggested. This will show the diameter and extent of the aneurysm and allow a determination of the need for arch replacement and circulatory arrest. Most importantly, however, is a careful examination of the distance between the posterior sternal table and the anterior wall of the aneurysm. We prefer CT scanning to MRI as the images are generally clearer and the software are more reliable when determining the proximity of the sternum to the aorta. In elective cases, cardiac catheterization is essential, especially in those patients who have had previous coronary bypass grafting. It is also important to delineate the course of patent grafts, especially a pedicled mammary graft. This can sometimes be lurking immediately below the sternal table and may be at risk for injury during reentry. In a majority of cases, as here in Figure 1, there is adequate distance between the aorta and sternum and an oscillating saw is used to open the previous sternotomy carefully. After standard anesthetic preparation, including right heart catheterization and a peripheral arterial line, we place the patient in the supine position. External defibrillation pads (Zoll Medical Corporation, Chelmsford, MA) are placed on the patient before sterile preparations are made. On the right side of the patient, the pad is placed behind the right scapula and on the left it is placed in the mid axillary line at approximately the 6th interspace. Femoral pulses are palpated on both sides to determine the best place for emergency femoral cannulation if needed. Once the patient is prepped and draped, the perfusion lines are brought onto the field and secured in their appropriate position. The previous sternal incision is opened and the wires are removed. We use a small Crile clamp to identify the lateral sternal edges before opening as the previous sternotomy may not have been perfectly midline. We first open the anterior table of the sternum the entire length of the sternum. We then proceed to open the posterior table carefully in a cranial to caudal direction. The saw is used with less than full power when dividing the posterior table to ensure full control of the depth of the blade. Once the sternum is divided, we use a combination of sharp dissection and bovie electrocautery to dissect away the mediastinal contents from the posterior sternal table before positioning a sternal retractor. Always keep the position of any coronary bypass grafts in mind when opening as entry into one of these can be catastrophic.
In this scenario, there is limited space between a large ascending aneurysm and the posterior sternal table. We do not use an oscillating saw for this situation. Rather, after setting up the patient as in Figure 1, we remove the wires and then proceed to open the linea alba in the midline just below the xiphoid process. We use bovie electrocautery on a moderate setting to enter the space immediately below the lower sternal edge. Once adequate space is established under the lower sternal edge, we place rake retractors on the right and left sternal edges. An assistant then lifts these retractors vertically and the mediastinal space is visualized. Under direct vision, sharp dissection is performed with a long Metzhenbaum scissors dissecting the mediastinal contents away from the posterior sternal table. In the nondominant hand, a sucker is used to clear minor venous bleeding from the operative field and to provide gentle countertraction for safer dissection. If resistance is encountered, or if visualization becomes poor, we use a standard reciprocating saw to open the sternum to the end of the area that has been cleared. We then reposition the rake retractors further along the sternum and spread the sternum a centimeter or so as the assistant is lifting. Two or 3 moves like this is usually adequate to open the sternum. Again, it is critical to know the location of any bypass grafts.
This patient has a large ascending aneurysm that is growing into the sternum. This scenario is best treated with CPB and PHCA before opening the sternum. After removing the sternal wires, we isolate the femoral artery and vein in preparation for cannulation. An 18-French femoral arterial cannula and 32-French long femoral venous cannula (Medtronic Corp., Minneapolis, MN) usually provide adequate flow for full cardiopulmonary bypass. Axillary artery and femoral venous cannulation is also appropriate but is our second choice in these cases. If we do use the right axillary artery for arterial inflow, we suture an 8-mm Dacron graft onto the axillary artery rather than cannulate this very friable artery directly. Once satisfactory venous drainage is established, we cool the patient to 18°C before opening the sternotomy. In patients with a competent aortic valve, a left ventricular vent is not necessary. Patients tolerate cold fibrillation quite well and myocardial protection is satisfactory. However, when significant aortic insufficiency is present, left ventricular distention will ensure after fibrillation. This must be avoided to prevent potentially irreversible myocardial damage. Left ventricular decompression is most directly established with a small anterior thoracotomy over the point of maximum impulse. Similar to the approach for a transapical aortic valve, a left ventricular vent is placed through a pursestring suture in the left ventricular apex through a small stab wound. Drainage is excellent and closure of this opening is reliably achieved at the end of the case. If the heart is to be mobilized more completely after the chest is open, this apical ventriculotomy can be closed with the heart arrested. Once an acceptable temperature is achieved, the sternum is opened with either an oscillating saw or reciprocating saw and the aneurysm is entered directly. We do not use adjuncts for cerebral protection in this scenario. Rather we prefer simple profound hypothermia. This further limits the amount of time under circulatory arrest by eliminating the need to isolate the superior vena cava for retrograde cerebral perfusion. a. = artery.
If the superior vena cava (SVC) can be identified easily, we place a 9-French Pruitt perfusion/occlusion catheter (Le Maitre Vascular, Burlington, MA) through a small pursestring suture in the SVC and use this to establish retrograde cerebral perfusion (RCP). Flow through this catheter is 200 mL/min, keeping the central venous pressure <30 mm Hg. A padded clamp is placed at the SVC and right atrial junction to prevent backflow of RCP into the right atrium. RCP delivery is confirmed with the return of dark, deoxygenated blood through the ostia of the great vessels. If axillary perfusion is being used, we will quickly dissect out the innominate artery and place a padded clamp on it to establish ACP. We flow at approximately 10 mL/kg/min when using this approach. If the anticipated period of PHCA is to be short, we proceed with arch repair without any adjunctive cerebral perfusion. A 1-branch Hemashield graft (Macquet Corp., Oakland, NJ) is used to reestablish CPB after arch reconstruction. We move the aortic cannula from the femoral artery into the side-branch graft and go back on cardiopulmonary bypass in an antegrade direction. The femoral venous cannula is then moved to the right atrium and proceeds to repair the femoral artery and vein at this time. A dose of antegrade cold blood potassium cardioplegia is then given directly into the coronary ostia and repeated every 25-30 minutes for the remainder of the period of myocardial ischemia. Systemic warming to 35°C is also initiated at this time.
In cases where the sternum can be safely opened without the need for presternotomy bypass, it is preferable to identify the anatomy of the great vessels, cardiac structures, and any patent bypass grafts before giving heparin. We use a no-touch technique with patent vein grafts to avoid potential embolization. We prefer obtaining control of a patent IMA graft during these reoperations. These procedures sometimes require prolonged periods of myocardial ischemia and the continued perfusion from a patent IMA can diminish protection substantially. Once the IMA is identified, a padded bulldog clamp is placed on it during the cross-clamp period. After cross-clamping the aorta, we administer cold blood potassium cardioplegia into the aortic root if there is no substantial aortic insufficiency. We also administer retrograde cardioplegia through the coronary sinus. Myocardial temperature is kept <15°C. Cardioplegia is also given down the vein grafts, especially if they are the only means of antegrade perfusion into the right coronary system. We use a soft-tipped 17-French catheter (Medtronic Corp.) to do this in a very atraumatic fashion. Once myocardial protection is established, we isolate the vein grafts with a small rim of native aorta around the site of the previous proximal anastomosis. We free up the vein grafts from the surrounding structures for a distance of 4 to 6 cm. Reattaching these to an aortic graft that is much smaller than the aneurysmal native aorta sometimes requires more length than one might imagine and tension must be avoided to prevent late pseudoaneurysm formation at these vein graft reattachment sites. Once this is accomplished, we move on to dealing with the aortic root and valve.
In patients with a dilated aortic root and their native aortic valve we use 2 options for root reconstruction: composite valve graft replacement and valve-sparing ascending aneurysm repair. If the native aortic valve is in need of replacement, the valve is excised and the annular calcium is debrided. Coronary artery buttons are created with small rims of aortic tissue around the ostia. Once this is complete, we place aortic valve sutures (2-0 ethibond; Ethicon Corp., Somerville, NJ) using an intra-annular technique (pledgetts on the top). (A) The 3 commissural sutures are placed first and gentle traction is placed on these to enhance exposure of the annulus. Each valve suture is placed so the first stitch of a new valve suture slightly overlaps the last stitch of the previous valve suture. The distance of “travel” with each stitch is kept to the width of the pledget. We do not have a fixed number of valve sutures in mind. The valve is then sized using either mechanical or standard porcine sizers. The sutures are then brought through the sewing ring of the valve and tied tightly in place. The left main coronary artery is then reattached into the back wall of the graft using 2 layers of 5-0 polypropylene suture. The distal end of the composite valve graft is then sutured to the native aorta or arch graft using 3-0 polypropylene suture. (B) The right coronary artery button is then attached to the anterior wall of the graft as high as possible with 2 layers of running 5-0 polypropylene suture. (C) Any patent saphenous vein grafts are then sewn to the main body of the CVG once the right coronary button is complete. We trim away as much native aorta as safely possible from around the ostia of the vein grafts before reattaching them. Sometimes additional length is needed to avoid tension on these anastomoses. A small length of interposition saphenous vein graft can be used in this circumstance. SVC = superior vena cava.
Patients having undergone previous type A dissection repair often have an extensive amount of Teflon felt in their aortic root. It is not uncommon for there to be a felt “sandwich” at the level of the sinotubular ridge. This may induce an intense inflammatory reaction in the area between the left main coronary artery and the right main pulmonary artery. Repeated attempts at trying to develop a left coronary button in this circumstance can lead to injury to either the left main coronary or the pulmonary artery; it can be difficult then if not impossible to repair. Similarly dense tissue planes are also seen in this area in patients having a previous Ross procedure. In these cases, we prefer the Svensson modification of the traditional Cabrol aortic root reconstruction. After the valve sutures are placed as in Figure 6, we pull the valve sutures in the left coronary annulus in a caudal direction to open up the area around the left main coronary. An 8- or 10-mm Dacron graft is sewn around the ostia of the left main coronary artery with 2 layers of running 4-0 polypropylene suture. Before creating this anastomosis, the graft is cut with a bevel. The short end of the bevel should be facing the surgeon and the superior vena cava so the “Cabrol” graft will lie without a kink in its eventual position behind the composite valve graft. After completing the anastomosis, cardioplegia is administered down this graft by placing 1 arm of our cardioplegia octopus into this left main graft infusing cardioplegia at 150 ml/min. This technique confirms absolute hemostasis in this area that will be very difficult to access after separating from bypass.
Figure 8  Once the CVG is tied in place, the left main graft is brought behind it and the distal end of the CVG is sewn onto the distal aorta or the previously placed arch graft with 3-0 polypropylene suture. The right coronary artery, which is usually amenable to the creation of a button, is then sewn onto the anterior wall of the CVG with a running 4-0 or 5-0 polypropylene suture. The left main graft is then brought off the right side of the CVG using a running 4-0 polypropylene suture. The aortic end of this graft is beveled in a way to create an anastomosis that avoids kinking the “Cabrol” graft as it passes behind the CVG.
Although rare, we have had patients with previously placed “bioroots” develop either severe stenosis or regurgitation of the bioprosthetic valve. If the previous coronary buttons are intact and the annular suture line is without any pseudoaneurysm or infection, we prefer to excise the bioprosthetic from within the CVG rather than take down the entire composite and risk injury to the delicate coronary buttons. Once the heart is arrested, we make a transverse incision through the Dacron of the CVG about 5 to 6 mm above the right coronary artery button, similar to an aortotomy for a standard aortic valve replacement. The graft is opened as much as necessary to visualize and access the bioprosthetic valve. Sometimes this mandates complete transection of the graft. The valve is then grasped on top of the strut (usually the strut between the right and noncoronary sinuses) and a number 15 blade is used to incise the Dacron on top of the nitinol stent supporting the biovalve commissure. Once this layer is entered, sharp dissection is continued circumferentially until the entire nitinol stent is exposed. This is then easily removed along with the pathologic leaflets. Once the support for the valve is removed, there is a ring of nitinol supporting the sewing ring of the valve. This can be grasped and removed using blunt dissection with an endarterectomy spatula. A new valve is then sewn into the annular area using standard valve implantation techniques.
Figure 10 (A) If we feel that the patient’s native aortic valve is appropriate for preservation, we will excise the aneurysm and retain that valve using a David I reimplantation valve-sparing technique. The valve is first inspected for appropriateness for preservation. If the leaflets have multiple fenestrations or are otherwise damaged, we proceed to composite valve-graft replacement. If valve-sparing is appropriate, the aorta is excised down to the sinotubular ridge. We grasp onto the intact aortic root and use it as countertraction to develop a circumferential subannular plane. The sinuses of Valsalva are then excised and coronary buttons are developed. We place silk stay sutures at the top of each commissure to assist in the placement of the subannular valve stitches. Nonpledgetted 2-0 ethibond aortic valve sutures (Ethicon, Inc.) are then placed as horizontal mattress sutures along a single horizontal plane in the left ventricular outflow tract immediately below the valve leaflets. The annulus is then sized with a Hegar dilator (Integra LifeSciences, Plainsboro, NJ) and a graft is selected that is 4 to 5 mm larger than the annulus. Most commonly this is either a 28- or 30-mm Dacron graft. The sutures are then gently tied over the Hegar dilator. This avoids significant plication of the annulus. The commissures are then suspended as high as possible within the graft using pledgetted 4-0 polypropylene suture. This is the key to avoiding leaflet prolapse and residual aortic insufficiency at the completion of the case.
(Continued) (B) After the commissural posts are secured, the valve is reimplemented inside the graft using a running 4-0 polypropylene suture. We start at the nadir of each sinus and work toward the peak of the commissures. This suture line is responsible not only for valve function but also for the hemostasis of this procedure. Any perceived gaps in this suture line are repaired with figure-of-eight 5-0 polypropylene suture. The left coronary button is then attached with 2 layers of 5-0 suture. Hemostasis, aortic valve competency, and left coronary patency are then confirmed by infusing cardioplegia into the Dacron graft through a large Foley catheter with a 30-ml occlusive balloon as previously described. Aortic insufficiency because of leaflet prolapse is addressed at this time with either free-edge shortening or free-edge plication using a CV-6 Gore-Tex suture (Gore, Inc., Flagstaff, AZ). The distal suture line is then performed with a 3-0 polypropylene suture and, finally, the right coronary button is reattached into the anterior wall of the graft with 5-0 polypropylene. LCA = left coronary artery; RCA = right coronary artery.
Results

Our most recent publication on this patient population outlined our experience with 242 patients having reoperations on the ascending aorta or aortic root after having previous cardiac or aortic surgery. Patients having endocarditis, including those with aortic root abscesses, were excluded. Nearly one-quarter of these patients had previous coronary bypass grafting and approximately 20% of the total cohort required further revascularization. The aortic valve was either replaced or repaired in 67% of the patients having these operations. One hundred thirteen of the patients had separate aortic reconstruction at the level of the sinotubular junction, sparing the aortic root. The remaining 129 patients had total root reconstruction: 103 with an exclusion Bentall, 21 with the Svensson modification of the Cabrol procedure, and 5 with a David I valve-sparing root replacement. The mean time on cardiopulmonary bypass was 172 minutes and the mean cross-clamp time was 98 minutes.

Our overall operative mortality was 4.1% (n = 10). A postoperative stroke was seen in 5 patients (2.1%), while 4 patients (1.6%) required temporary renal support with hemodialysis. Eleven patients (4.5%) required reexploration for postoperative hemorrhage and 9 patients (3.7%) required a temporary tracheostomy for ventilator weaning. Ten patients (4.1%) developed postoperative heart block and required a permanent pacemaker. Myocardial failure was fortunately infrequent and intra-aortic balloon support was only necessary in 4 patients (1.6%). The need for blood transfusion after surgery was favorably low. The mean number of packed cell and fresh frozen plasma transfusions was 1.4 U per patient and the mean number of platelet transfusion was 3.8 U per patient.

Patients undergoing reoperations on the ascending aorta and aortic root are at greater risk than those having elective, first-time procedures. Predictors of perioperative mortality include age >75 years, previous bypass surgery, the need for intra-aortic balloon pump support, and prolonged cardiopulmonary bypass and cross-clamp times. Patients in need of a tracheostomy after surgery also have predictably worse outcomes. Technical problems, particularly those related to sternal reentry, contribute heavily to mortality. A thorough and thoughtful review of all preoperative data and imaging is essential to achieve a successful outcome.

References