Operative Techniques in Thoracic and Cardiovascular Surgery

Heart Transplantation After Left Ventricular Assist Device

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Congestive heart failure is a devastating clinical syndrome, which affects millions of individuals. In fact, half of the individuals diagnosed with congestive heart failure die within 5 years of diagnosis.[1] The best treatment option for individuals with end-stage heart failure is heart transplantation; however, the effectiveness of this modality is limited by a donor shortage. Because of the discrepancy between the number of potential recipients and available donors, an increasing number of patients have been bridged to transplant with mechanical circulatory support, particularly left ventricular assist devices (LVAD).

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The initial results with bridge to transplant therapy with the first-generation pulsatile-flow devices were mixed. However, with the introduction of the smaller, more durable, continuous-flow devices, posttransplant survival outcomes have improved and are equivalent to transplantation outcomes for patients who are not supported on an LVAD.[2,3] These encouraging results, coupled with a continued donor shortage, have led to a dramatic increase in the use of LVADs for bridging to transplantation. In fact, in 2011, 37% of transplant recipients were bridged with LVADs.[4]

The increased use of LVADs has undoubtedly improved patient outcomes, yet at the same time, it has created new technical challenges for the cardiothoracic surgeon. This article reviews the operative technique of heart transplantation in patients with continuous-flow LVADs (Figs. 1-13).

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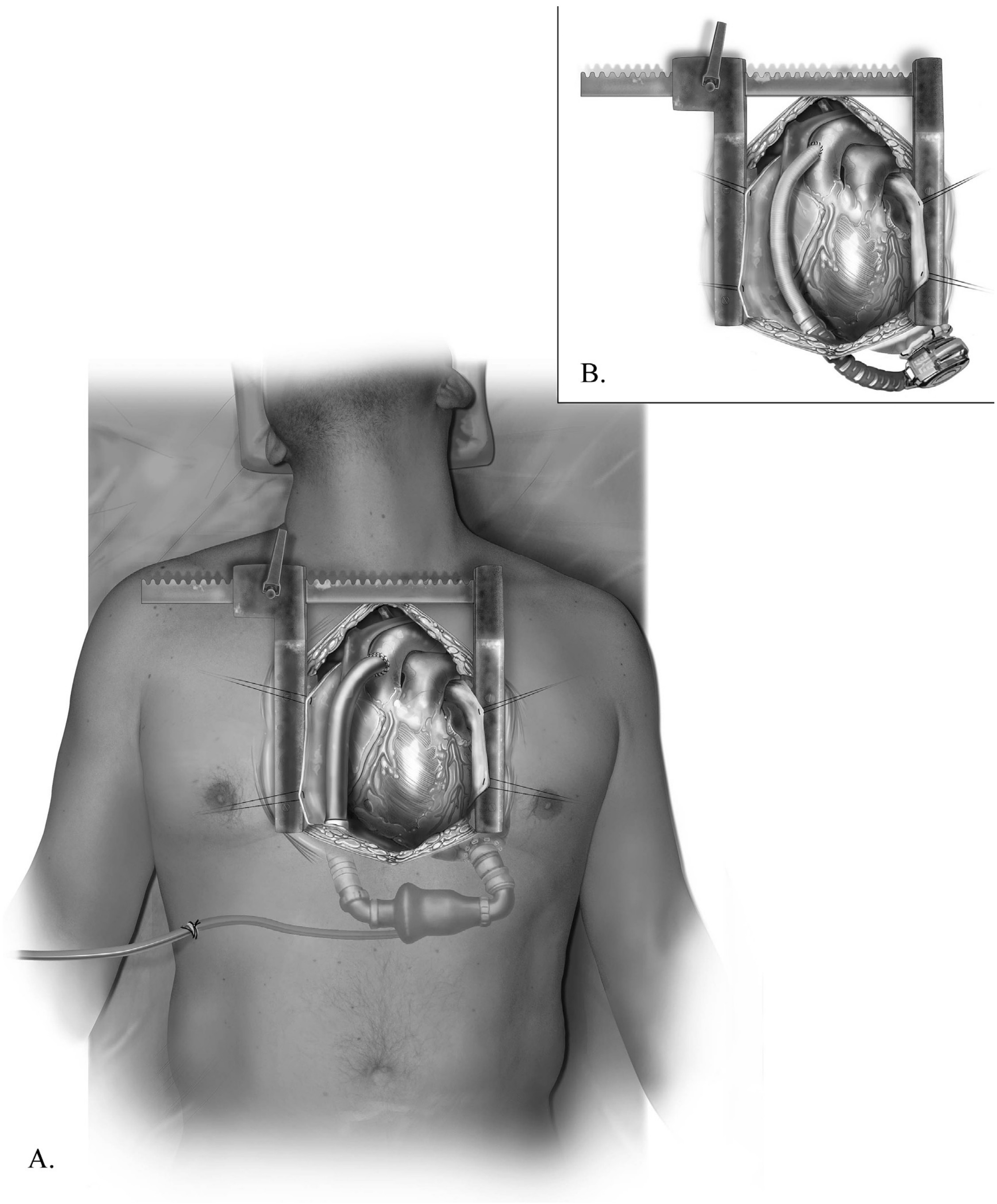


Figure 1 Implantation of LVAD. The future transplant procedure should be considered at the time of the LVAD implant procedure. The important structures, which can become scarred to the posterior sternal closure, include the LVAD outflow graft and the right ventricle (RV). The outflow graft for both axial flow (A) and centrifugal pumps (B) should be positioned just lateral to the right atrium and not immediately posterior to the sternal closure. Furthermore, the graft should be attached lower on the ascending aorta and to the right lateral aspect. The lower positioning of the outflow graft on the ascending aorta leaves ample distal ascending aorta, which can be used for the subsequent aortic anastomosis during heart transplantation.

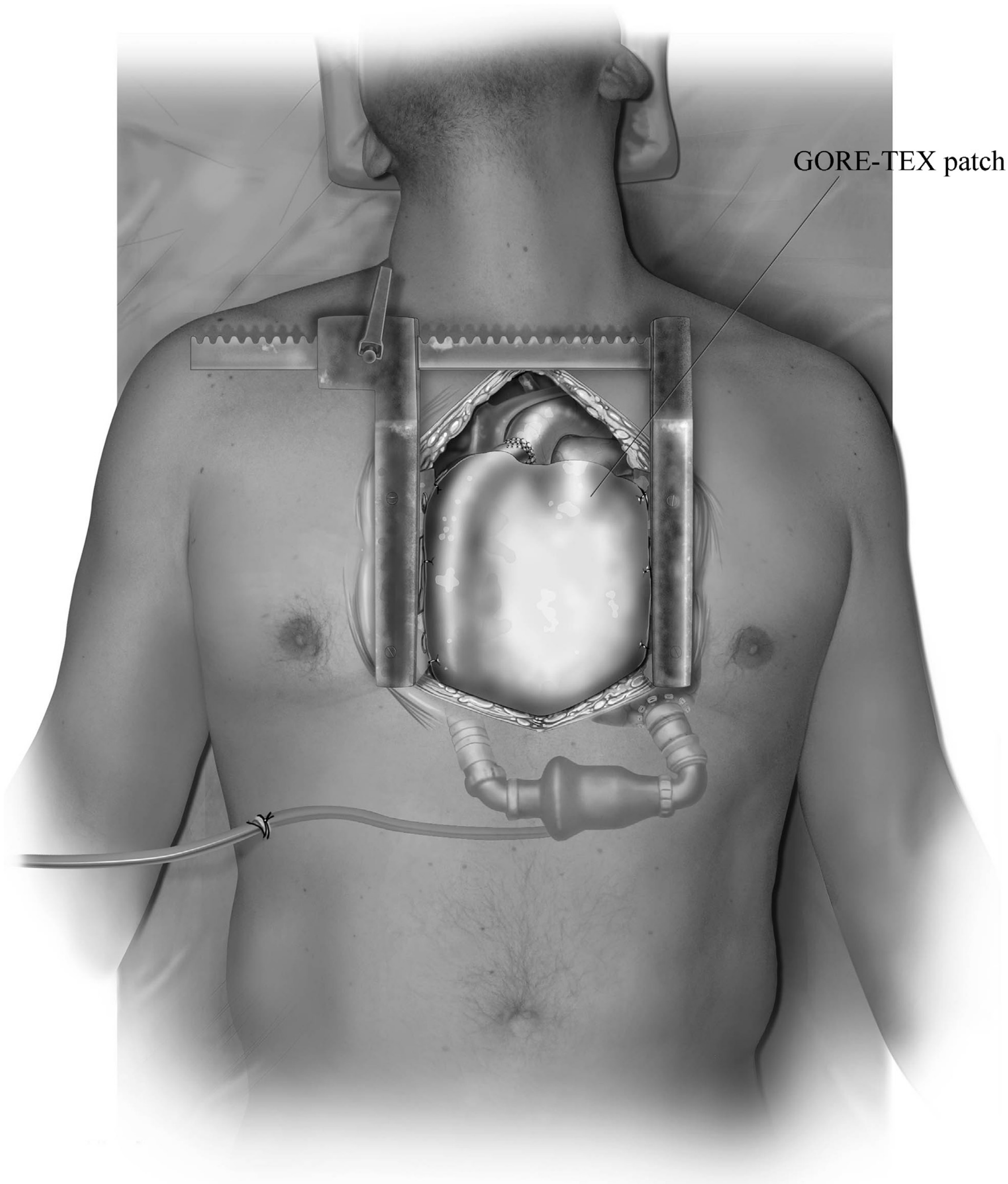


Figure 2 Placement of GORE-TEX patch. Many surgeons use a prosthetic membrane to cover the RV and the outflow graft at the time of sternal closure after the LVAD implant. This membrane is most commonly composed of GORE-TEX and is sutured to the lateral pericardial edges. This membrane serves to protect the right ventricle, the outflow graft, and other important cardiac structures. Because the membrane is sutured laterally to the pericardial edges, it also helps the surgeon identify the pericardial edges at the time of reoperation. RV = right ventricle.

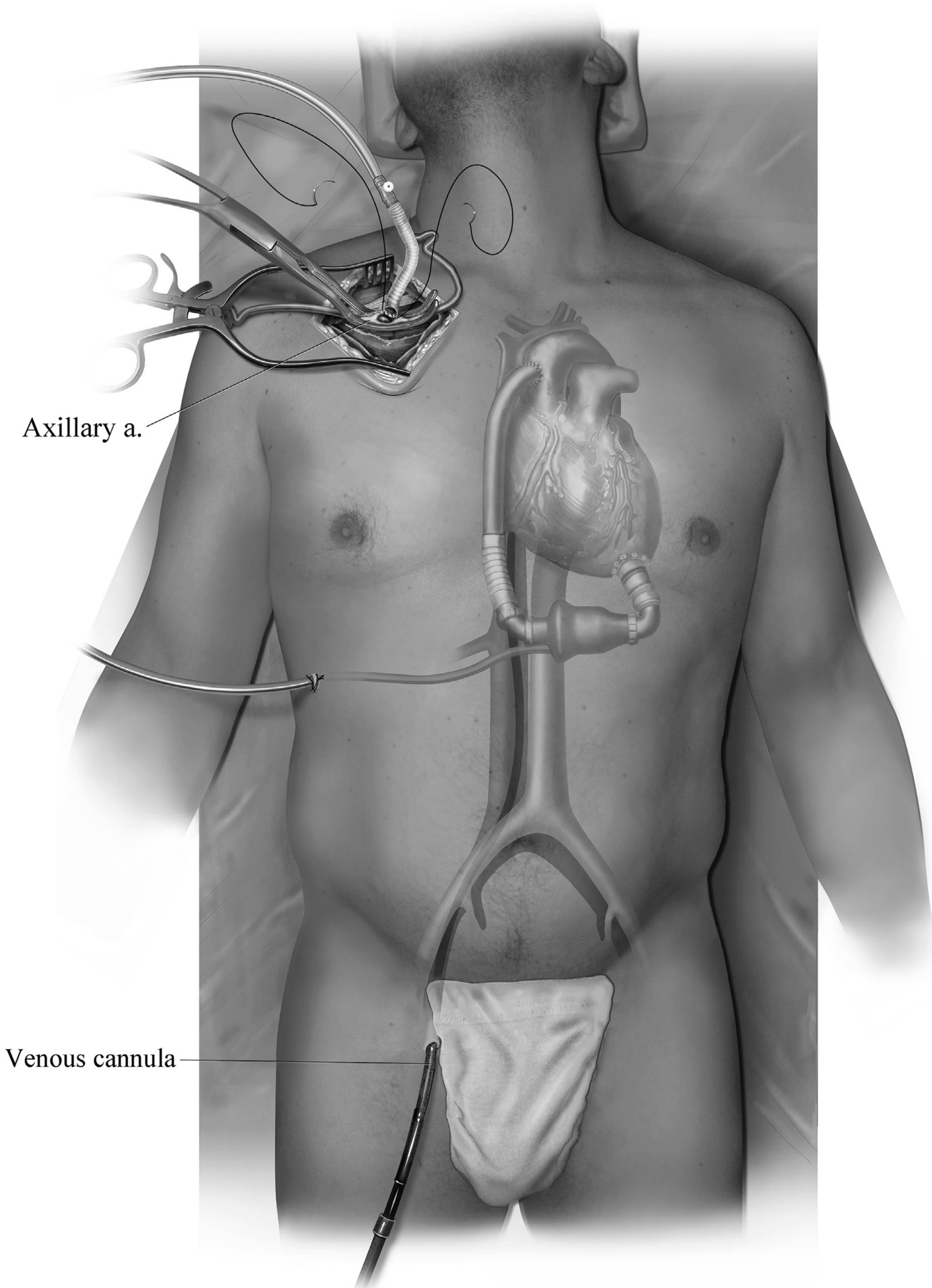


Figure 3 Peripheral cannulation. After a period of outpatient convalescence and end-organ recovery, the LVAD patient is considered for subsequent heart transplantation. Typically, the period of recovery between the LVAD procedure and heart transplantation is greater than 2 months. Preoperative chest CT should be obtained routinely to further define the anatomy before considering transplant. A suitable donor heart is matched to the recipient based on size, ABO blood type compatibility, and HLA antibody compatibility. Once the procurement operation has begun and the donor heart is visualized and determined to be suitable, the recipient LVAD removal and heart transplant procedure can be initiated. After general anesthesia, a radial arterial line and a right internal jugular Swan-Ganz catheter are placed. The Swan-Ganz catheter is left in the SVC during the procedure and floated into the pulmonary artery once the patient is weaned off cardiopulmonary bypass (CPB). After the patient is positioned, and the skin prepared, peripheral cannulation for CPB is established before the reoperative sternotomy. Although reoperative sternotomy can generally be performed without injury to vascular structures, peripheral cannulation adds safety. Although there are many options for peripheral cannulation, we prefer cutting down the right axillary artery and application of an 8-mm Hemashield graft in an end-to-side configuration to provide arterial inflow for CPB. Venous drainage for CPB is established percutaneously by accessing the right common femoral vein. Intraoperative transesophageal echocardiography (TEE) is used to confirm the position of the guide wire introduced from the right femoral vein and guided into the right atrium. This site is sequentially dilated, and then a #25 French multistage venous cannula is guided over the wire into the right atrium. Before these cannulation procedures, the patient should be systemically administered heparin. Importantly, after initiating CPB, the LVAD pump speed should be decreased to avoid generation of negative pressure in the LV, which could lead to air entrainment and subsequent embolization. However, the LVAD pump should not be turned off if the outflow graft cannot be clamped, as regurgitant flow will occur, and may lead to LV distention. CT = computed tomography; HLA = human leukocyte antigen; SVC = superior vena cava; LV = left ventricle.

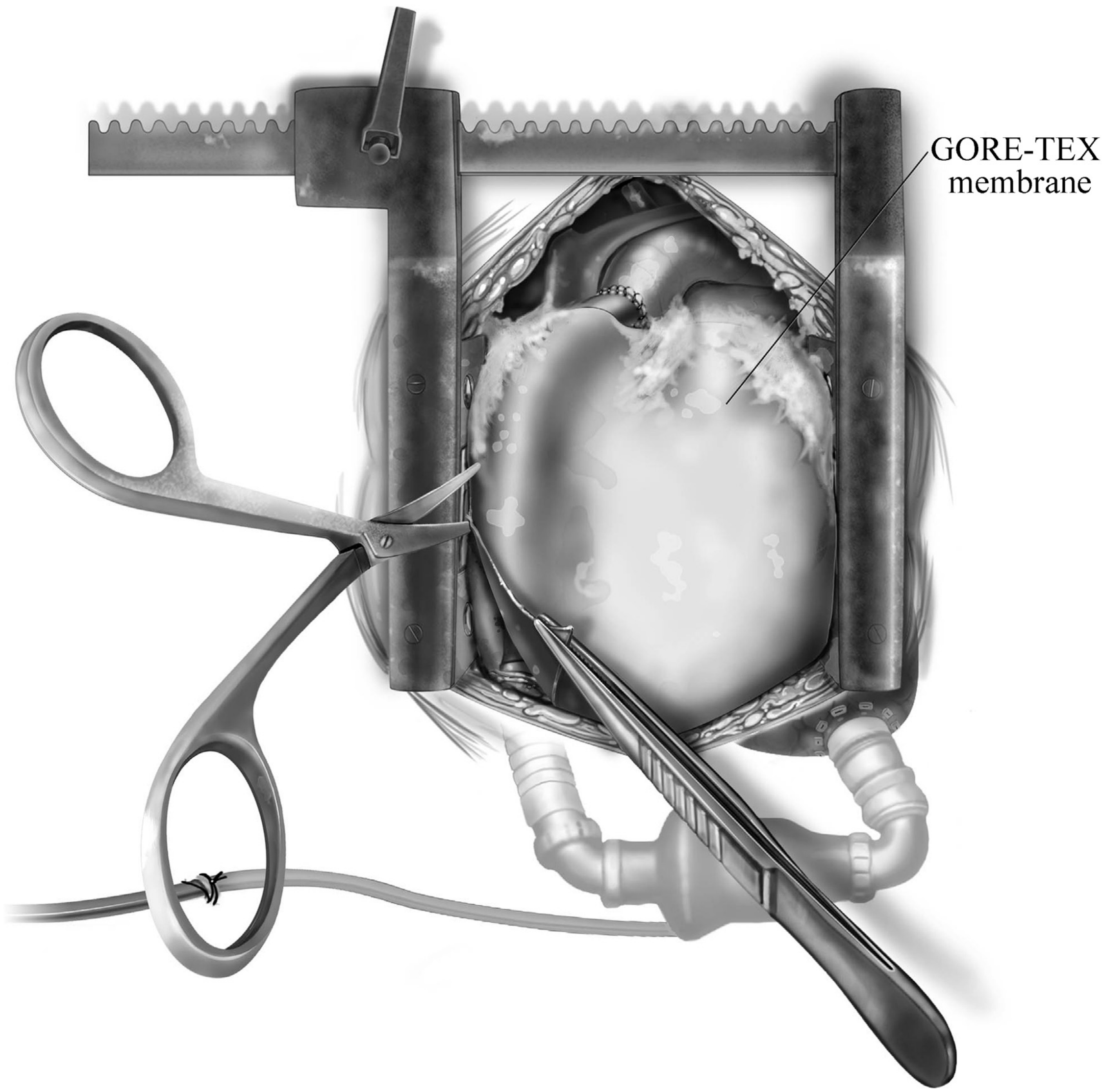


Figure 4 Sternotomy or removal of GORE-TEX membrane. After peripheral cannulation for CPB is secured, median sternotomy is performed with an oscillating saw. The posterior table of the sternum is sawed while providing upward traction. After the sternotomy is completed, the GORE-TEX membrane should be visible. Dissection is conducted toward the lateral margins of the prosthetic membrane, which should lead to the pericardial edges. Once the pericardial edges are defined, dissection is conducted to free the pericardium from the underlying epicardium or LVAD components. Typically, during reoperative cardiac surgery, the diaphragmatic pericardium is a good point of initiation for the dissection. On LVAD cases, however, this region is usually more scarred owing to the presence of the pump and the outflow graft. Therefore, the left lateral pericardium in the region of the main pulmonary artery is often a better starting point. After the pericardial edges are dissected in all directions, the GORE-TEX membrane is removed and discarded. CPB = cardiopulmonary bypass.

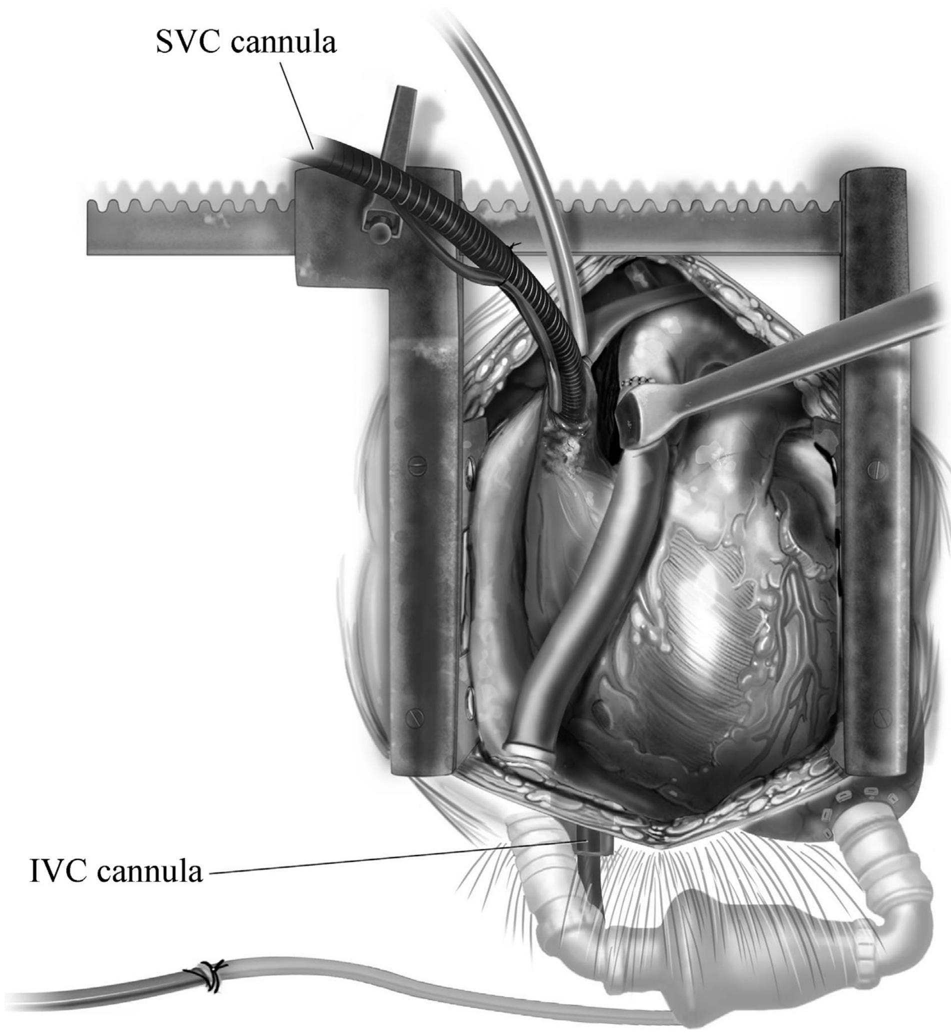


Figure 5 Bicaval venous drainage. The bicaval heart transplant technique requires dual venous drainage for CPB. The percutaneous femoral vein drainage cannula can be withdrawn into the IVC, and clamping above this level enables performance of the IVC anastomosis. Other surgeons have described dividing the IVC and utilizing vacuum drainage to clear the field without a clamp on the IVC. The SVC must also be identified. The aorta and LVAD outflow graft are retracted medially; the SVC is identified and cannulated with a right angle venous drainage cannula. The SVC is circumferentially dissected at the level of the right pulmonary artery, and an umbilical tape is placed around the SVC. The SVC cannula is spliced into the venous drainage line. Tightening the tape around the SVC cannula and clamping the IVC at the level of the diaphragm achieve complete bicaval venous drainage. CPB = cardiopulmonary bypass; IVC = inferior vena cava; SVC = superior vena cava.

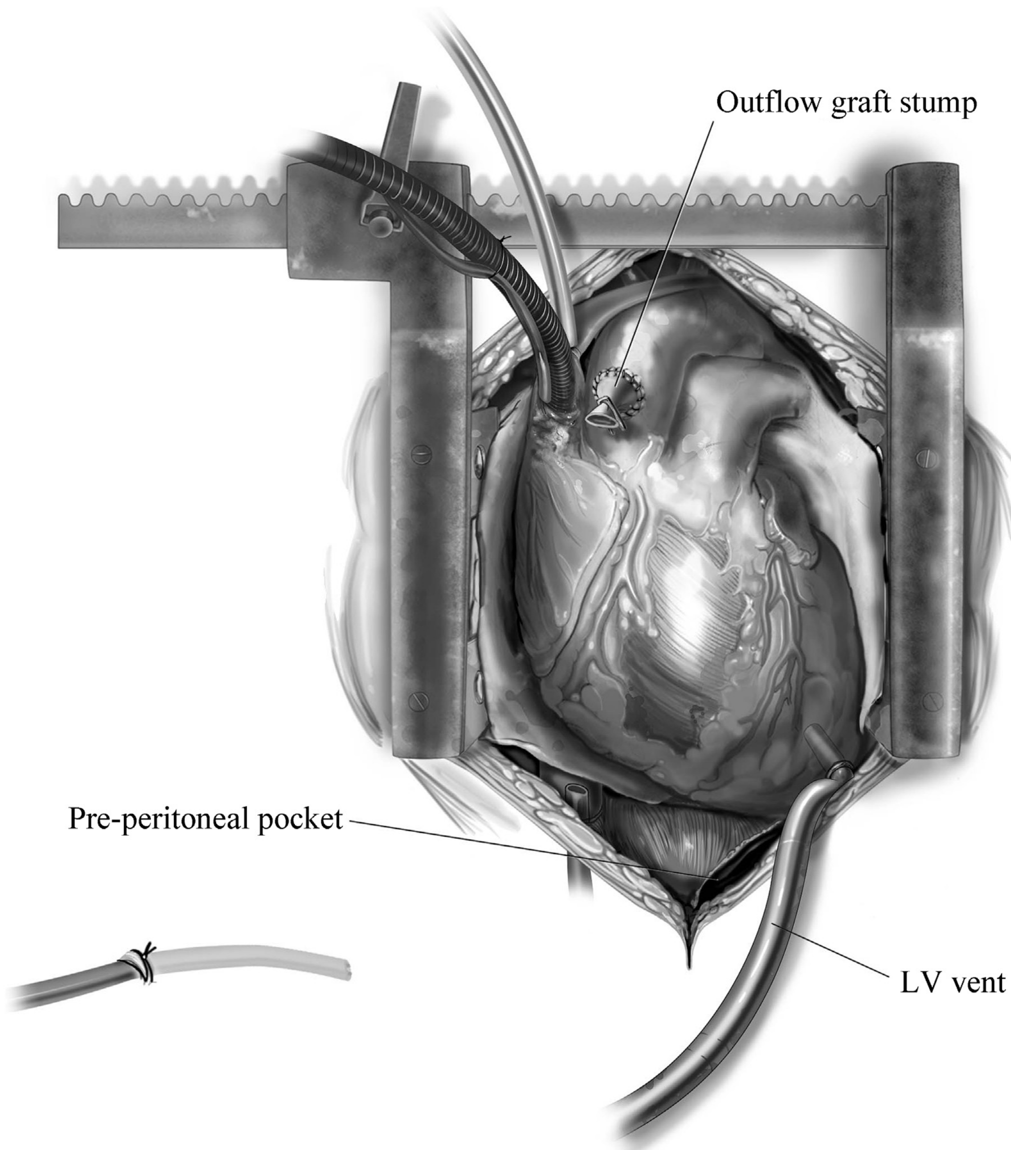


Figure 6 Extirpation of LVAD. The LVAD pump is generally encased in a pocket of dense scar tissue, which must be incised. After complete mobilization of the LVAD pump, while on cardiopulmonary bypass, the LVAD pump is turned off, and the outflow graft is clamped and divided near the ascending aorta. The LVAD inflow cannula is then removed from the LV apex, and a LV vent is placed through the apical hole into the LV cavity. Finally, the power cord, which usually courses through the right rectus muscle, is dissected, mobilized, and divided. At this time, the LVAD pump is removed from the field. Any residual power cord can be removed at the end of the procedure by dissecting the tract beginning from the site where the cord exits the abdominal wall. This exit site and the inside of the power cord are contaminated; therefore, this is done at the end of the procedure. The residual tract in the abdominal wall can be packed with gauze and treated with dressing changes postoperatively. LV = left ventricle.

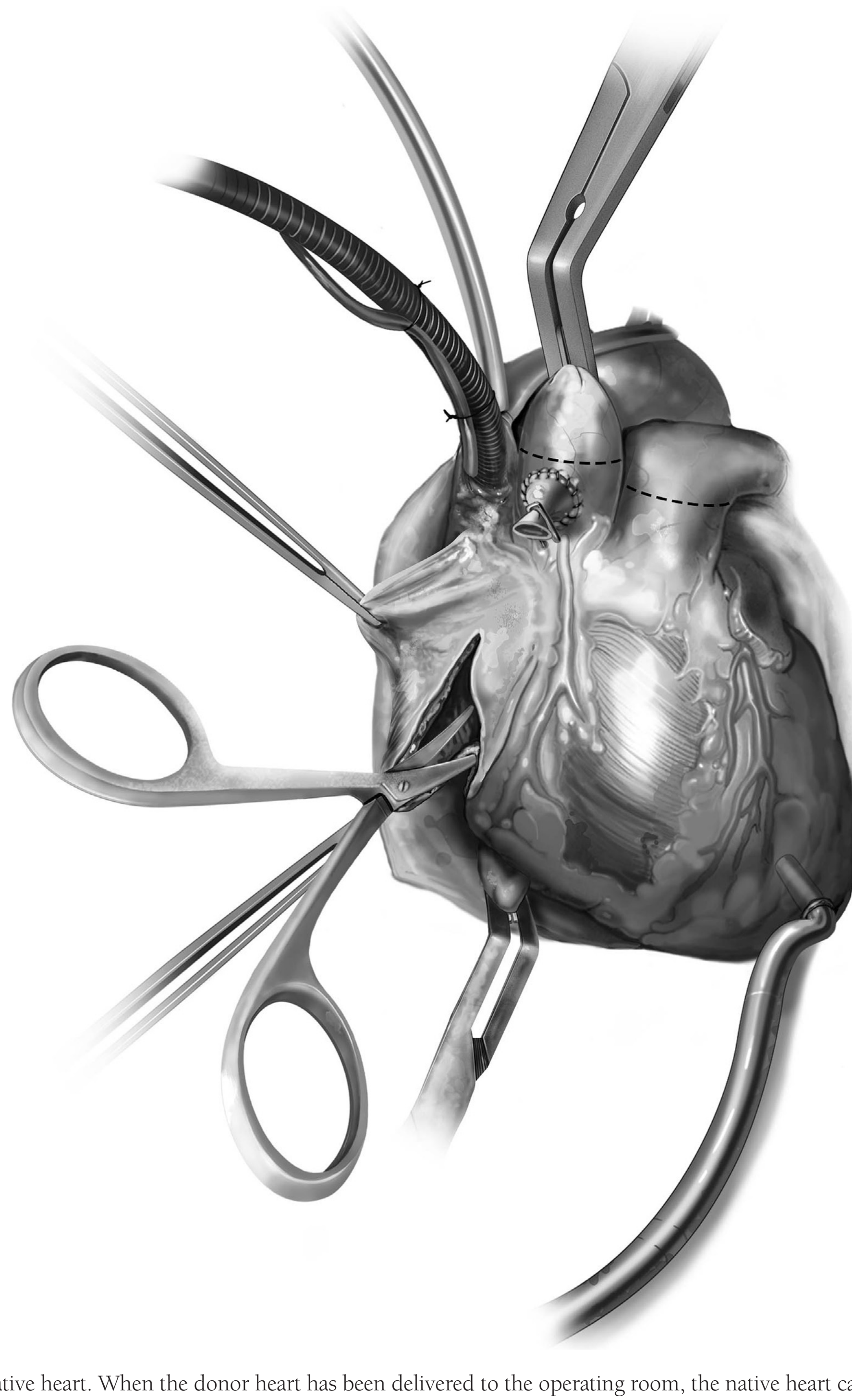


Figure 7 Excision of native heart. When the donor heart has been delivered to the operating room, the native heart can be excised. The aorta is cross clamped. The SVC tape is tightened around the SVC cannula, and the IVC is clamped at the level of the diaphragm above the femoral venous cannula. The native heart is excised at the level of the right and left atrioventricular grooves, initially leaving much of the native atria. On the right side, the excision is conducted near the course of the right coronary artery, inferiorly toward the coronary sinus. The aorta is then divided at the level of the sinotubular junction. Most of the native aorta is initially retained and trimmed back later. The main pulmonary artery is divided at the level of the pulmonic valve. Next, the left ventricle is excised. On the left side, the excision is conducted through the coronary sinus, which travels in the left atrioventricular groove. This dissection essentially retains the majority of the native left atrium, which is trimmed back later. The native heart is then removed from the field. SVC = superior vena cava; IVC = inferior vena cava.

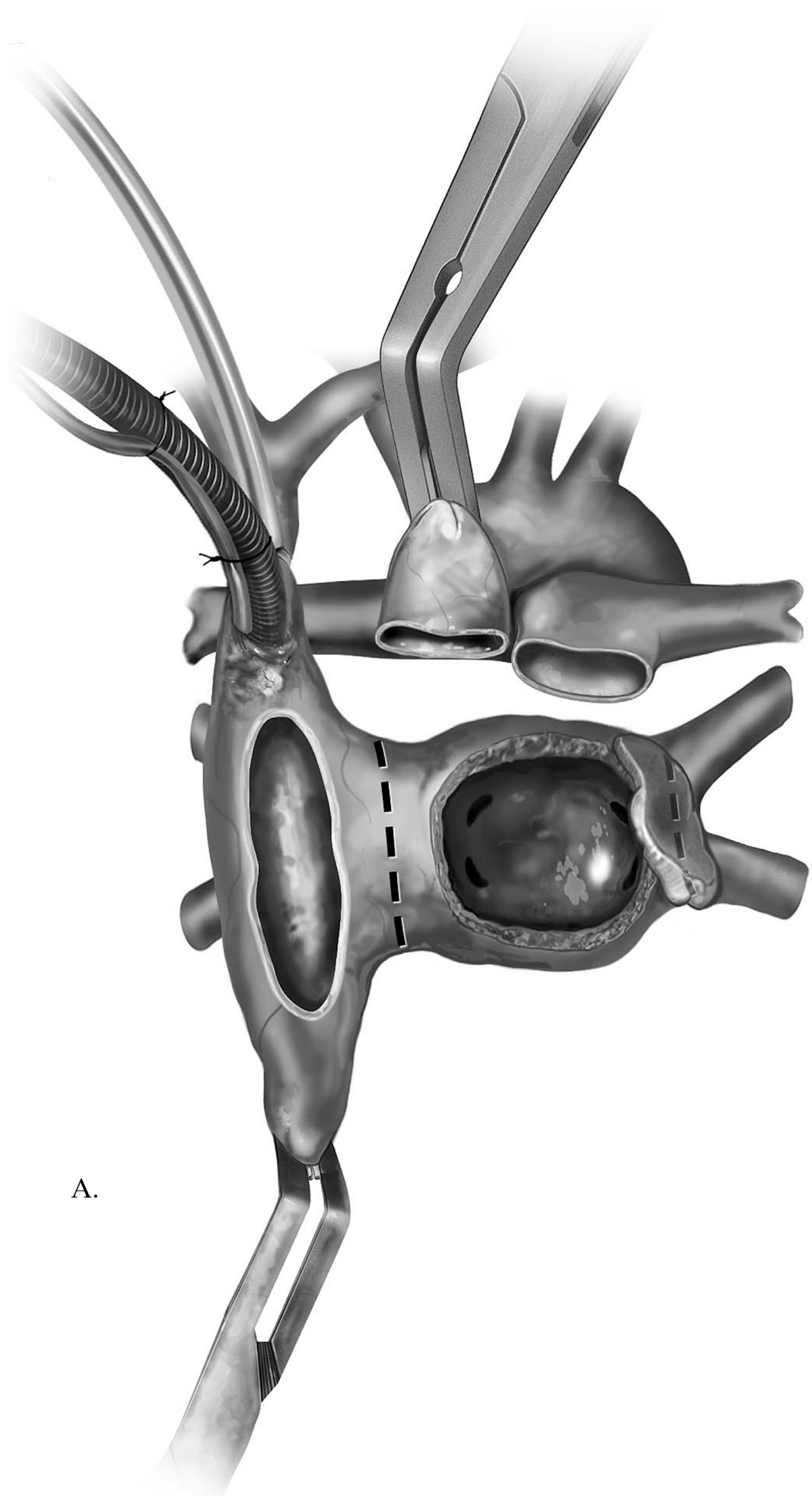
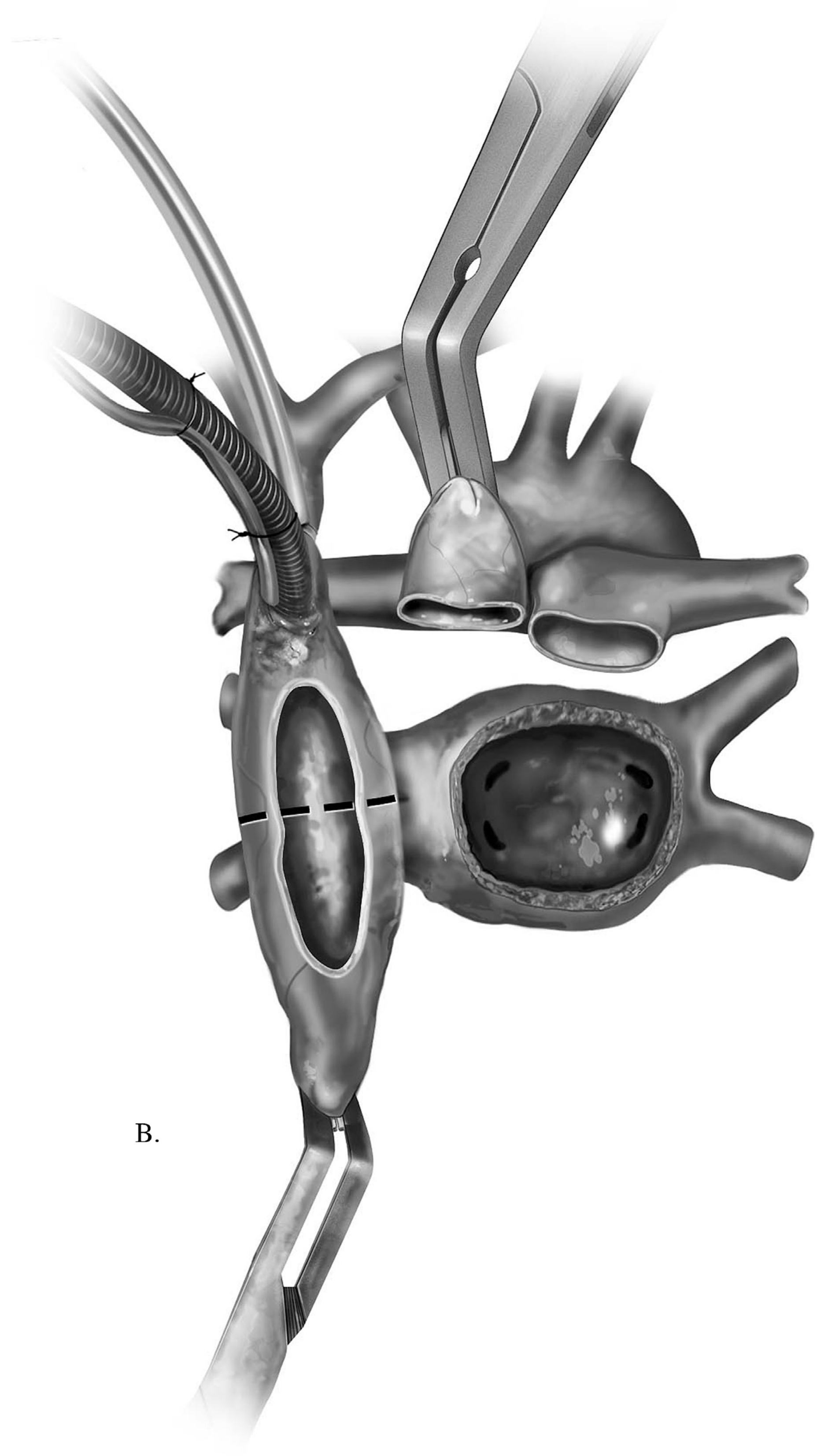


Figure 8 Creation of left atrial, SVC, and IVC cuff. (A) The interatrial groove is dissected to separate the left and right atrial cuffs.



B.

Figure 8 *Continued* (B) The right atrial cuff is then divided into 2 cuffs, one attached to the SVC superiorly and another to the IVC inferiorly.

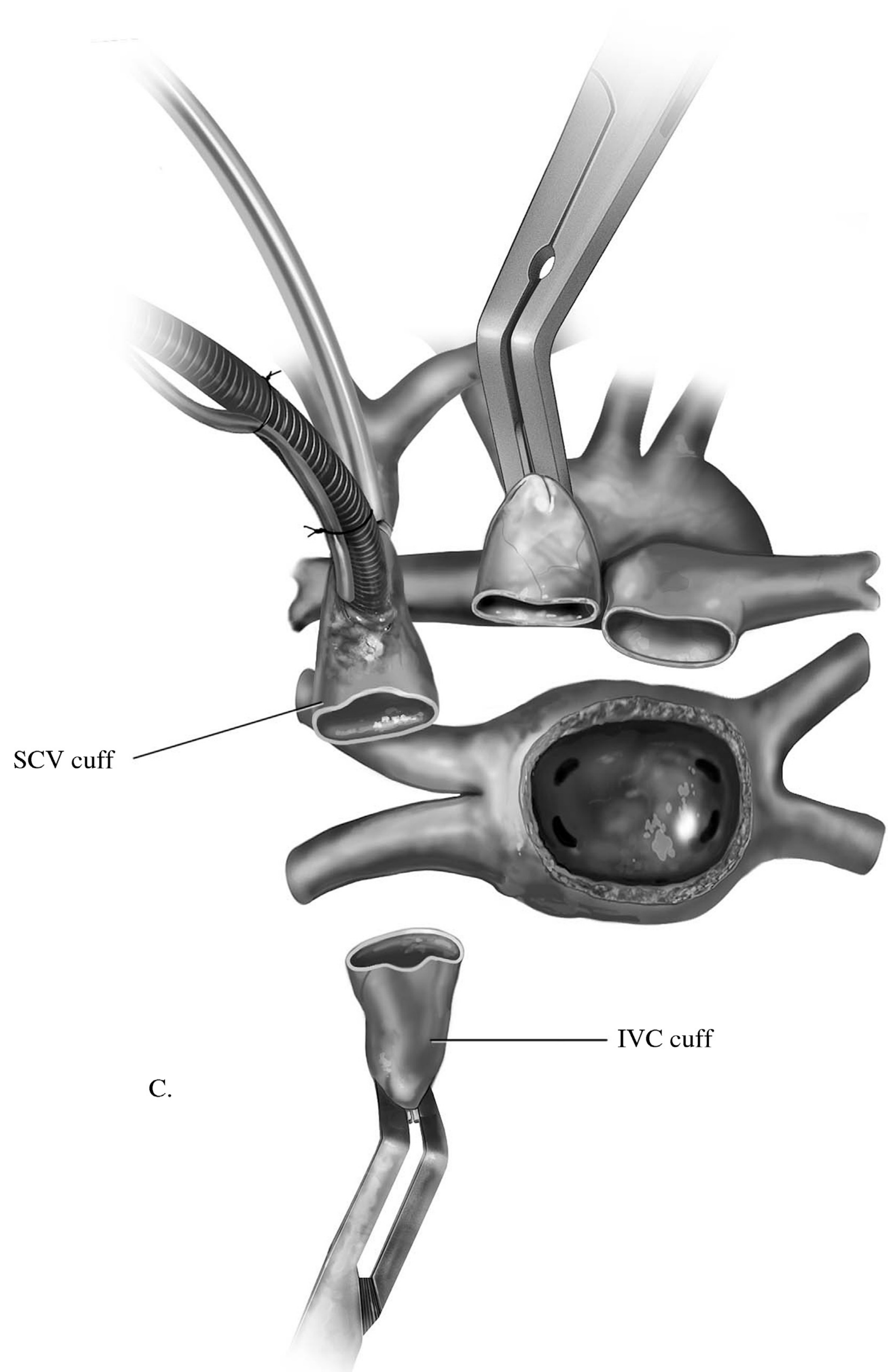


Figure 8 *Continued* (C) The SVC cuff is mobilized to the level of the azygos vein, taking care to avoid injury to the right pulmonary artery. The IVC cuff is mobilized back to the diaphragm, taking care to avoid injury to the right inferior pulmonary vein. SVC = superior vena cava; IVC = inferior vena cava.

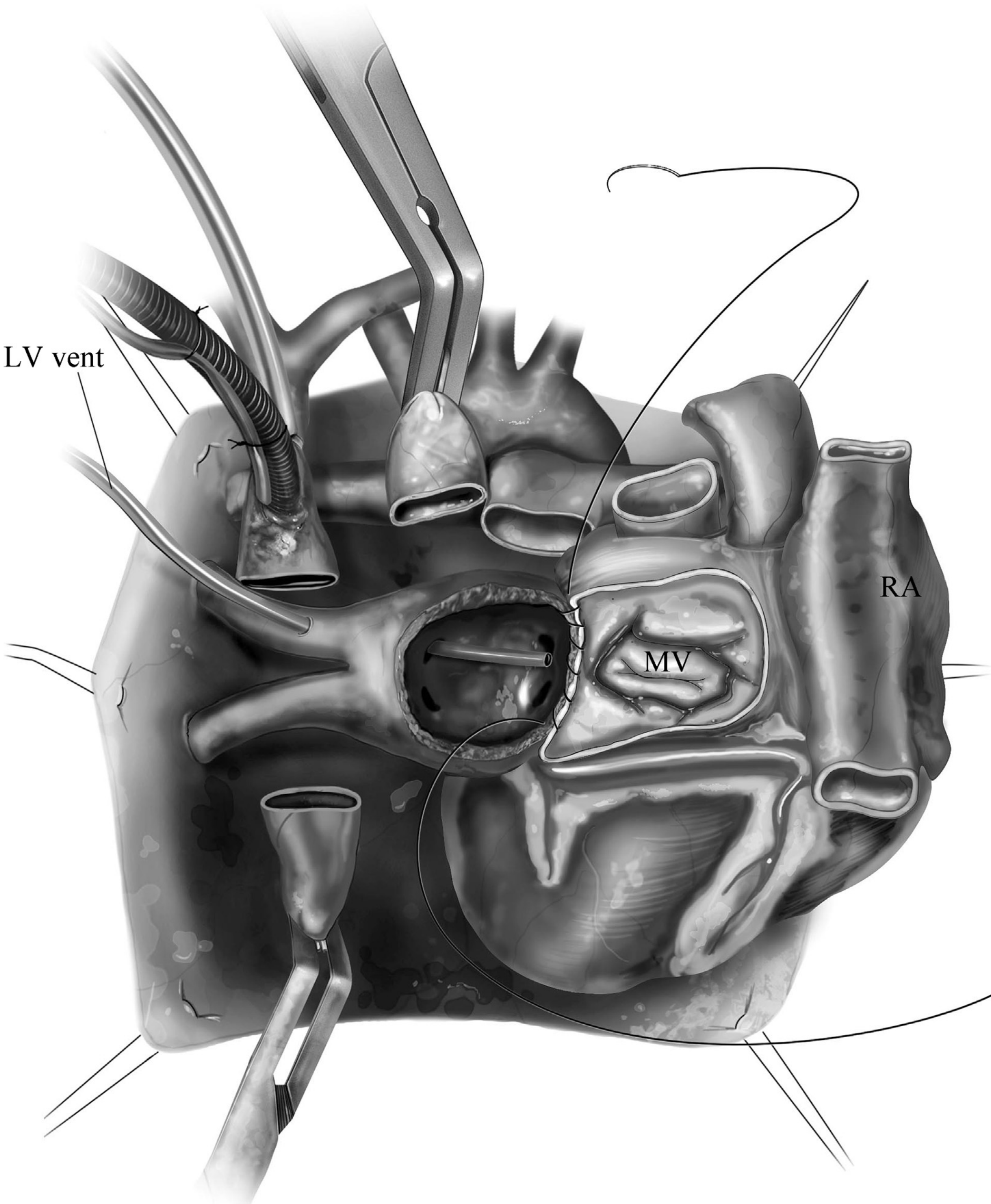


Figure 9 Preparation of donor heart and left atrial anastomosis. The future LV vent is now placed through a purse-string suture in the right superior pulmonary vein; the vent is guided across the left atrial cuff, and the tip is temporarily positioned in the left pulmonary veins. The left atrial cuff is trimmed, and the recipient left atrial appendage is removed. Next, the donor heart is taken out of the cold static storage and brought up to the field. While on ice, the interatrial septum is inspected and any patent foramen ovale is closed with a 4-0 PROLENE suture. The pulmonary veins if still present on the left atrium are opened into a confluent left atrial cuff. If the donor was used for lung grafts, the pulmonary veins will have been removed from the left atrium and remain with the lung graft. The donor aorta and pulmonary artery are carefully separated. All valves are inspected, and any intracardiac thrombus is removed. The first anastomosis to be performed is the left atrial anastomosis. The heart is held toward the assistant's side (patient's left side), and the left lateral part of the anastomosis is performed. Typically, we use a running 3-0 PROLENE suture. After the running suture is completed to the point of the left atrium closest to the IVC, the other limb of the suture is used to complete the anastomosis at the roof of the left atrium. Before completion of the anastomosis, the LV vent is repositioned across the mitral valve into the left ventricle of the donor heart. LV = left ventricle; RA = Right atrium; MV = mitral valve; IVC = inferior vena cava.

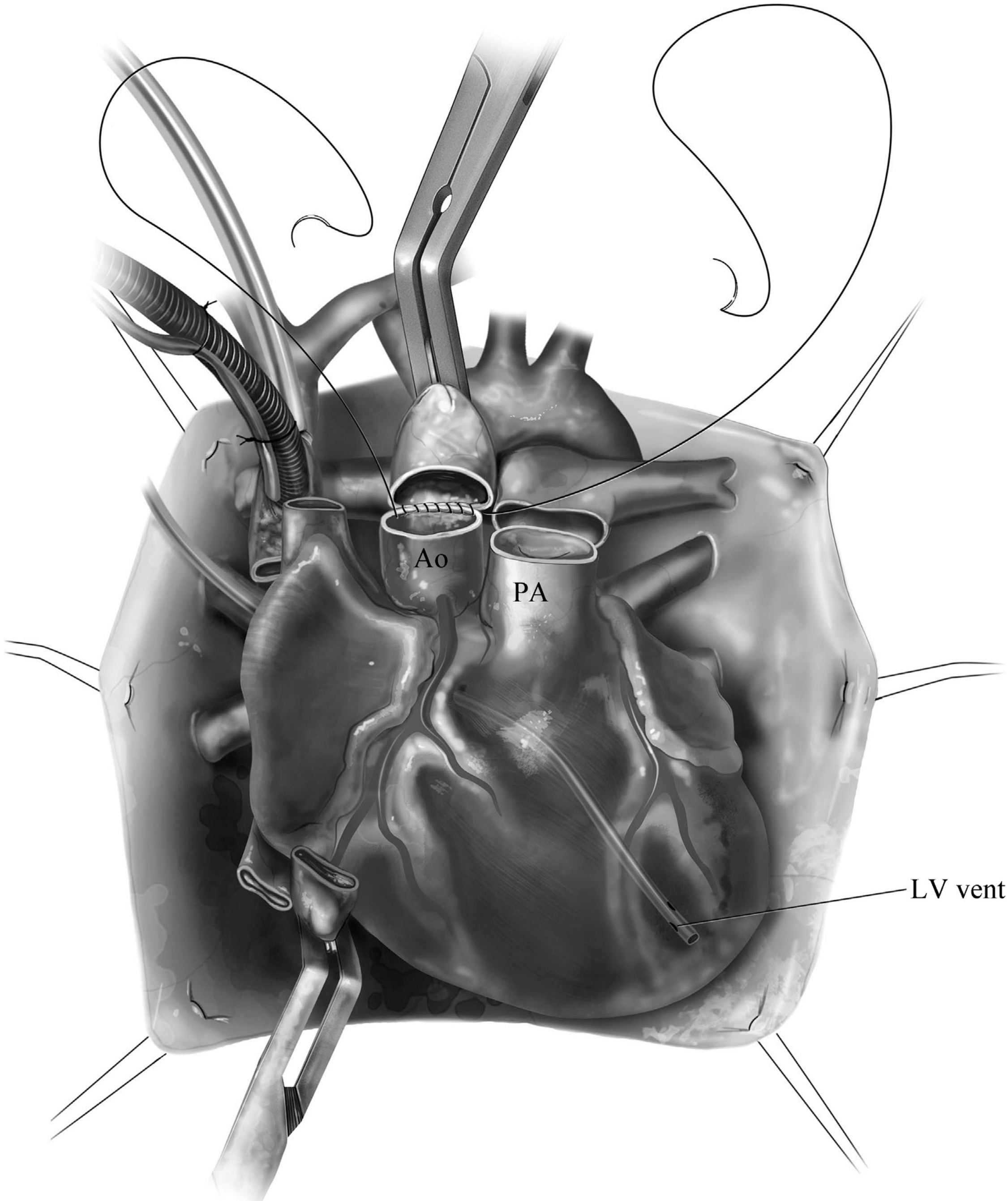


Figure 10 Aortic anastomosis. After completion of the left atrial anastomosis, a solumedrol bolus (1000 mg) is administered intravenously. The heart is then treated with cold blood cardioplegia, which is administered into the ascending aorta, which can be temporarily clamped. The cardioplegia should be visualized emanating from the coronary sinus. After the cardioplegia is delivered, the donor and recipient aortas are trimmed and a tension-free end-to-end aortic anastomosis is performed with running 4-0 PROLENE suture. Before completion of the aortic anastomosis, the left heart is deaired. The operative field is continuously flooded with carbon dioxide. Next, the aortic cross clamp is removed and the donor heart is reperfused. Following reperfusion, an additional ascending aortic vent is placed for further deairing. The LV vent is turned on to fully decompress the left ventricle. Additionally, intraoperative TEE is used to assess for the presence of intracardiac air, which can be removed with the LV or aortic root vents. Ao = aorta; PA = pulmonary artery; LV = left ventricle; TEE = transesophageal echocardiography.

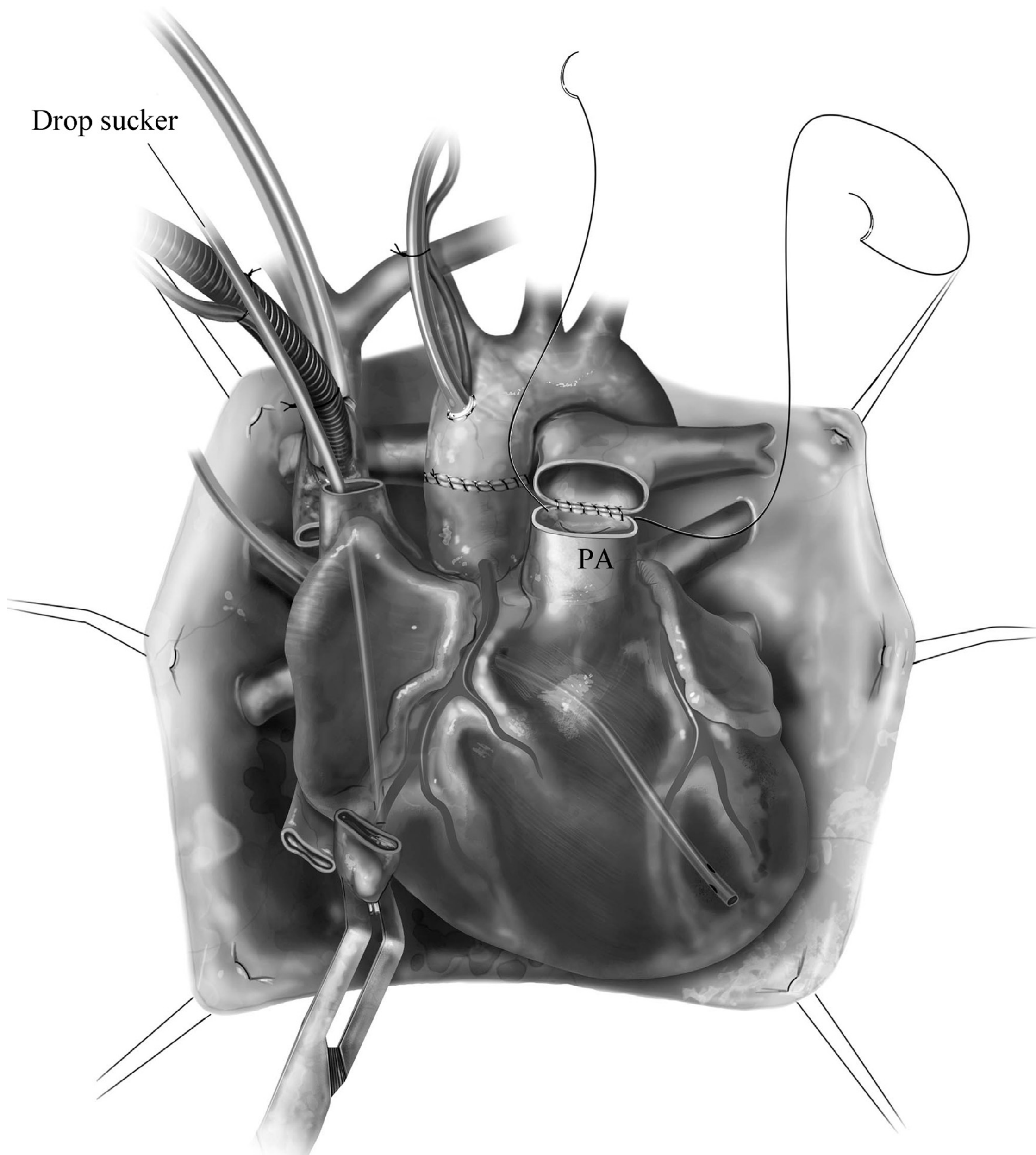


Figure 11 Pulmonary artery anastomosis. After reperfusion, a drop sucker is placed through the superior vena cava into the coronary sinus to capture the heart's venous drainage. The remaining anastomoses (pulmonary artery [PA], IVC, and SVC) can be performed with the heart reperfused, thus reducing the duration of the ischemic period. Owing to anatomical constraints, it may be difficult to complete the back wall of the PA anastomosis after the completion of the aortic anastomosis. If this is the case, the back wall of the PA anastomosis can be performed before the aortic anastomosis, and the anterior portion of the PA anastomosis can then be completed after reperfusion. The PA, IVC, and SVC anastomoses are generally completed in this order with running 4-0 PROLENE sutures. Again, pump sucker clearance of the coronary sinus effluent is necessary to facilitate visualization. IVC = inferior vena cava; SVC = superior vena cava.

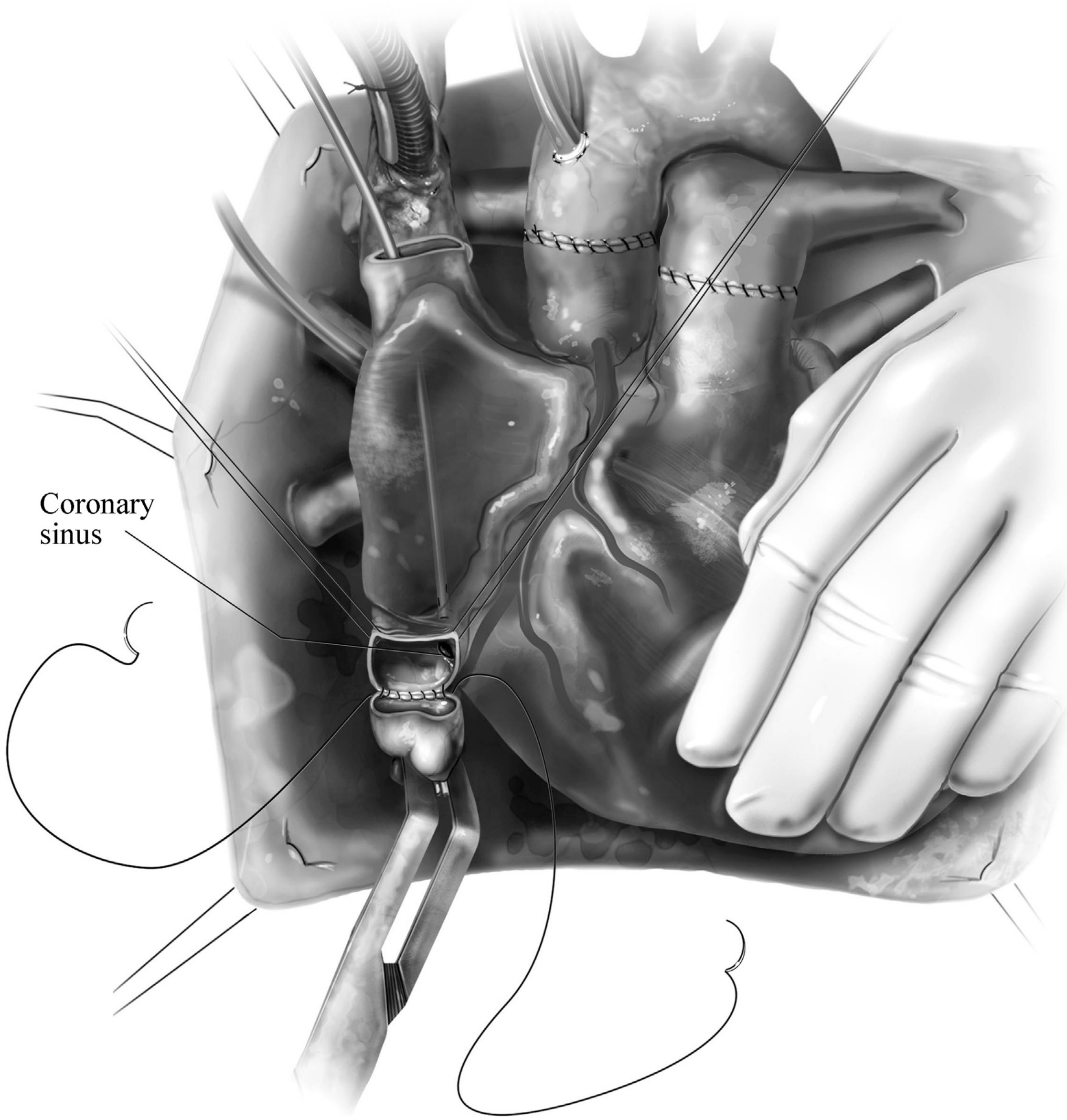


Figure 12 IVC anastomosis. The IVC anastomosis is facilitated by positioning the patient in a head-down (Trendelenburg) position. Additionally, stay sutures can be placed on the anterior aspect of the donor IVC retracting the acute margin of the heart cephalad enabling visualization. The PA, IVC, and SVC cuffs must be carefully trimmed and sized to avoid redundancy, which can lead to a kink after the heart fills. IVC = inferior vena cava; PA = pulmonary artery; SVC = superior vena cava.

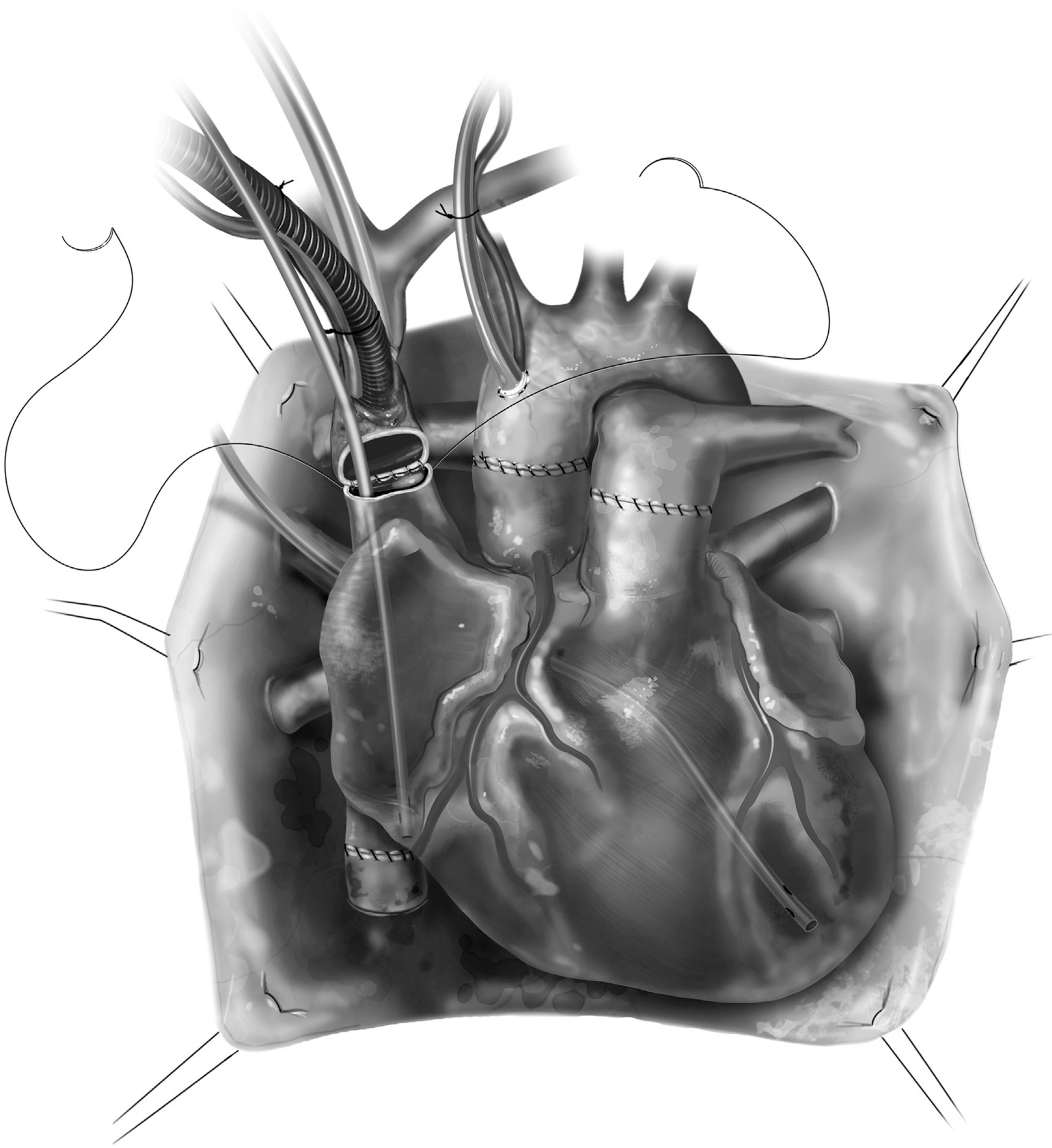


Figure 13 SVC anastomosis. The SVC anastomosis is constructed around the drop sucker, which continues to evacuate blood from the coronary sinus (this sucker is removed before completion of the anastomosis). After completion of all the anastomoses, the SVC tape and the IVC clamp are removed. All anastomoses are inspected for bleeding. Atrial and ventricular epicardial pacing wires are placed. The lungs are re-expanded, and the heart is deaired with intraoperative TEE guidance. After deairing is completed, the LV vent and ascending aortic vents are removed. Typically, a dobutamine or low-dose epinephrine infusion is started before discontinuing CPB. Inhaled nitric oxide in the ventilator circuit is frequently employed if there is high pulmonary vascular resistance or RV dysfunction. After CPB is terminated, the heparin is reversed fully with protamine. Patients are typically receiving warfarin before the procedure; therefore, fresh frozen plasma and vitamin K reversal of warfarin are warranted. Continuous-flow LVAD patients frequently experience a form of acquired von Willebrand disease with destruction of high-molecular-weight von Willebrand factor. Therefore, desamino-D-arginine vasopressin (0.3 μg/kg) and platelet transfusions may be warranted as well. If there is RV dysfunction or coagulopathic bleeding, sternal closure may be delayed. Finally, intraoperative TEE is used to inspect RV and LV functions, as well as to examine all valves and anastomoses. SVC = superior vena cava; IVC = inferior vena cava; TEE = transesophageal echocardiography; LV = left ventricle; CPB = cardiopulmonary bypass; RV = right ventricle.

Postoperative Management

The postoperative management of heart transplant recipients bridged with LVADs is similar to conventional heart transplantation. Patients are transferred from the operating room to the intensive care unit. Patients are mechanically ventilated, and standard monitoring consists of continuous arterial blood pressure, pulse oximetry, and electrocardiogram. Hemodynamics are monitored via a Swan-Ganz catheter. Urine output, temperature, and mediastinal drain output are also monitored.

Early complications include hemorrhage and primary graft dysfunction, most frequently right-sided dysfunction. Late complications consist of acute rejection, cardiac allograft vasculopathy, infection, renal insufficiency, and neoplasm.

Immunosuppression protocols may vary. However, at our institution, high-risk patients are induced with Simulect in addition to a solumedrol bolus. All patients are managed with a maintenance regimen consisting of tacrolimus, prednisone, and CellCept.

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