Operative Techniques in
Thoracic and
Cardiovascular Surgery

HeartWare HVAD: Principles and Techniques for Implantation

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Cardiac transplantation is still considered the gold standard for treatment of advanced heart failure refractory to medical therapy. More than 16 million people suffer from heart failure (HF) in the United States and Europe. Its prevalence is estimated to be 2.5% of the population and increases considerably after 65 years of age. The limiting factor to treating advanced HF with cardiac transplantation remains the lack of suitable donors. The development and use of ventricular assist devices (VADs) has become an important therapy in treating refractory HF. Approximately one-fourth of all patients undergoing transplantation in the United States have been supported with these VADs. Furthermore, the use of these devices as permanent or destination therapy is increasing rapidly.

The first-generation left VADs (LVADs) were pulsatile-flow devices. These pumps were large-sized devices necessitating extensive surgical dissection and were not suitable for smaller-sized patients. Although these devices provided excellent support, they lacked long-term durability owing to bearing wear. Second-generation pumps represented a significant advance over the previous generation of pulsatile-flow devices. Second-generation devices had a continuous-flow axial design pump that offered virtually noiseless operation with improved durability, thereby resulting in improved long-term survival. Additionally, the smaller size of these pumps limits the surgical dissection required for implantation and allows for a wider application in smaller women and children. The HeartWare HVAD (HeartWare International Inc, Framingham, MA) is a third-generation LVAD that is a continuous-flow centrifugal pump with an integrated inflow cannula. The HVAD has only 1 moving part and no mechanical bearings. The wide-blade impeller is levitated by a hybrid passive magnet and hydrodynamic fluid forces. It is able to generate an output of 10 L/min and operates at pump speeds between 2400 rpm and 3200 rpm. It is a small pump with a displacement of 50 cc and weighs 140 g, which facilitates implantation and is intended for intrapericardial placement. Communication from the pump to the control and power components is provided by an externalized, flexible polyurethane-covered driveline. A continuous power supply is provided by the AC wall power or lithium-ion batteries for portable use. The HVAD has been approved for use as a bridge to transplantation, and it is currently in trial for evaluation for destination therapy indication. This article describes the implantation technique for the HeartWare HVAD. (Figs. 1-6)

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Operative Technique

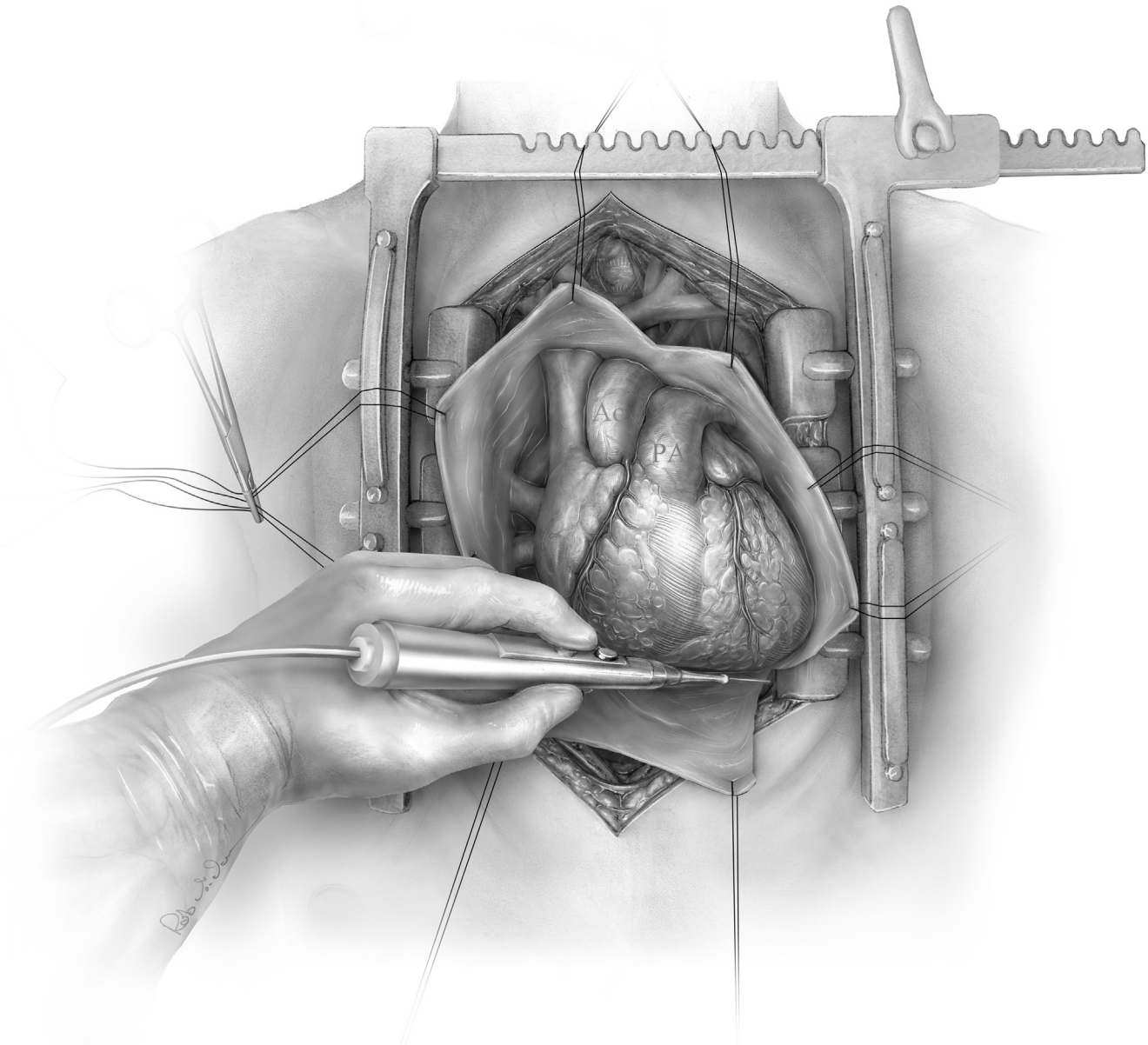

Figure 1 Patient and surgical preparation. Patients with advanced HF are preoperatively maintained with inotrope infusions to optimize organ function. To minimize infectious risks, a new central venous pulmonary artery (PA) catheter should be inserted no more than 24 hours preoperatively. The routine use of PA catheters for LVAD implantation may assist with perioperative therapies including pulmonary vasodilator therapy with nitric oxide as well as inotropic and vasoconstrictor support. The general preparation is similar to other cardiac surgical procedures with the patient prepared and draped in the standard sterile fashion. Routine broad-spectrum antibiotics are administered intravenously. In addition to the PA catheter, an arterial line and a Foley catheter are inserted. A transesophageal echocardiogram (TEE) is used to assess for a patent foramen ovale, valvular dysfunction, and intracardiac thrombi before implantation and is used to optimize pump speed while weaning from cardiopulmonary bypass following implantation. A standard median sternotomy is performed and the pericardium is incised; this incision is carried to the left, along the pericardial reflection to the apex. Ao = aorta.

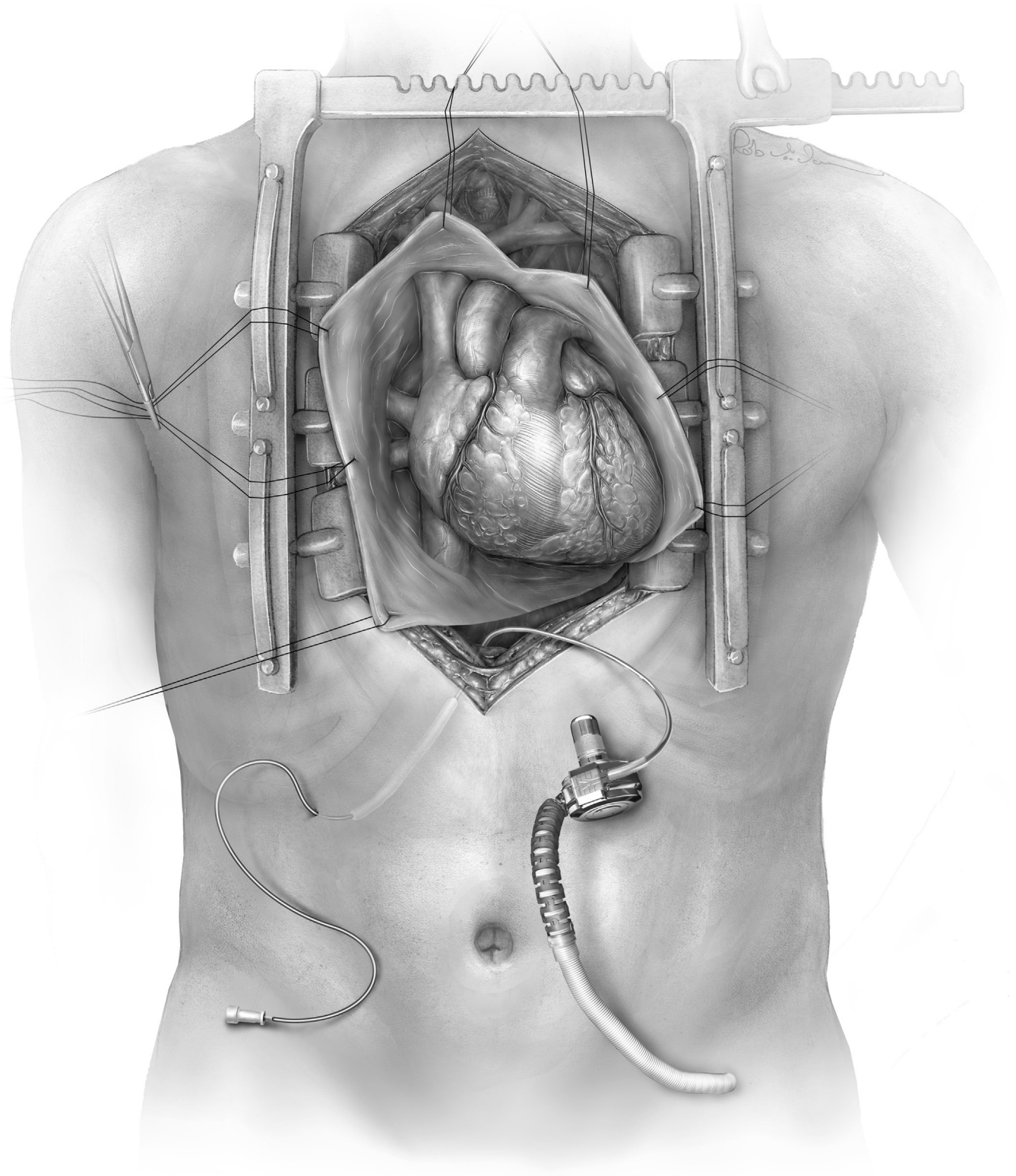

Figure 2 Preparation of the driveline exit site before administration of heparin. We routinely exit the driveline along the anterior axillary line, approximately 2 cm below the costal margin on the right side. Using the tunneling device, the driveline is tunneled through the rectus muscle. The woven polyester portion of the driveline should be completely housed in the subcutaneous tissue 1-2 cm from the skin exit site. The pump and driveline are temporarily wrapped in an antibiotic-soaked laparotomy pad.

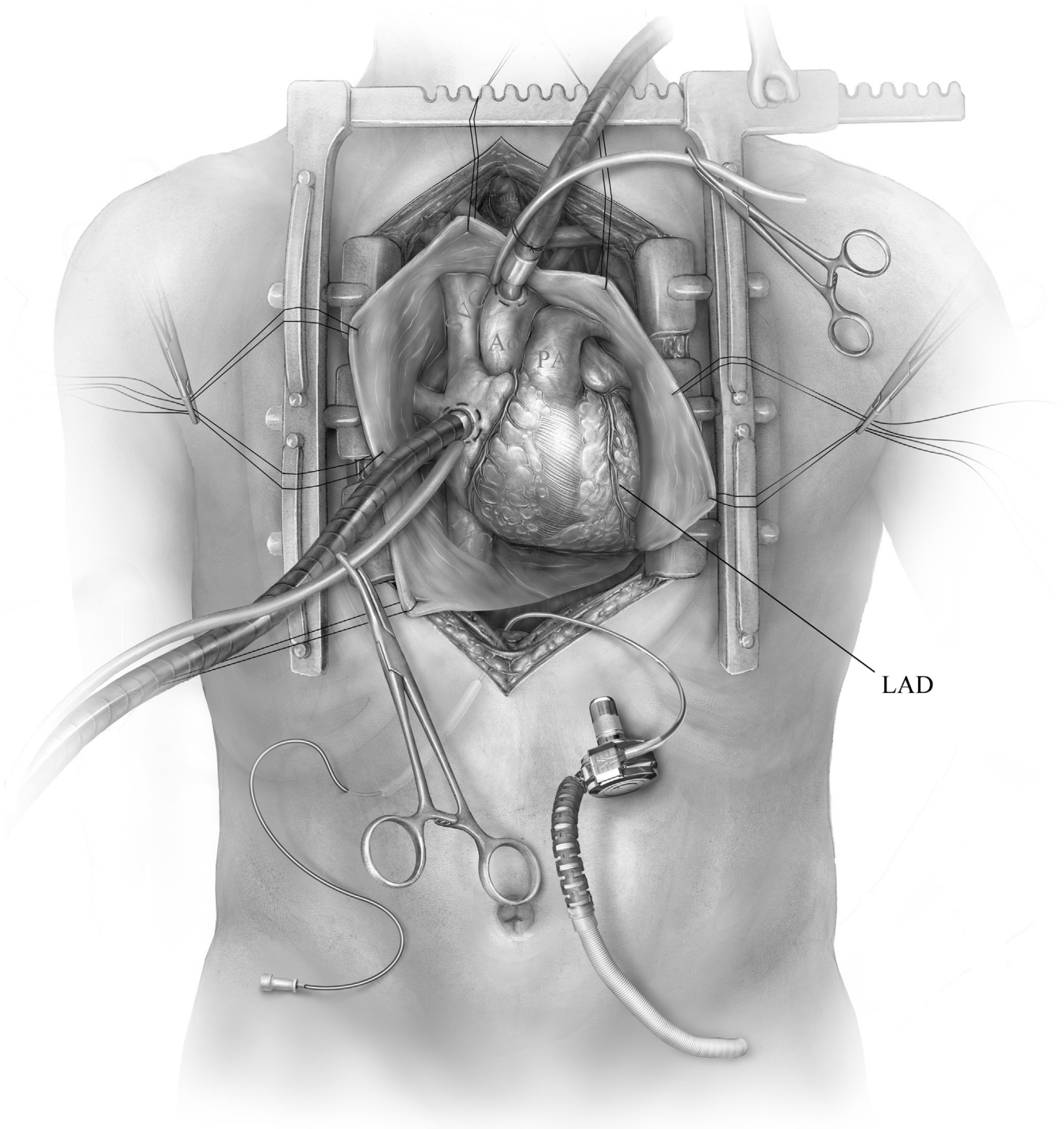

Figure 3 Cannulation. The patient is systemically heparinized. Cannulation for cardiopulmonary bypass is accomplished with an arterial cannula in the distal ascending aorta or proximal aortic arch. It is important to leave enough length on the aorta for a deairing cannula and positioning of the outflow graft. A 2-stage venous return cannula is used for venous return. Bicaval cannulation is used if closure of a patent foramen ovale or tricuspid valve repair or replacement is performed concomitant with LVAD implant. LAD = left anterior descending; Ao = aorta; PA = pulmonary artery.

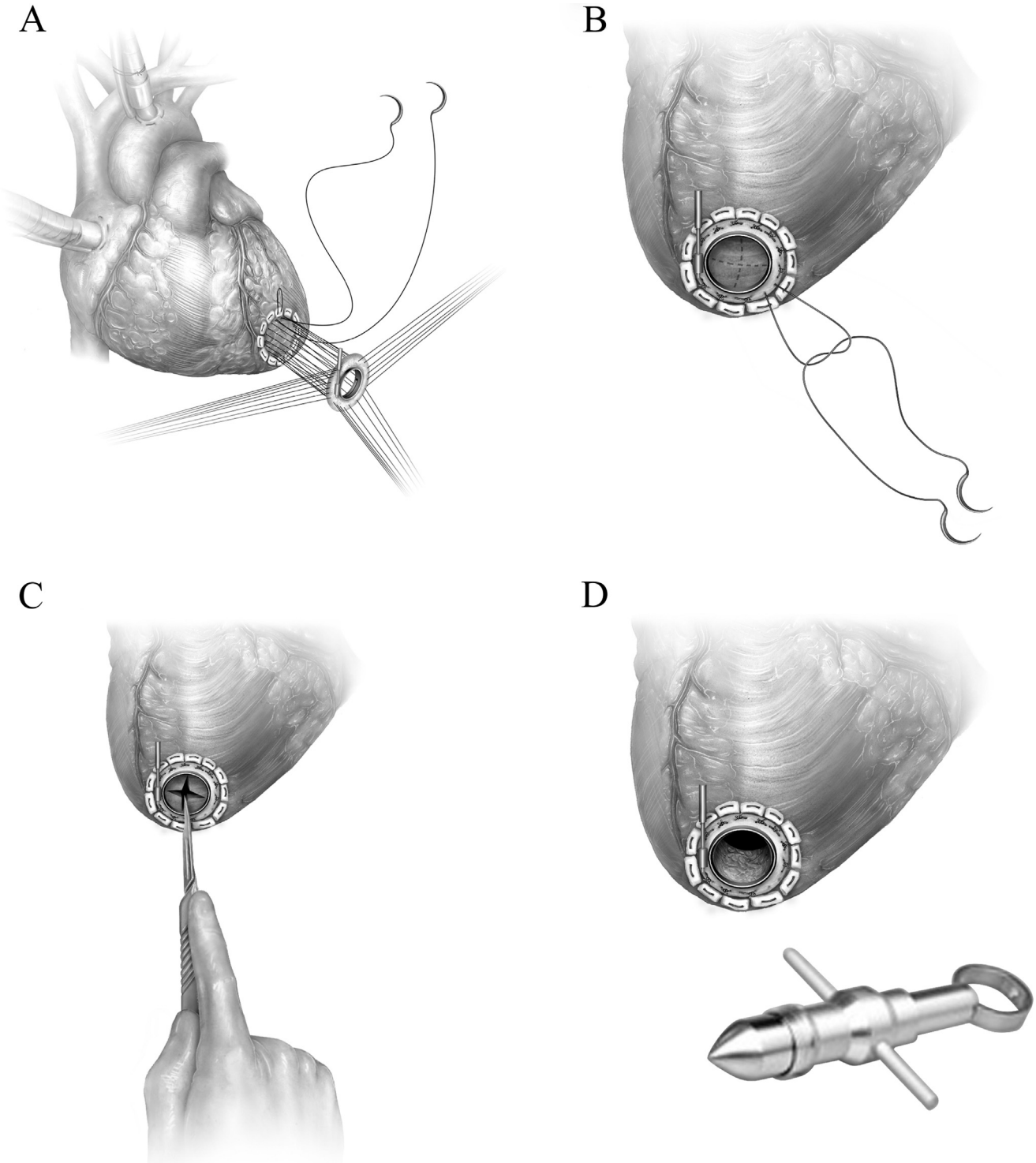

Figure 4 Placement of the inflow cannula. The procedure is performed on full cardiopulmonary bypass on the beating heart. The heart is elevated and supported with moist laparotomy pads to expose the left ventricle (LV) and apex. Correct positioning of the inflow cannula is essential. It should be parallel to the interventricular septum and directed toward the mitral valve. To achieve this, the sewing ring is attached to the distal anterior surface of the LV, approximately 2 cm lateral to the left anterior descending artery. (A) We place 12, 2-0 ETHIBOND pledgeted sutures deep in the myocardium and then through the Dacron sewing ring. It is recommended that the integrated screw of the sewing ring be oriented parallel to the LAD and pointing toward the base of the heart to facilitate tightening. (B) Once the sewing ring is seated, all sutures are tied down. (C) A full-thickness cruciate incision is made in the myocardium within the middle of the sewing ring. (D) The myocardium within the ring is then excised with the punch device supplied by HeartWare. The LV is then inspected for thrombus and crossing trabeculae, which are excised as necessary.

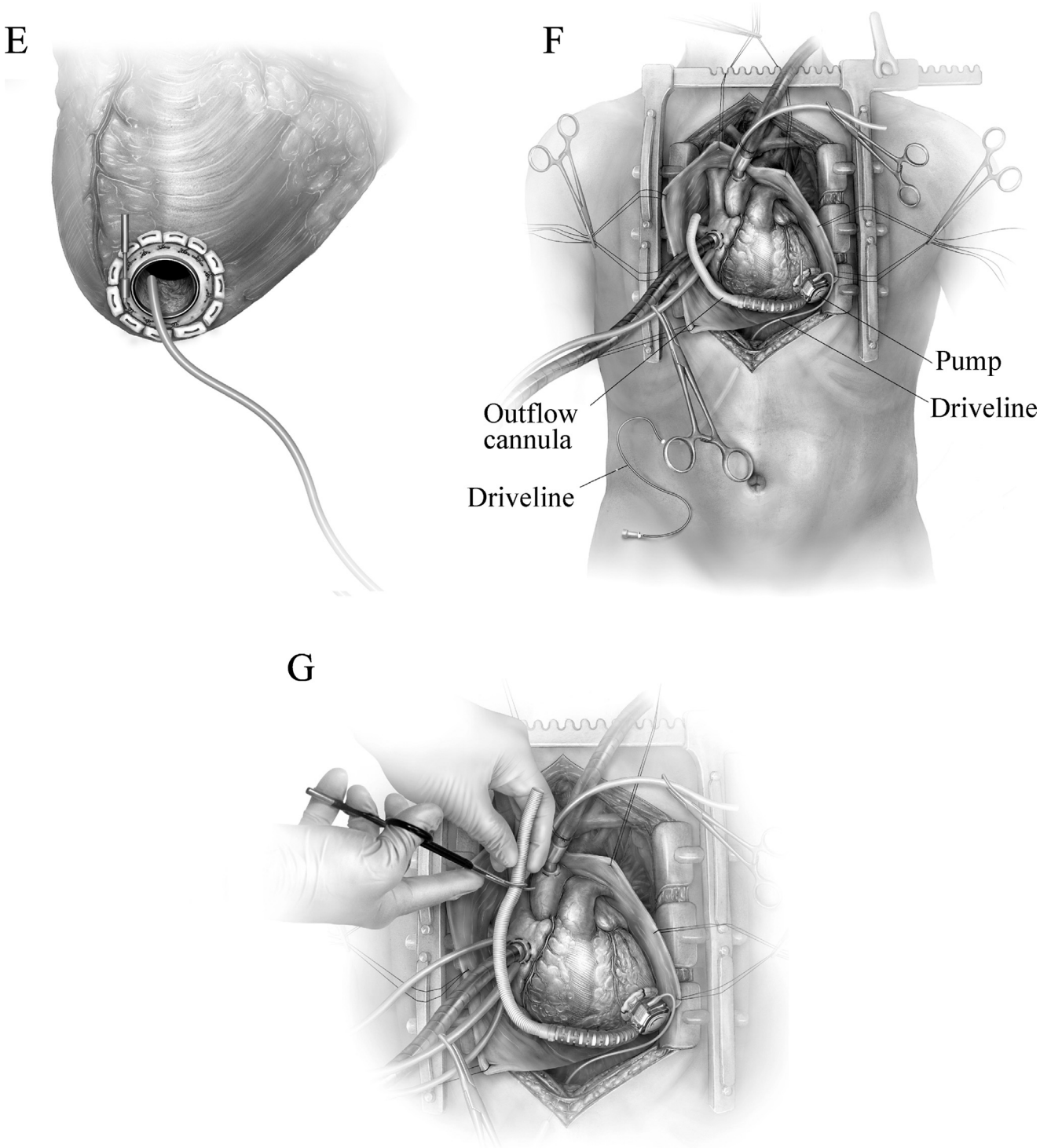

Figure 4 (*Continued*) (E) At this point, it is our practice to infuse CO_2 into the LV cavity to facilitate deairing of the LV. (F) The inflow cannula is then inserted into the sewing ring and the device is positioned with the outflow graft and driveline parallel to the diaphragm, and the screw on the sewing ring is tightened. Additional deairing is accomplished by passively filling the heart and pump and elevating the apex and gently shaking the ventricle. (G) The outflow graft is then distended, clamped, and trimmed to proper length.

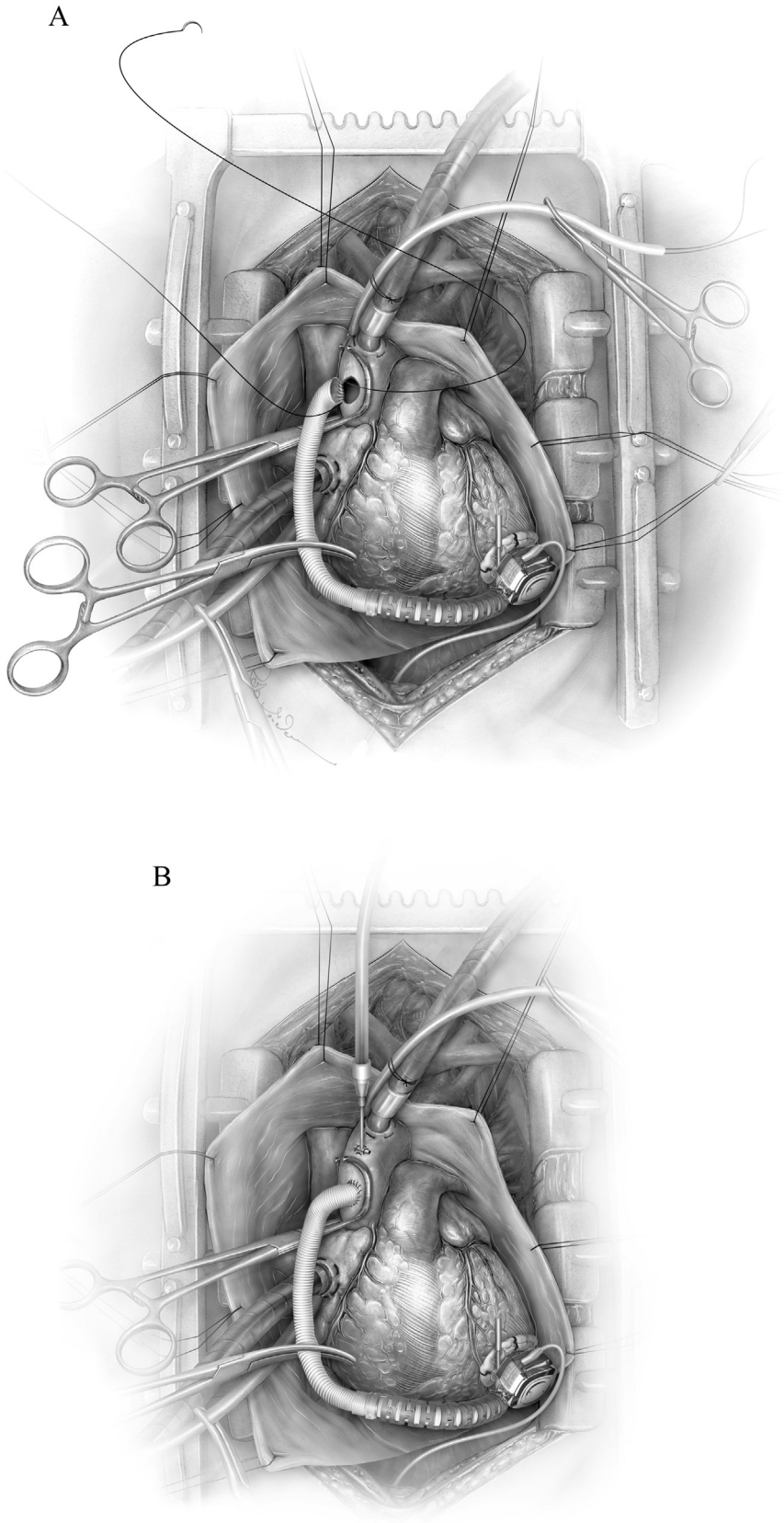

Figure 5 Outflow graft anastomosis. It is crucial to determine the appropriate length of the outflow graft as excess length may lead to kinking of the graft. Conversely, a short graft may cause added tension to the anastomosis and lead to bleeding or obstruction. The outflow graft should lie along the right atrium. (A) The anastomosis is performed along the proximal anterolateral ascending aorta. A partial-occlusion clamp is placed without dissecting the plane between the aorta and PA. The aorta is incised and the anastomosis is sewn with a 4-0 polypropylene suture. Pledgets are usually not necessary for this anastomosis. The anastomosis is deaired. The partial-occlusion clamp is then removed to assess hemostasis. A vascular clamp should remain on the outflow graft while the device is off to avoid retrograde flow into the aorta. (B) A deairing cannula is placed in the ascending left ventricle between the outflow graft and aortic cannula. It is important to place the graft as proximal as possible to allow for future cannulation and aortic anastomosis at the time of heart transplantation.

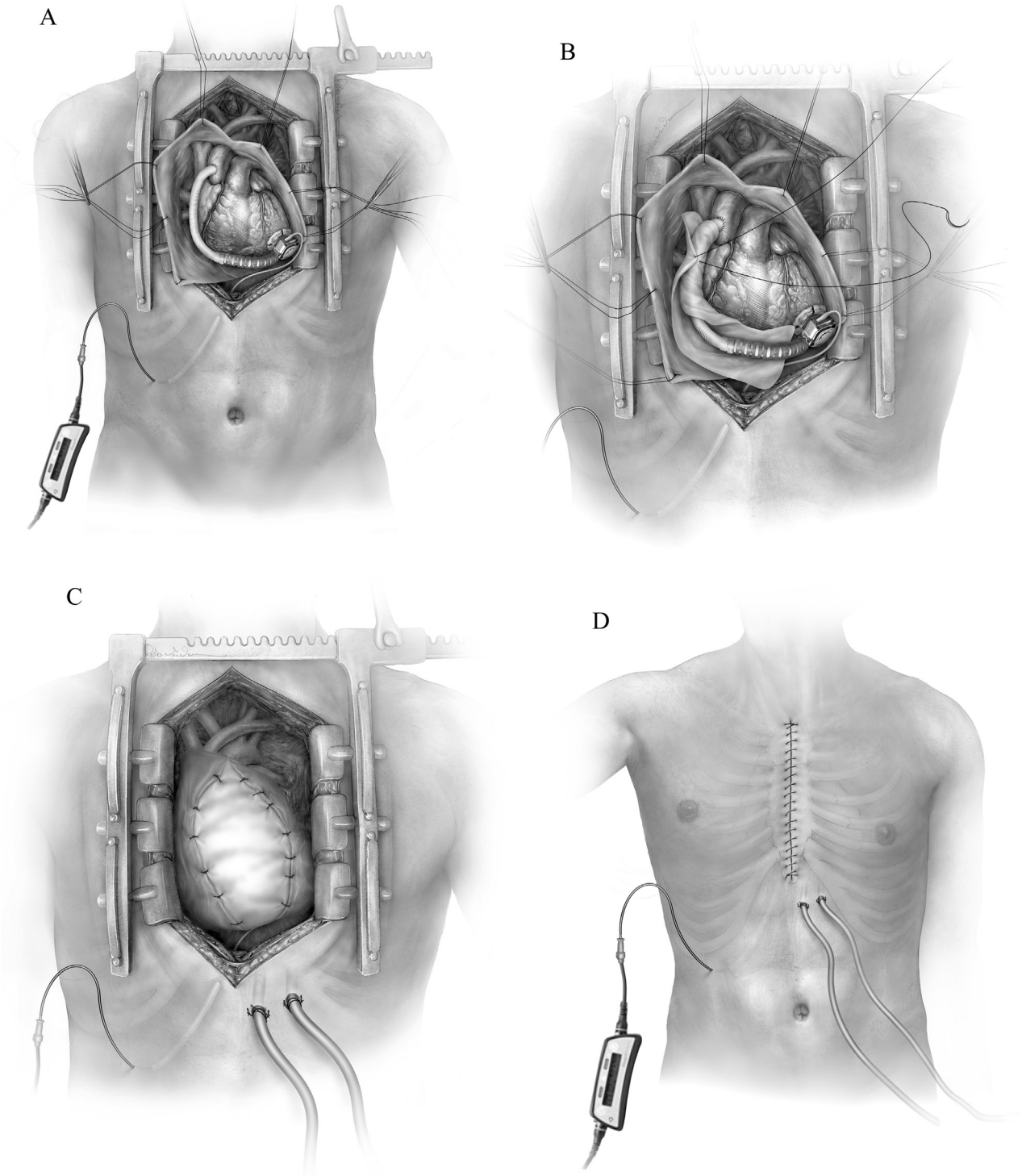

Figure 6 Deairing and weaning from cardiopulmonary bypass and closure. In addition to the deairing cannula in the ascending aorta, the patient is placed in the Trendelenburg position and ventilation is resumed. The device driveline is connected to the controller. At this point, administration of nitric oxide is started as well as a combination of vasopressor and inotropic support to assist the right heart. (A) The patient is then gradually weaned from cardiopulmonary bypass. Once flow is less than 2 L/min, the vascular clamp on the outflow graft is removed and the HVAD is started at 1800 rpm and increased as cardiopulmonary bypass is terminated. The increase in speed should be in increments no greater than 100 rpm with a 20-second interval between speed changes to gradually increase flow and help prevent ventricular collapse. To optimize and set pump speed, the TEE is used to visualize the position of the interventricular septum, size of the LV, and intermittent opening of the aortic valve. The recommended operating speed is 2400-3200 rpm. The flow trough should be more than 2 L/min and a target flow pulsatility of 2-4 L/min, as measured from peak to trough of the flow waveform on the device monitor, is desired. Once deairing is confirmed by TEE, the vent cannula in the ascending aorta is removed. When the hemodynamics is appropriate, protamine is administered and the cannulae are removed. (B) To minimize adhesions and facilitate reoperation at the time of transplantation, we wrap the outflow graft with a GORE-TEX pericardial membrane secured with a 4-0 polypropylene suture. (C) Additionally, a piece of GORE-TEX membrane is sewn to either side of the pericardium to cover the heart and device. (D) Mediastinal chest tubes are inserted and the chest is closed in the standard fashion. The driveline is secured at the skin edge with a 5-0 polypropylene purse-string suture and a 2-0 polypropylene stitch is used to secure the driveline to the abdominal wall approximately 5 cm from the exit site to prevent accidental dislodgement in the early postoperative period.

Postoperative Considerations

The patients are weaned off inotropes, vasoconstrictors, and nitric oxide over the 24-48 hours following implantation. Pump speed may vary during this weaning period to optimize hemodynamics and treat suction events. One may consider obtaining a transthoracic echocardiogram to assist in setting the HVAD rpm to ensure appropriate interventricular septal position and appropriate LV unloading. Systemic antimicrobial prophylaxis is continued for 48 hours. Once prophylactic antibiotics are discontinued, broad-spectrum antimicrobials are started until the chest tubes have been removed and drainage from the driveline site has stopped. Anticoagulation should be individualized for each patient. Chest tube drainage should be less than 40 mL/h for at least 3 hours and the hematocrit should be stable without the need for transfusion of blood products. In general, low-dose heparin infusion of 400-500 units/h is begun on postoperative day 1 to a target partial thromboplastin time of 40-50 seconds. The heparin dose is gradually increased to maintain a partial thromboplastin time in the range of 50-60 seconds. Warfarin administration is then initiated and titrated to maintain the international normalized ratio at 2.0-3.0; additionally, aspirin 325 mg is initiated on postoperative day 1. Dual antiplatelet therapy with dipyridamole, for example, may be considered to compliment the anticoagulation regimen.

Summary

As the use of LVADs to treat advanced HF continues to increase and the technology advances, LVADs will continue to evolve into smaller and more efficient pumps. The small size of the HeartWare HVAD enables positioning in the pericardial space, thereby minimizing the need for extensive dissection. The unique integrated screw mechanism of the sewing ring simplifies attachment to the inflow cannula. Additionally, the small size of the device permits application to patients with a small body habitus. The absence of contact bearings with a single magnetically and hydrodynamically levitated moving part may improve long-term durability and efficiency. As our population ages and the need for assist devices increases, implantation of LVADs will continue to increase.