

SURGICAL TECHNIQUE

Principles of HeartMate II Implantation to Avoid Pump Malposition and Migration

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ABSTRACT Proper left ventricular assist device (LVAD) insertion will help maximize LVAD flow and may reduce adverse events such as right heart failure and pump thrombosis. Although no standardized insertion technique has been universally accepted, the goals are: unobstructed inflow cannula, unobstructed outflow graft with avoidance of right ventricular compression, and prevention of pump migration. To achieve these objectives for the HeartMate II LVAD, we delineate four principles: proper pump pocket creation, optimized positioning of inflow cannula and outflow graft, proper pump position in the body, and fixation. These basic principles are easy to implement and have been beneficial in our patients, assuring long-term unobstructed LVAD flow. doi: 10.1111/jocs.12478 (*J Card Surg* 2015;30:296–299)

In order for an LVAD to provide long-term hemodynamic support,^{1,2} it is essential that the device is positioned properly at implantation and that position is maintained over time. LVAD malposition can result in cannula and graft obstruction, right ventricular compression, and low-flow conditions that can result in adverse events. Obstructed flow can result in poor washing of the pump components, which can lead to pump thrombosis.^{3,4} Surgical technique has been recently shown to have a significant effect on pump thrombosis.^{5,6}

Figure 1A shows an example of a properly placed HeartMate II LVAD (Thoratec Corporation, Pleasanton, CA, USA), whereas Figure 1B and 1C show malpositioned pumps with inflow cannulas impinging on the

interventricular septum and left ventricle (LV) free wall. Causes often result from a small, insufficient preperitoneal pump pocket, pump placement too high or pump migration superiorly, inflow cannula angled toward the septum or free wall, and an outflow graft that is too short, compressing the right ventricle, or too long resulting in kinking (RV) (Fig. 2).

We identify four key surgical principles (Fig. 3) that are important to obtain and maintain optimal HeartMate II pump and cannula positioning and prevent pump migration.

Principle 1: Deep pump pocket

It is important to make the pocket inferiorly deep and sufficiently lateral so that the inflow cannula and pump in its final position do not push upward against the heart. The heart should remain in its most natural anatomic position. Making the pocket too small is a potential cause of cannula malposition, kinking of the inflow strain relief, and pump compression of the RV. Pump pockets can shrink over time, and the pump will have a tendency of being displaced superiorly and medially. Contraction of the pocket and resultant pump migration will exacerbate any inflow cannula angulation, which may result in partial inflow obstruction.

After standard median sternotomy, a preperitoneal pocket is created below the left rectus muscle,

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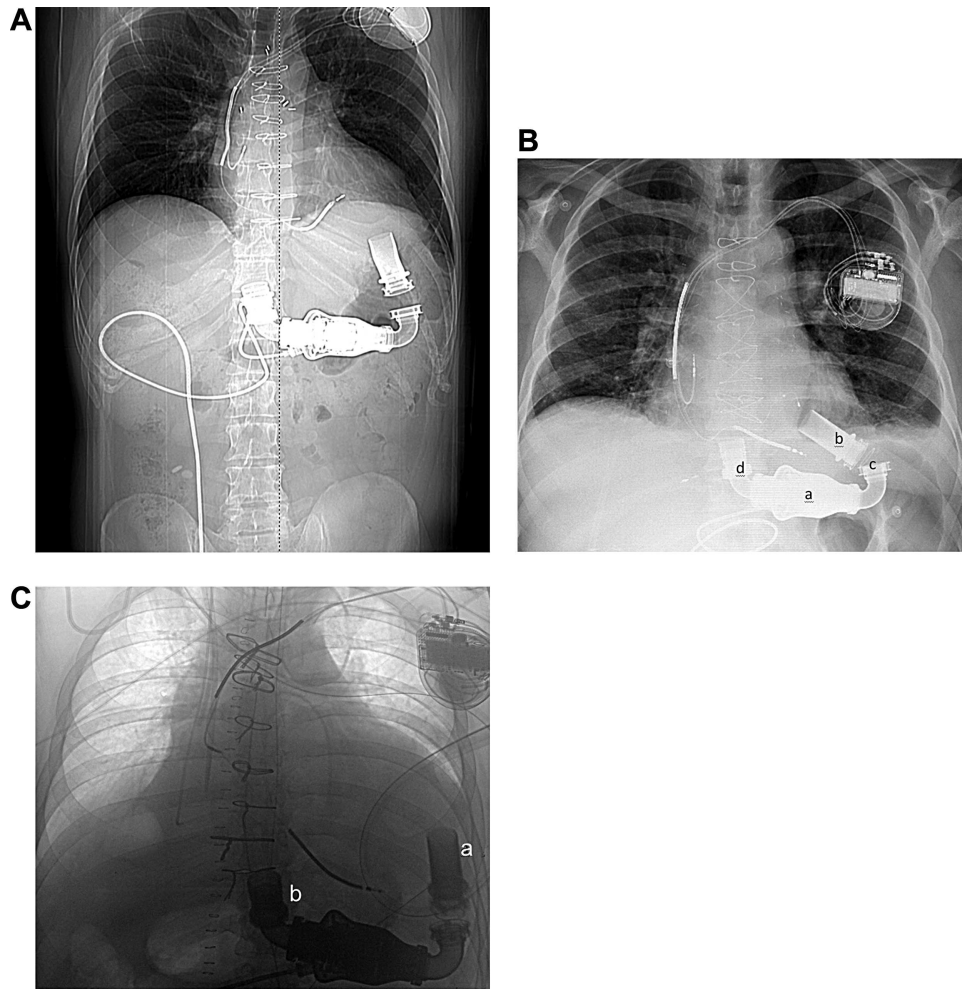


Figure 1. A. Proper placement of a HeartMate II LVAD. The preperitoneal pump pocket is inferiorly deep, with the pump body perpendicular to the spine, inlet cannula angled approximately 20° to vertical and oriented toward the center of the LV without strain relief distortion, and the outlet cannula oriented to avoid the RV. B. Malpositioned pump with associated thrombosis showing superiorly positioned or cephalad-migrated pump (a); medially angled inflow cannula, possibly secondary to a lateral core site (b); distorted inflow strain relief (c); and outflow connector and graft compressing the RV directly under the sternotomy incision (d) due to medial migration of the pump body, too short outflow graft, and/or insufficient pump pocket. C. Chest X-ray of malpositioned pump with similar issues as in Figure 1B but resulting in inflow cannula partially obstructed against the free wall of the LV (a).

separating the posterior rectus sheath from the preperitoneal fat. In one method, the reflection of the diaphragm to the rib cage is separated about 1 cm from the costal margin using a covered Endo-GIA stapler; the pocket should be sufficient in its inferior and lateral extent for the pump to remain fixed below the diaphragm without restriction. The greater the preoperative cardiomegaly the more lateral development of the pocket is needed.

Principle 2: Inflow cannula parallel to septum

Coring of the LV is the most important step, which we recommend to be made at the apex, typically about 1–2 cm lateral to the left anterior descending (LAD) artery. Anterior- or laterally placed core sites increase the risk of early partial inflow obstruction as well as later obstruction with ventricular remodeling or pump migration. The inflow cannula should lie parallel to the

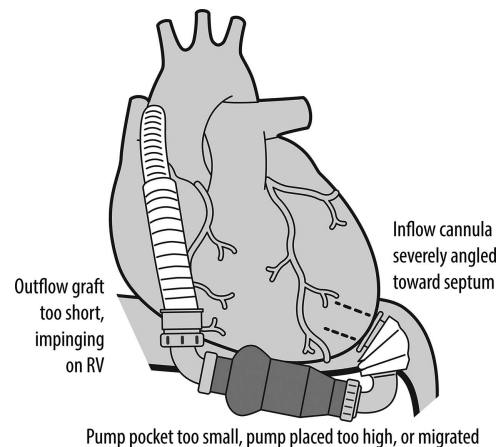


Figure 2. Potential causes of malpositioned LVAD.

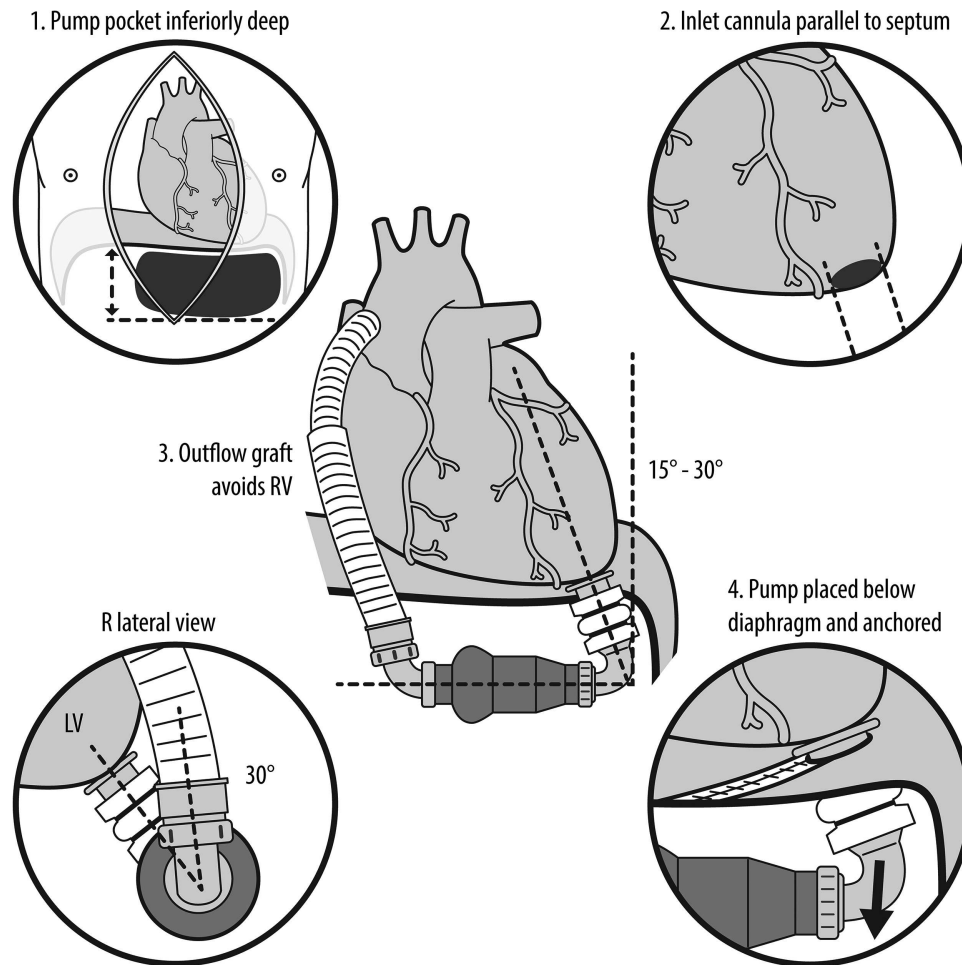


Figure 3. Illustration of four principles to avoid cannula malposition and pump migration. Principle 1: Create deep pump pocket—inferior and lateral enough for pump to remain fixed below the diaphragm without restriction. Principle 2: Locate inlet cannula parallel to septum—through apical core and preferred over anterior, superior, or lateral locations. Principle 3: Optimize outflow graft to avoid RV compression—to the right of sternal midline and with inflow and outflow offset by 30% (seen on R lateral view). Principle 4: Position and anchor pump below diaphragm—perpendicular to the spine and inferior to and parallel with acute margin of RV. One fixation method: secure diaphragm around inflow strain relief while retracting pump inferiorly into pocket.

apical portion of the interventricular septum and aim toward the center of the LV.

Principle 3: Outflow graft avoids RV compression

The outflow graft should be cut to the appropriate length. With the graft on, full stretch measurement should be made from the aortotomy site to below the xyphoid. When the graft is cut, it should terminate at approximately the end of the outflow strain relief in its relaxed state, or slightly longer especially when extreme cardiomegaly is present. If cut too short, the outflow graft will cross the acute margin of the RV, potentially impairing RV function. If too long, it can result in kinking. The graft should be slightly spatulated and sewn to the right lateral side of the aorta at the level of the right pulmonary artery. A portion of the aorta is resected to assure that the anastomosis is not restrictive and local tension is minimized. Pump outflow should be aimed to the right of the sternal midline, with the outflow graft long enough to go around the lateral border of the right atrium and avoid compression of the

RV. This is facilitated with the inflow cannula offset posteriorly approximately 30° relative to the pump body (Fig. 3, right lateral view).

Principle 4: Pump position and fixation

The pump should be positioned below the diaphragm in the preperitoneal pocket, approximately perpendicular to the spine, and inferior to and parallel with the acute margin of the RV, with the inflow cannula roughly parallel to the septum and at an angle of approximately 15°–30° from the vertical axis (75°–60° relative to the axis of the pump).

Fixation of the pump is important to prevent migration. One method illustrated here can be accomplished by closing the diaphragm with felt strips around the inflow cannula, with the full inflow strain relief below the diaphragm. During final diaphragmatic closure, the pump (while connected to the heart) should be pulled slightly inferiorly and medially. This straightens the ventricle and aims the inflow cannula to the center of the LV. Unimpeded flow is

checked in the operating room with echocardiogram ramped-speed study and confirmed after the chest is closed.

Ease of reentry for removal or exchange is assured by keeping the outflow graft connector well below the xyphoid, with the strain relief to the right of the midline and the graft lateral to the right atrium, away from the sternum.

DISCUSSION

General and specific implantation techniques for the HeartMate II LVAD have been described,^{7,8} including clinical management practices representing the consensus of knowledge gained during the HeartMate II clinical trial.⁷ However, we believe that some recommendations can be improved. Common mistakes that are easily avoidable include 1) LV coring on the anterior surface of the LV or positioned too far laterally, resulting in partial inflow cannula obstruction; 2) pump pocket too small, resulting in migration superiorly and cannula impingement onto the septum or lateral wall; 3) aortic outflow graft too short, resulting in compression of the RV; or too long resulting in kinking, and 4) pump unsecured, resulting in pump migration, especially with weight gain or loss or reverse remodeling. We believe that adoption of the four basic principles described here will enhance unobstructed flow through the device and reduce the risk of adverse events, including pump thrombosis and right ventricular failure.

Data have shown less pump thrombosis when surgical techniques consistent with our recommendations were adopted, especially the creation of adequately sized pump pocket and placement of appropriately directed inflow cannula at the time of operation.⁵

In some cases, the anatomy of the VAD recipient is not ideal. For the morbidly obese patient, the intra-abdominal organs tend to push superiorly so that the pocket may be higher than the level of the LV apex resulting in a more acute inflow cannula angle. The offsetting of the inflow and outflow cannulas, directing the inflow more posteriorly may be beneficial. For patients with exceedingly large LV (>9 cm), there could be tendency for the outflow graft to compress the RV. However, if the left ventricle is cored adjacent to the ventricular septum and the pump is pulled inferiorly and medially before pump fixation, then a properly sized outflow conduit generally will avoid the right ventricular acute margin but these patients tend to have a more vertically oriented cannula. In patients with a narrow chest wall, where the pocket cannot be made more lateral the key to avoid the inflow pointing to the lateral wall is coring at the apex adjacent to the ventricular septum and fixating the pump more medially at closure. If, despite following all recommendations, the inflow is

pointing laterally, possibly caused by cardiomegaly or a lateral core site, the key is to pull the pump inferiorly, which will straighten the ventricle out and move the inflow cannula more into the center of the ventricle. Issues to note preoperatively for proper surgical planning include degree of cardiomegaly and extremely small BSA (<1.3). Pectus excavatum, hostile abdomen, and small or resected left lung also can present challenges.

At the end of the surgical implant, we recommend a few tests to assure unobstructed flow paths. Functional assessment can be performed in the operating room with the chest closed, using a pump ramp-speed study to document reduction in arterial pulsatility and trans-esophageal echocardiography to demonstrate that the left ventricular cavity is decompressing. Anatomic assessment with PA and lateral chest radiography, including the upper abdomen, can be performed at any time postoperatively if pump placement questions arise.

Should a pump exchange or pump removal be required at some later time, this can be done through an upper abdominal midline incision or a subcostal incision without entering the chest, with access to both the inflow and outflow connectors below the diaphragm.

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