

Minimally invasive is the future of left ventricular assist device implantation

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Abstract: There have been many factors that have allowed for progressive improvement in outcomes and lower complication rates. These include the improvement in left ventricular assist device (LVAD) technologies, combined with better understanding of patient management, all these. Nowadays the numbers of LVAD implantations exceed the number of annual heart transplants worldwide. Minimally invasive procedures are shown to improve the surgical outcome in both LVAD insertion and replacement. These minimally invasive techniques can be grouped grossly into shifting from on-pump to off-pump implantation, alternative access for implantation other than sternotomy, and a combination of both, which should be the ultimate aim of minimally invasive LVAD implantation. Here we describe the alternative techniques and configurations of minimally invasive and sites of implantation.

Keywords: Left ventricular assist device (LVAD); minimally invasive; off-pump; ventricular assist device (VAD)

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Introduction

The use of left ventricular assist devices (LVADs) in patients with congestive heart failure (CHF) has excellent outcomes when compared to medical therapy (1-3). LVADs have become an important option for the treatment of patients with advanced heart failure (4-7). Nowadays the number of LVAD implantations exceeds the number of annual heart transplants worldwide. The improved pump technology, enhanced performance of the pumps, increased device durability, reduced size of the new LVAD devices, combined with a better understanding of patient management, all these have allowed for progressive improvement in long-term outcomes and pump durability after implantation (3,4,8). These advances led to new implantation strategies which considered the novel art in LVAD surgery (9-16).

The concept of minimally invasive implantation was introduced by Hill *et al.* (17) by using a combination of a right minithoracotomy and small left subcostal incision

to implant the Thoratec paracorporeal LVAD. Gregoric *et al.* (12) subsequently described a less invasive approach for implanting axial flow LVADs without median sternotomy utilizing a subcostal incision and a right minithoracotomy when they implanted six patients with HeartMate II. Nowadays that minimally invasive surgery is possible for the implantation, explanation, and exchange of LVADs. The minimally invasive techniques can be grouped grossly into shifting from on pump to off-pump implantation, and alternative access for implantation other than sternotomy. Here we discuss all these alternative techniques and configurations of minimally invasive and sites of implantation as well as their advantages and disadvantages.

Minimally invasive off-pump strategy

Implantation of ventricular assist devices (VADs) is typically performed with the patient on cardiopulmonary bypass

(CPB). However, CPB is associated with harmful effects well documented in the literature, including activation of inflammatory mediators, increased pulmonary vascular resistance, platelet activation, coagulopathy and impaired renal function (18-21). The postoperative course of these ill patients usually accounts for many complications because of their preoperative comorbidities, or for surgical complications (18,22). The patient population that requires VAD implantation often has evidence of end-organ dysfunction, including liver congestion, renal insufficiency, and pulmonary edema. VAD placement under CPB often exacerbates these pre-existing conditions, resulting in post-operative coagulopathy, bleeding and worsening right heart failure. VAD implantation without the use of CPB could help to minimize these post-operative complications without hemodynamic compromise or excessive bleeding during implantation (15,20,23). The short term benefits of an off-pump strategy to reduce blood-product transfusion, reoperation for perioperative bleeding, acute kidney injury and respiratory complications have been demonstrated in a large randomized study (24). Minimizing blood product transfusions and reducing exposure to blood antigens decreases the risk of recipient sensitization, thus preserving donor pool availability for bridge-to-transplantation candidates undergoing LVAD implantation (8).

Sun *et al.* (25) in their series of 25 patients off-pump implanted LVAD, concluded that placement of long-term LVADs can be performed without the use of CPB, and concluded that these techniques can be implemented with acceptable outcomes and minimal blood utilization in selected patients who do not require correction of additional cardiac pathology, there are multiple ways used for off-pump LVAD implantation, we discuss here the most commonly used as well some promising techniques. Reliant on the experience in transcatheter valve implantation by the use of rapid pacing, Centofanti *et al.* (26) reported inserting off-pump Jarvik LVAD with rapid pacing for the insertion; this was also reported multiple authors (15,27,28).

Implantation of LVAD with non-fibrillatory technique by administering of an intravenous bolus of adenosine to induce a short bradycardic arrest during off-pump LVAD placement was also described (8,29). In spite of Adenosine-induced asystole it further reduces blood loss by reducing both the volume of blood ejected from the heart during LVAD implant (reduction in blood pressure) and decreasing the heartbeats. In this method Adenosine mediates pulmonary vasodilatation, which may reduce pulmonary pressures and protect the RV function (30,31). Anastasiadis *et al.* (32) reported successful

insertion of Jarvik 2000 device by using ECMO in spite of CPB for cardiac support during the procedure. This technique was associated with decreased duration of operation, reduction in blood transfusion, need for inotropic support, duration of mechanical ventilation, and length of hospital stay.

Other promising techniques (in animal lab) also reported by Cohn (33) who reported a new modified technique of off-pump LVAD insertion by using vacuum-assisted coring tool with occlusion endovascular balloon, inserted via femoral artery to minimize the bleeding and to maintain steady hemodynamics during the insertion on the inflow cannula.

There are circumstances where an off-pump LVAD placement is not appropriate. These include patients who require concomitant surgery for left ventricular or atrial appendage clot and patients who have significant AI, mitral stenosis, or severe tricuspid regurgitation, right-to-left shunts with worsening hypoxemia, and thrombus formation (8,29).

Minimally invasive LVAD insertion technique

The LVAD insertion is divided into three steps: (I) inflow cannula and pump insertion; (II) outflow graft (OG) insertion; (III) drive line insertion. The minimally invasive procedure could be done for the first two steps. Inflow cannula sites approaches are shown in (*Figure 1*), OG site insertion locations are shown in (*Figure 2*), and all minimally invasive LVAD insertion configurations are shown in (*Figure 3*).

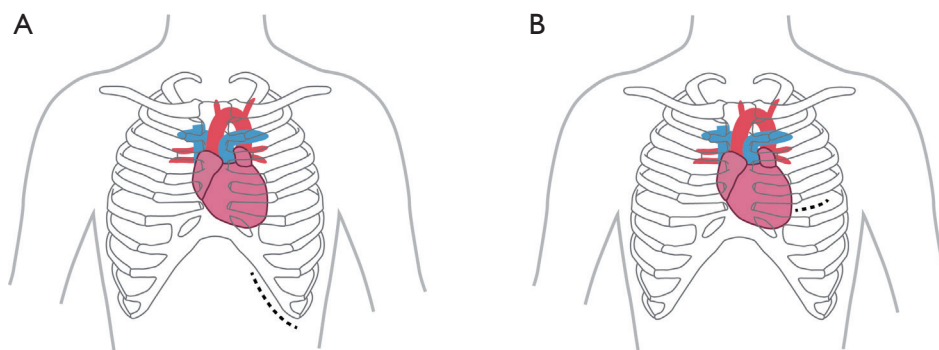
Inflow and pump insertion

There are two insertion approaches for the minimally invasive techniques, a left subcostal incision mainly used now for HeartMate II (14,17,34) this incision will help in preparing the pocket for HMII (*Figure 1A*). The other approach is via left anterior thoracotomy at 5th or 6th intercostal space (*Figure 1B*).

The advantages of this access are to avoid redo-sternotomy in a difficult sternal entry, to avoid opening the pericardium, it can be used for a porcelain aorta with OG in the axillary artery or the descending aorta, this approach, if done without sternotomy is particularly appealing in patients with a history of coronary artery bypass surgery, and is preferentially utilized in bridged patients to spare the sternal incision for heart transplantation.

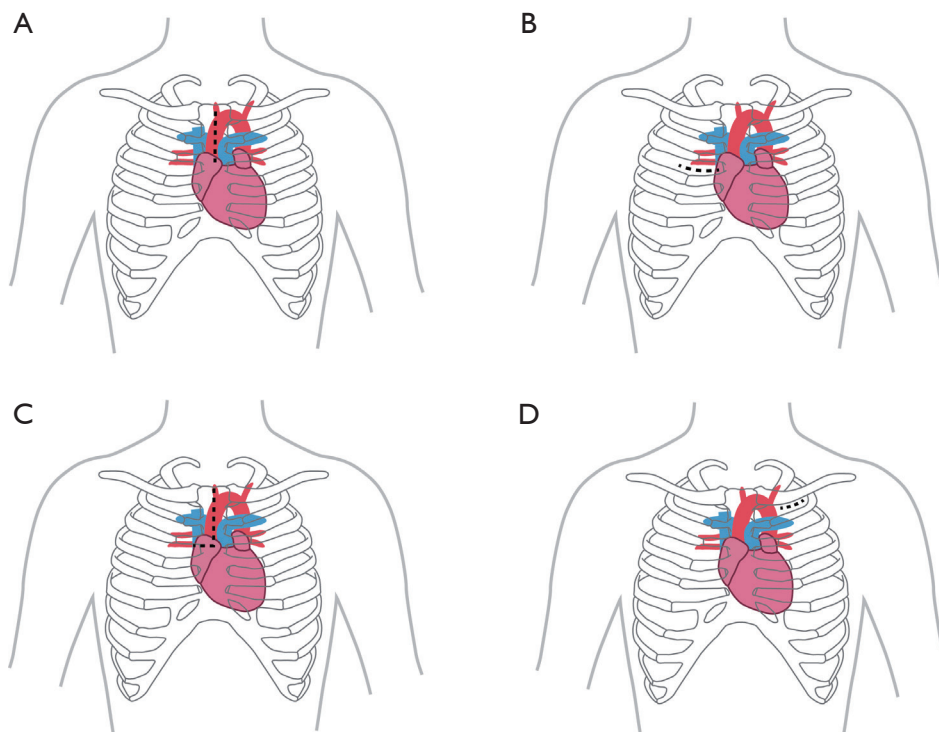
OG insertion

This could be done by multiple techniques and in different



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Figure 1 Inflow cannula sites. (A) Sub-diaphragmatic; (B) left thoracotomy.



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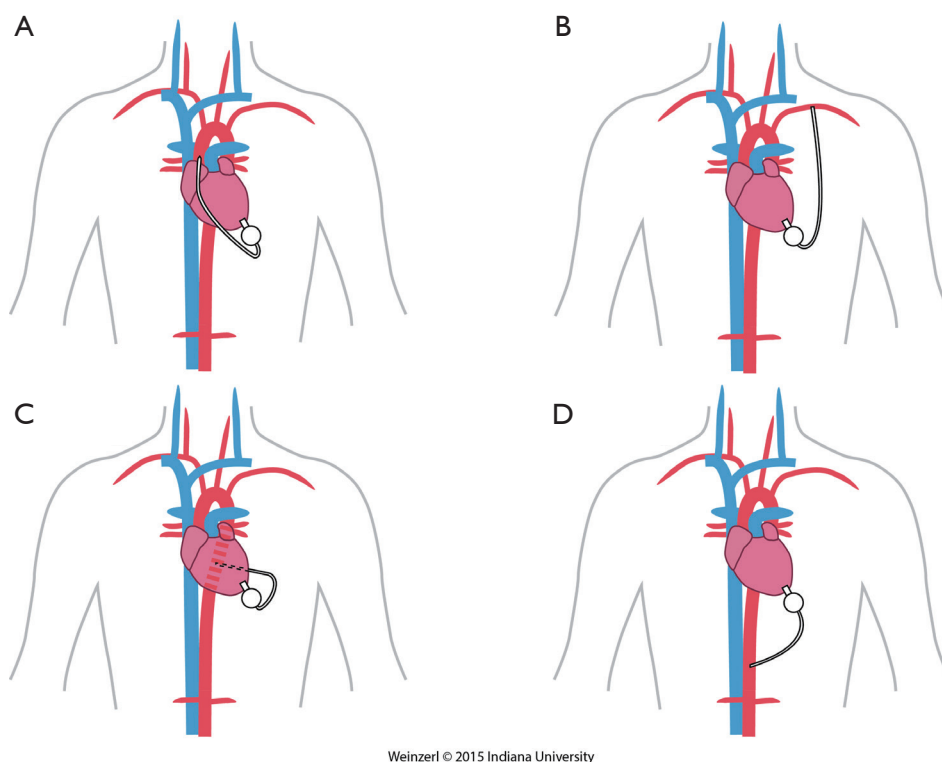
Figure 2 OG site insertion. (A) Upper hemisternotomy; (B) right minithoracotomy; (C) upper hemisternotomy & right hemithoracotomy J shape incision; (D) axillary. OG, outflow graft.

locations, which include right minithoracotomy, split upper hemisternotomy, axillary and subclavian arteries, Supraceliac abdominal aorta, innominate artery, and descending aorta (35).

Upper hemisternotomy for OG (Figure 2A)

This is the most commonly used for on-pump minimally invasive strategy and was already described by Schmitto

(9,16,36). It can be associated with either inflow pump incisions, this technique permit to initiate CPB off-pump placement of the LV apex sewing ring, and tunneling of the driveline to the right or left upper quadrant. For the majority of patients, the OG is tunneled and passed within the pericardium and anastomosed to the proximal ascending aorta. The OG could be passed in the anterior mediastinum behind the sternum in case of previous sternotomy (8).



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Figure 3 Minimally invasive LVAD insertion configurations. (A) OG to ascending aorta; (B) OG to axillary artery; (C) OG to descending aorta; (D) OG to supra-celiac aorta. LVAD, Left ventricular assist device; OG, outflow graft.

Right minithoracotomy OG implants (Figure 2B)

The OG could be also inserted through a 4–6 cm right anterior minithoracotomy. The incision is made at 2nd–3rd intercostal space which allows access to the ascending aorta to initiate the CPB and/or to perform the outflow anastomosis (Figure 3A) (16,36,37). This technique is preferentially utilized in bridged patients to spare the sternal incision for heart transplantation. This approach is particularly appealing in patients with a history of coronary artery bypass surgery (8).

Upper hemisternotomy with right hemithoracotomy J shape incision (Figure 2C)

A combination of the previous two incisions (38).

Left axillary artery (Figure 2D)

Left subclavian OG anastomosis has been increasingly utilized for specific patient situations when OG anastomosis to the ascending or the descending aorta is prohibited.

The OG is tunneled through the right or the left pleural cavity, passed through the 2nd intercostal space to be anastomosed to the subclavian artery (Figure 3B). Major

concerns about this technique include, the compression of the OG by the surrounding structures, excessive blood flow to the arm, and flow disturbances with extensive elevation of the arm. Banding of the subclavian artery is mandatory if there is a mean pressure difference of more than 20 mmHg to avoid excessive blood flow to the arm (28). Some authors described progressive increase of the pump speed over a few days to allow gradual distal adaptation to the increased of pump flow and decrease the risks of arm hypoperfusion.

In this case if CBP is required it is initiated by cannulating both the common femoral artery and vein.

Single left thoracotomy incision with descending aorta anastomosis for high-risk patients (Figure 3C)

For this approach, the femoral vessels are exposed for CPB if needed. Surface echocardiography is used to enter the left pleural space and expose the LV apex. The inferior pulmonary ligament is freed to optimize exposure. The LVAD positioning is mainly done by using TEE and guide wire if needed. The OG is placed in the left pulmonary fissure, measured and anastomosed end-to-side to the descending aorta or the aortic arch using a partial cross

clamp (8,39).

Supra-celiac abdominal aorta (Figure 3D)

This is used by making left subcostal incision and dividing the diaphragm to make the pocket. This allows the LVAD to be implanted on the diaphragmatic surface of the left ventricle and the supra-celiac aorta is then exposed by extra peritoneal exposure. The outflow is trimmed and anastomosed end to side anastomosis using side biting clamp on the supra-celiac aorta (14).

Conclusions

LVAD insertion by minimally invasive procedures is feasible and safe, minimally invasive techniques improve the survival and reduced mortality in LVAD insertion when compared to reoperative sternotomy, this was also proven for LVAD exchange (40,41). LVAD implantation without the use of CPB has the potential to minimize post-operative complications such as excessive bleeding during implantation without compromising hemodynamics. By minimizing the needs for blood transfusions, patients have decreased exposure to blood antigens which ultimately reduces the risk of sensitization in transplant candidates. We believe that a combination of minimally invasive LVAD insertion with off-pump should be the ultimate goal of minimally invasive LVAD implantation.

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Footnote

Conflicts of Interest: The authors have no conflicts of interest to declare.

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