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Less Invasive Thoratec LVAD Insertion: A Surgical Technique

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ABSTRACT

Left Ventricular Assist Device (LVAD) implantation is historically a complicated, invasive operation performed on critically ill patients and is often associated with bleeding and multiorgan morbidity. The purpose of this investigation was to devise an LVAD insertion technique, utilizing the concepts of less invasive cardiac surgery, that would be a less complicated operation, with low morbidity, and still meet all the goals of the standard procedure. We describe the technical details of a "less invasive" LVAD implantation.

INTRODUCTION

Acute and chronic implantable or paracorporeal cardiac support devices are a 20-year-old technology. Historically, the therapy is associated with a complicated invasive operation performed on very ill patients and is often associated with bleeding and multiorgan morbidity. Although outcomes have steadily improved, the basic surgical procedure has changed little. In recent years, the surgical objectives have become much more clearly defined, and the concepts of less invasive cardiac surgery can be applied to make this operation a less complicated, anatomically-focused procedure with greater clinical impact.

The objective of this investigation was, therefore, to devise a Left Ventricular Assist Device (LVAD) insertion procedure that would be a less difficult operation, with lower morbidity, applicable to a wider range of patients, and still meet all the goals of the standard procedure.

There are two anatomic areas that must be exposed for LVAD insertion: the left ventricular apex and the ascending aorta. In the technique described, these two targets are separated into isolated incisions and surgical tasks. Sequenced together, the LVAD is inserted without the standard sternotomy incision. In this report, we describe the technical details of the surgical procedure.

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MATERIALS AND METHODS

Demographics

Since August 1999, three selected patients at our Center (two male patients, one female patient) underwent a less invasive surgical insertion of a Thoratec LVAD (Thoratec Laboratories Corp, Pleasanton, CA, USA). All had idiopathic, dilated cardiomyopathy. Demographic information is found in Table 1 (◎).

Operation Setup

The patient is placed in a supine position on the operating table with arms at the sides and the abdomen extended 5 degrees at the waist to expose the left subcostal margin. Intravascular access and monitoring lines are diagrammed in Figure 1 (◎). The use of a temporary transvenous pacemaker via the left internal jugular vein is optional since the right and left ventricles are readily accessible through the subcostal incision. The patient is draped from chin to mid thigh.

Cardiopulmonary Bypass

The ascending aorta and left ventricular apex are exposed through separate incisions prior to cannulation for cardiopulmonary bypass (CPB). Either aprotinin or tranexamic acid is used before and during the procedure to minimize bleeding.

The right or left common femoral artery and vein are used to cannulate for CPB. Intravenous lung bovine heparin (300 units/kg) is administered intravenously. The venous cannula is 28-French (Fr) or greater, wire reinforced, and thin walled with a bullet-shaped, multi-hole tip; it is inserted using a purse-string suture and positioned in the right atrium (Figure 2, ◎). Augmented venous drainage is used. Perfusion is at 34°C. Coronary suction is used as required. The LVAD cannula is used to de-air the left ventri-

Table 1. Patient Characteristics

Patient No.	Sex	Age, y	Diagnosis	Wt (kg)	Procedure	Incision	Duration LVAD Support (mo)
1	M	54	Idiopathic	65	LVAD	Left Subcostal/Right 2nd ICS	0.75
2	F	38	Idiopathic	83	LVAD/Mitral Valve Repair	Left Subcostal Right 4th ICS	1
3	M	48	Idiopathic	75	LVAD	Left Subcostal Right 2nd ICS	3.3

LVAD indicates left ventricular assist device; ICS, intercostal space.

cle before the cannula is attached to the ventricular assist device (VAD). No other venting is done. The aorta is not cross-clamped and no cardioplegia is used except in an instance in which the mitral valve is also repaired. At the conclusion of CPB, protamine sulfate (3 mg/kg) is given intravenously and the patient is decannulated.

Thoracic Incisions

The VAD cannulation system is placed in the left ventricular apex (VAD inflow) and ascending aorta (VAD outflow) using two separate incisions. The left ventricular apex is exposed using a left subcostal supradiaphragmatic pericardiotomy incision (Figure 3, ◎). The skin incision (6–7 cm in length) is made just below the edge of the costal margin, beginning 1–2 cm lateral to the xiphoid. The dissection is carried deeper and hugs the edge of the costal margin. The rectus abdominus is transected at the costal margin, and the other muscles and fascia making up the abdominal wall junction with the costal margin are also cut along the costal margin. The inferior, anterior left mediastinum is entered and the inferior surface of the

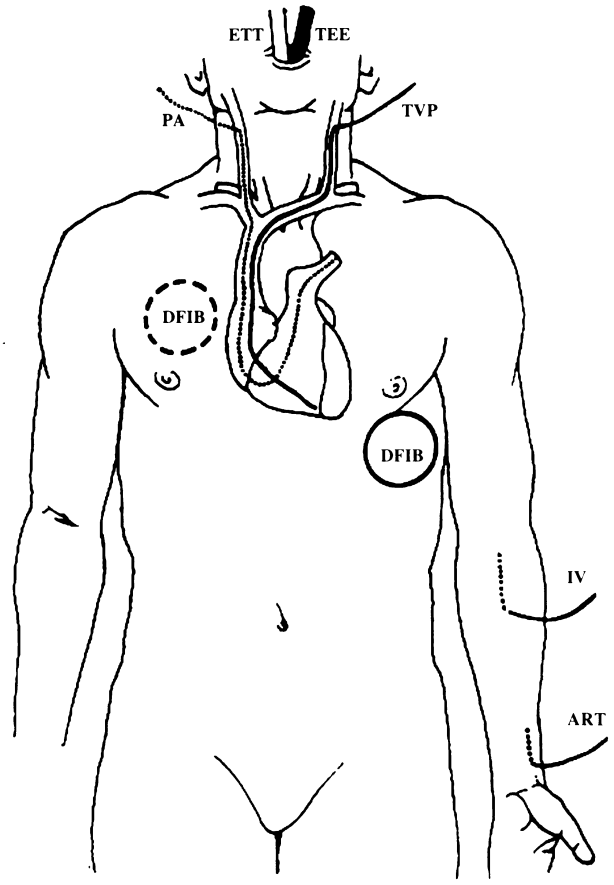

Figure 1. Intravascular access and monitoring lines. ETT indicates endotracheal tube; TEE, transesophageal echocardiogram probe; PA, pulmonary artery catheter; TVP, transvenous pacemaker; DEFIB, defibrillator pads; IV, 14-gauge intravenous catheter; ART, arterial pressure line.

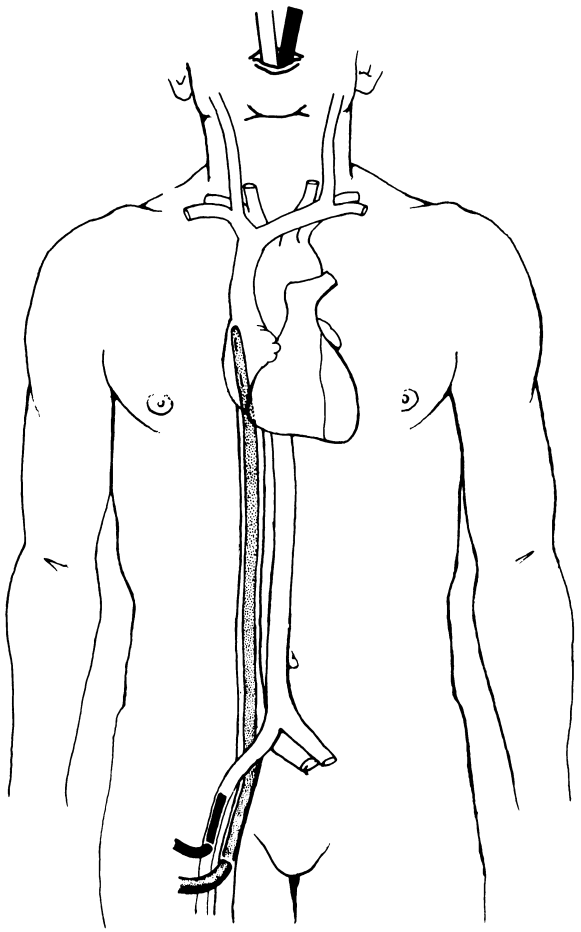

Figure 2. Cardiopulmonary bypass circuit. 28-French, thin-walled, wire-reinforced, venous cannula used for draining to the right atrium using augmented flow. Arterial perfusion via the common femoral artery.

pericardium is visible. Two 1-inch Rultract (Genzyme Corp, Cambridge, MA, USA) or Thompson rake retractors (Thompson Surgical Instruments, Inc, Traverse City, MI, USA) are positioned along the costal margin to elevate it up and cephalad. The pericardium is incised 6–7 cm transversely. The inferior wall of the right ventricle is visualized. Retraction guide sutures are placed in the pericardium and anchored along the edge of the wound (Figure 4, ◎).

CPB is begun and the heart is decompressed. A Thompson rail clamp (Thompson Surgical Instruments, Inc, Traverse City, MI, USA) is attached to the side railing of the operating table and a horizontal bar attached to it traverses the abdomen 8–10 cm below the incision. To that horizontal bar, a 3.8 cm broad malleable retractor is attached and placed inside the lower edge of the pericardium, interfacing against the pericardium where it is fused to the diaphragm. By exerting force on the retractor inferiorly and posteriorly the diaphragm is pulled down and back. A moist sponge is placed behind the left ventricle and the apex of the left ventricle is centered in the wound. The access and visibility are very good and the left ventricular apex cannula can be seated and secured in the left ventricle using any conventional methodology (Figure 5, ◎).

Once positioned, the cannula is brought out on the anterior abdominal wall 4–5 cm inferior to the subcostal incision by traversing the anterior edge of the diaphragm. Using conventional connectors, the apex cannula is attached to a vent suction line from the CPB circuit. This is left on low suction until it is time to connect the LVAD to the apex cannula.

The outflow conduit of the LVAD is attached to the right anterior aspect of the ascending aorta using a standard right 2nd intercostal-space incision that one uses to access the aortic valve minimally invasively. Once the pericardium is visualized, its fat pad is excised, the pericardium is incised, and the ascending aorta is visualized. The 14- or 18-mm preclotted woven dacron vascular-outflow VAD conduit is anastomosed to the ascending aorta using a side-biting vascular clamp.

The excised thumb of a surgical glove is then placed over the LVAD end of the cannula and secured with a suture loosely tied around the cannula. Any long, straight clamp is then introduced into the subcostal incision, passed under the pericardium, up over the right ventricle, and then exited through the pericardial opening over the ascending aorta. The LVAD outflow cannula is then grasped loosely at its end by the clamp and withdrawn out through the subcostal incision. Alternatively, a longer than normal, custom-built Thoratec type cannula trocar can be passed through the same route and the cannula withdrawn through it. The LVAD outflow cannula is thus placed under the pericardium. Using standard forceps, the intrathoracic part of the outflow cannula is moved laterally to lie beside the right lateral wall of the right atrium. The outflow cannula is then brought out onto the abdominal wall inferior to the subcostal incision by traversing the anterior fibers of the diaphragm. Depending on the thickness of the abdominal wall tissues, both the inflow and outflow cannula can lie over the top of the diaphragm while traversing the floor

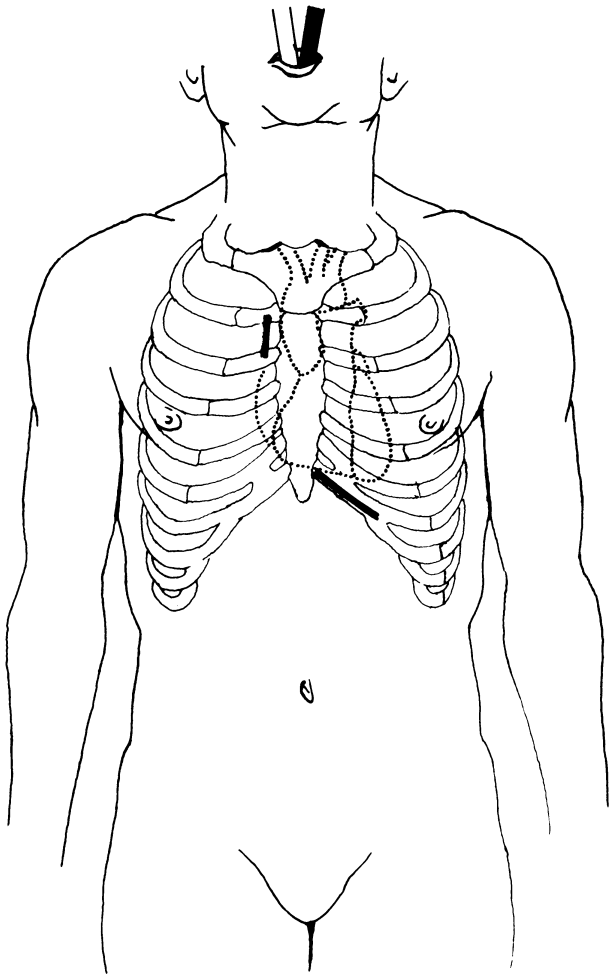

Figure 3. Incision at right second intercostal space to access ascending aorta. Left subcostal incision made to access left ventricular apex.

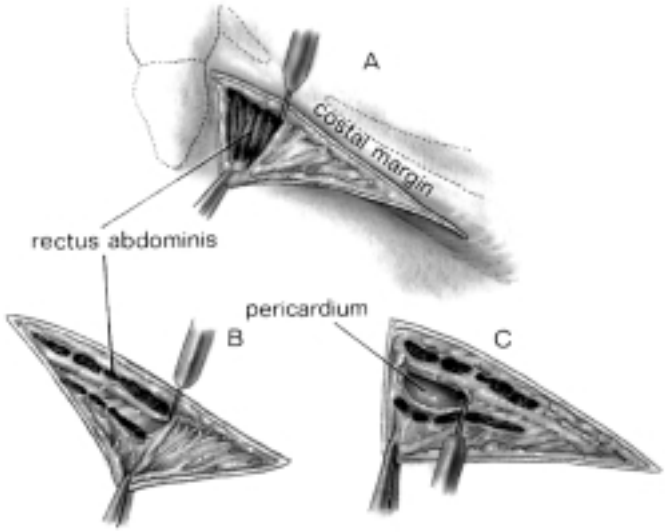

Figure 4. Anatomical details of the subcostal incision showing the muscles and fascia being dissected off the costal margin (A, B, and C)

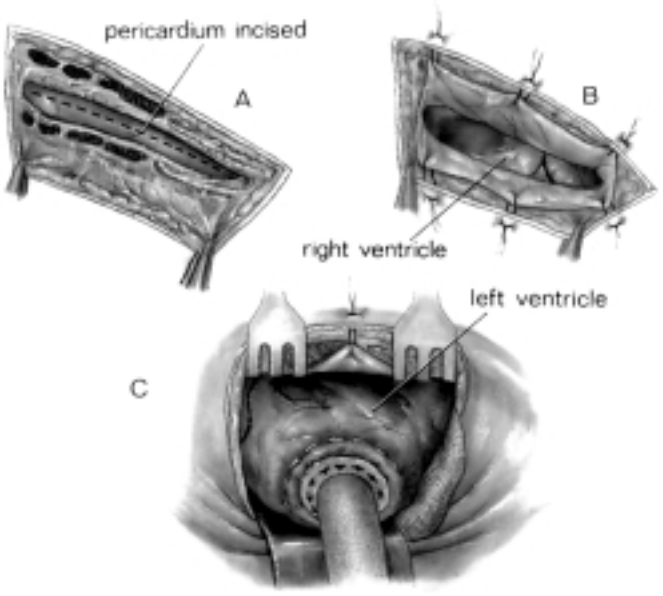

Figure 5. A, Visualization and incision or the pericardium; B, retraction of the pericardium; C, left ventricular apex centered in the wound with the apex cannula in place.

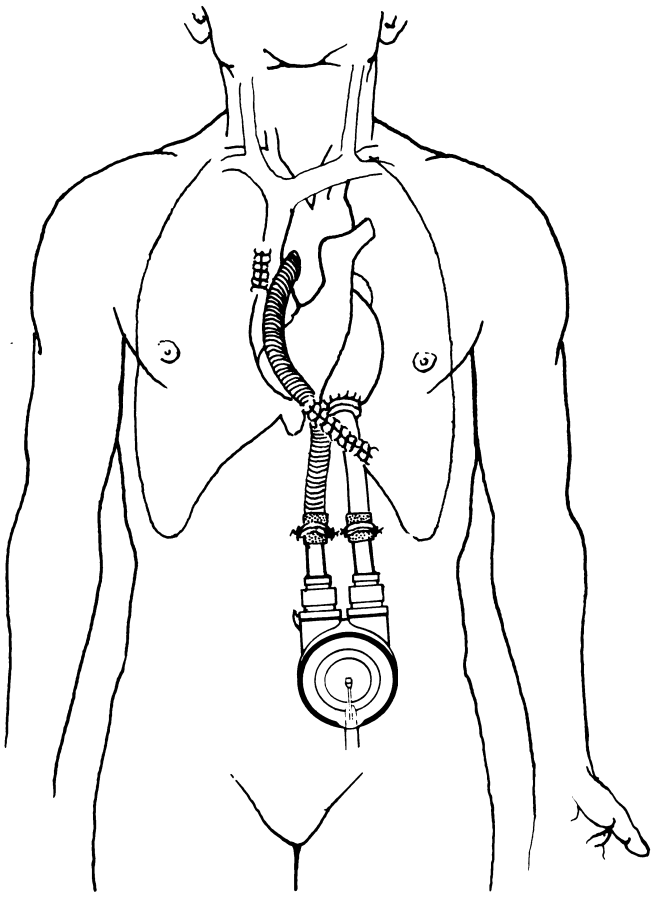

Figure 6. Completed implantation.

Table 2. Postoperative Complications Related to LVAD Insertion

Patient No.	Surgical Complication
1	None
2	Right hemothorax and right calf compartment syndrome
3	Right hemothorax

LVAD indicates left ventricular assist device.

of the subcostal incision to exit onto the abdominal wall, 4-5 cm inferior to the subcostal incision.

The LVAD and the inflow and outflow cannulae are then de-aired and connected using standard techniques (Figure 6, ◎). Once CPB is discontinued and left-sided support taken over by the LVAD, protamine is administered.

A straight, 28-F chest tube is placed in the right gutter, adjacent to the right atrium, going up to the level of the ascending aorta. A second, right-angled chest tube is placed over the diaphragm and down into the pocket of the posterior pericardium by moving the heart anterior and medially by the apex cannula. No chest tubes were placed in the right pleural space, which is entered while accessing the ascending aorta through the thoracic intercostal space incision. One could be easily placed and would be protection against unexpected intercostal or internal mammary artery bleeding postoperatively.

In patient no. 2, a mitral valve repair was done in addition to the LVAD implant. In this instance, the second intercostal incision was not made. A 6–7 cm 4th intercostal incision was made and the mitral valve repaired using less invasive cardiac surgery techniques including transcutaneous aortic clamping and cardioplegia. Through this same incision, the LVAD outflow cannula was anastomosed to the right side of the ascending aorta. This cannula was then passed over and around the right atrium to exit the subcostal incision using the technique described above.

RESULTS

In each case, the operation was performed with comparative technical ease and the goals of the operation were achieved. The apex cannula can be inserted into the left ventricle more easily than through a median sternotomy. All wounds healed well.

There were three postoperative complications related to the procedure (Table 2, ◎). Two patients (nos. 2 and 3) had bleeding from the wound edges or intercostal arteries of the thoracic incision that caused blood accumulation in

Table 3. Current Status of LVAD Patients

Patient No.	Outcome	Current Status
1	Transplanted	Alive and well (9 mo)
2	Mortality (atherosclerotic stroke)	—
3	Transplanted	Alive and well (6 mo)

Table 4. Coagulation Parameters and Blood Product Use

Patient No.	LVAD Implantation Pre-operative Lab and Postoperative Blood Use						Transplantation Pre-operative Lab and Postoperative Blood Use					
	Anti-Fibrinolytic	PTT	INR	RBC Units	FFP Units	Platelet Units	Anti-Fibrinolytic	PTT	INR	RBC Units	FFP Units	Platelet Units
1	Aprotinin	—	1.20	2	0	1	Tranexamic acid	78.4	—	4	2	2
2	Aprotinin	—	0.97	7	0	0	—	—	—	—	—	—
3	Tranexamic acid	—	2.29	6	17	1	Tranexamic acid	—	5.00	2	11	2

LVAD indicates left ventricular assist device; PTT, partial thromboplastin time; INR, international normalized ratio; RBC, red blood cell; FFP, fresh frozen plasma.

the right pleural space, which had to be evacuated with the insertion of a chest tube. This bleeding also resulted in postoperative transfusions of packed red blood cells.

Patient no. 2, a large, young patient (38 years old), developed a right calf compartment syndrome that required a fasciotomy. This resulted from common femoral artery occlusion (mitral valve repair plus LVAD insertion) and near normothermic perfusion (34°C) of a large leg muscle mass. This patient was subsequently found to have unsuspected peripheral arterial atherosclerosis, which presumably contributed to the ischemic syndrome in the leg; she died one month post LVAD insertion from a stroke. At the time of the stroke, emergency cerebral arteriography was performed with the intent of performing thrombolysis. Surprisingly, significant atherosclerotic lesions were found in the right common and internal carotid arteries and in the right middle cerebral artery, the vascular supply for the infarcted area (Table 3, ◎).

The remaining patients (nos. 1 and 3) were subsequently transplanted without incident. Each of these re-operations to perform orthotopic cardiac transplantation was performed with ease and with very minimal adhesions compared to those experienced after median sternotomy for LVAD placement. The pre-LVAD and pre-transplant coagulation parameters, antifibrinolytic use, and postoperative transfusion requirements are documented in Table 4 (◎).

DISCUSSION

The current results of LVAD therapy for bridge to transplantation (and sometimes what becomes bridge to recovery) are excellent (60%–70% overall survival) when benchmarked against the outcome without the availability of this therapy. Much of the mortality and morbidity is related to the pre-operative condition of the patient. In the last decade, a major direction to improve the success of the therapy has been to improve patient selection. This research and its clinical application made LVAD (or, in some cases, BiVAD) therapy the standard of care of certain patients in Class IV heart failure.

The standard exposure for VAD insertion is median sternotomy. Sternotomy-sparing approaches for VAD insertion using large right or left lower thoracotomy incisions have been described before by us and others [Hill 1986, Pasic 1999]. The incisions provide limited exposure for their size and are quite painful postoperatively. The incisions also carry a significant violation of the pleural spaces that are often accompanied by annoying postoperative morbidity.

Subramanian has described a transabdominal approach for off-pump coronary revascularization [Subramanian 2000]. The incision is subcostal but larger and by necessity enters the abdominal cavity. It is reported to result in little pain and provide adequate exposure.

We specifically wanted to stay out of the abdominal and pleural spaces in the lower chest. The incisions we developed are small, focused, rib- and sternum-sparing, do not violate the abdominal cavity, and do not intrude into the pleural space in any significant way. The approach is targeted. The postoperative pain is minimal and the wounds heal quickly and easily. Patient mobility is quickly restored. Because the procedure offers a less invasive operation with the same benefits, it may tend to increase the number of patients to be considered for LVAD therapy. The potential clinical advantages that this operation may offer patients are listed in Table 5 (◎). The number of patients in our initial series is too small to draw any definitive conclusions.

Many of the patients considered for LVAD therapy are receiving anticoagulation therapy. The small incisions limit blood loss and minimize transfusions, reducing the risk of sensitizing the patient to a potential donor heart. In this series, the blood requirements for two of three patients were not low. This was due to bleeding from the thoracic incision, which is uncommon and preventable.

The ease with which a subsequent operation is performed is a major advance. There are no sternotomy-induced, early mediastinal adhesions that must be dissected out in the presence of dacron or polymer vascular conduits traversing the operative field. This saves time, diminishes risk, and reduces blood loss and transfusion needs.

Table 5. Potential Clinical Advantages of Less Invasive LVAD

Sternotomy sparing
Easier re-operation
Easier apical cannulation
Less blood product use
Less risk of sensitization
Wound-healing risks reduced
Psychologically less invasive

LVAD indicates left ventricular assist device.

Table 6. Potential Opportunities of Less Invasive LVAD

Redos
BiVADs
Implantable VAD(s)
One Incision
Apex Cannulation
Mitral valve repair
Post pericardial arterial conduit
No coronary suction
No cardiopulmonary bypass

LVAD indicates left ventricular assist device; BiVAD, biventricular assist device.

No sternotomy means no risk of a sternal infection, which can compromise the surgical plan for cardiac transplantation. Wound infections could, of course, occur in the incisions described in this approach but would probably be handled more easily.

Lastly, the mental picture of a complicated thoracic surgical procedure not requiring a sternotomy incision is appealing to the patient at a time when he or she is already burdened with significant mental stress, including alterations in body image.

These initial technical successes lead one to consider a less invasive approach to other situations requiring VAD insertion and to introduce other methodologies to minimize the operation further. These opportunities are listed in Table 6 (◎) and include using this approach for BiVAD insertion or in redo operations. Redo operations may present a challenge because of the cardiac mobilization necessary and the degree of exposure available to do it. With experience, performing the operation without coronary suction is also possible.

In selected hemodynamically stable patients, performing the entire procedure without the aid of CPB is a possibility for the future. We now know the left ventricle can be lifted and rotated with reasonable safety, so that inserting the apical cannula into the apex without bypass can be considered. In bovine animal experiments, this is the standard technique to insert a LVAD. Humans with congestive heart failure, of course, may be another story. The apical insertion technique would have to be streamlined to make it a reasonable approach. There is also the issue of apical or left ventricular thrombus being present in the left ventricular chamber. Despite the accuracy of transesophageal echocardiography in detecting thrombus in the left ventricular chamber, the current methodology of apical cannulation is to explore the chamber via the apical incision and remove any thrombus. A surgeon would have to be supremely confident of the absence of thrombus in the chamber before inserting a cannula into it without inspecting it first.

Transapical mitral valve repair through the small apical incision is a possibility. This would require the use of cardioplegia and a camera to properly visualize the valve and its leaflets. This opens the opportunity for transapical cardiac surgery.

Placing the arterial outflow cannula of the VAD into the descending aorta behind the pericardium is being considered. We have already used this approach in a median sternotomy setting and are looking at the technical requirements of doing it through the subcostal incision. The advantage would be to have one less incision in the patient. More importantly, if bridge to recovery continues to be a potential therapy for a large number of patients, removing the LVAD through one subcostal incision is a very attractive surgical option for the patient being considered for such a therapeutic approach.

Finally, the patients described in this report all had paracorporeal LVADs. It is expected that in the next 12 months, there will be an implantable Thoratec VAD. That device will be smaller than the current LVAD and will most certainly be able to be implanted using the less invasive techniques described above.

CONCLUSION

A new surgical technique to insert a Thoratec LVAD (Thoratec Laboratories Corp, Pleasanton, CA, USA) is described. Three patients were treated using this less invasive technique. In each instance, the surgical procedure met the goals of the operation. Too few patients have been treated to accurately characterize the potential advantages or disadvantages of the operation. The procedure does offer the opportunity to insert an LVAD with less morbidity. It will require more data from us and others before this approach will find its place in the treatment of patients with end-stage heart failure.

Acknowledgments

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