A 29-year-old man with a history of ICM (EF ~10-15%) and ICD placement presents for VAD implantation. He has a history of DM, HTN and hyperlipidemia. His home medications include Furosemide, Metformin, Lisinopril, Irbesartan, Rosiglitazone, Atorvastatin, and 81 mg ASA. His ICD tachycardia therapy was suspended and the pacemaker was programmed to VVI of 90 bpm. His most recent TEE reveals a dilated, severely hypokinetic LV with an estimated EF ~ 10-15%, mild MR, spontaneous echo contrast in the LAA and LV, no apical or LV thrombus, moderate HK of the right ventricle, mild TR, trace PI, normal trileaflet AV without any insufficiency and AICD wires within the RA and the RV. He is intubated (8.0 ETT).

1. Will you insert a TEE?
2. Why will you need a TEE? Is it indicated?
3. What pertinent findings are relevant in the pre-CPB time period?
4. Is there any finding that would preclude insertion of a VAD? If so, what is it?
5. What types of invasive intraoperative monitors will you use intraoperatively for VAD implantation?

On bypass, the outflow cannula is sewn to the ascending aorta and the inflow cannula is sewn into the left ventricle.

6. What are the indications for VAD insertion?
7. What are the various types of VAD devices?
8. What is the inflow cannula?
9. What is the outflow cannula?
10. Where do the cannulas go for an RVAD?
11. Are there other positions for LVAD canulation?
12. What should be noted about cannula position?
13. What are the pertinent TEE findings after LVAD insertion?

You note turbulent flow in the inflow cannula and communicate this with the surgeon. The appropriate maneuvers are performed.

14. What should the flow be (qualitatively and quantitatively) in the inflow cannula?
15. How should the inflow cannula be positioned?

The patient is transitioned off CPB and onto the LVAD. 0.1 mcg/kg/min of epinephrine is initiated. The surgeon asks you to initiate protamine.
16. Can you give a patient with an LVAD protamine?
17. If so, how much will you give?
18. What are the indications for anticoagulation in patients with a VAD?

After bleeding is controlled, the chest wall is approximated and the surgeon starts to sew the skin incision. On the TEE, you note RV dilatation and moderate HK.

19. Why is it necessary to monitor the RV when coming off CPB onto the LVAD?
20. Are there any risk factors that can be identified to help determine high risk patients for RV failure after LVAD insertion?
21. Why would patients who receive LVADs be at a higher risk for RV failure?

The epinephrine is increased, the RV function returns to normal and the skin incision is closed. You note that the pump speed is set at 9000 rpm.

22. Is this a normal setting?
23. What determines pump speed?
24. What is the optimal pump speed?
25. Are there any findings on TEE that can assist you in determining optimum pump speed?

The patient is taken to the ICU stable. In the ICU, it is noted that the Pulsatility Index (PI) has suddenly dropped.

26. What is the Pulsatility Index?
27. What does it mean when it suddenly drops?

The patient is transfused two units of blood and the PI approaches initial values. On POD #2, the patient is noted to be stable and is discharged from the ICU.

DISCUSSION
1. A complete TEE exam should be done for this procedure. It carries a level 2, (expert consensus) opinion according to the ASA/ACC guidelines for perioperative TEE.


2. TEE is indicated in order to assess for structural and functional abnormalities such as AI and MS, PFO, ASD, and VSD. It is helpful to assess overall LV function and to check for LV thrombus, which may occur in patients with greatly decreased LV function. It is also a good idea to assess the proximal ascending aorta to determine if there is an aneurysm, a dissection, or large atheroma present. TEE can also be utilized to monitor cardiac function after device placement and assist in device programming.


3. TEE evaluation prior to LVAD insertion should confirm that the aortic valve is not regurgitant and the absence of mitral stenosis or a septal defect (including PFO). Surgeons should be informed if an atheroma in the ascending aorta or a thrombus in the left ventricle is present. Assessment of right heart function is also important, as some form of RV dysfunction is present in most of these patients. The degree of RV dysfunction will help to determine what mechanical/pharmacologic support will be necessary to wean from CPB and maintain optimal tissue perfusion.

4. A PFO, ASD, or other intracardiac shunt would have to be repaired prior to VAD insertion. If the patient has aortic insufficiency this should also be repaired.

Chumnanvej S, Wood MJ, MacGillivray TE, Meol MFV. Perioperative echocardiographic examination for ventricular assist device implantation. Anesthesia and Analgesia

5. An arterial line should be placed prior to induction of anesthesia to closely monitor blood pressure, as these patients have greatly decreased myocardial function. Large bore, central intravenous access is also necessary in these patients. A
Swan-Ganz catheter is also useful to monitor SvO2 and follow volume status, assess the need for transfusion, and to monitor right heart function.

6. There are 3 indications for LVAD insertion:

   a. Bridge to transplant in patients who are transplant candidates but may not survive until an organ is available.
   b. Destination therapy, which is for patients in heart failure who are not transplant candidates
   c. Bridge to recovery for patients in who heart function may recover.

   All these indications are for patients who have advanced heart failure and who do not improve or stabilize when placed on optimal medical treatment, intraaortic balloon pump, or mechanical ventilation.

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7. There are several types of ventricular assist devices. The newest devices utilize either axial or centrifugal pumps that offer improved longevity and smaller size. VADs are either intracorporeal where the pumping chamber is inside the patient’s body, or extracorporeal where the pumping chamber is outside the patient’s body.

8. The inflow cannula is the part of the LVAD that takes blood from the body to the LVAD

9. The outflow cannula is the part of the LVAD, which transfers blood from the device to the body.

10. When an RVAD is used the inflow cannula is typically anastamosed to the right atrium and the outflow cannula is anastamosed to the pulmonary artery.

11. The inflow cannula may also be sewn into the left atrium or the left superior pulmonary vein for an LVAD. There are also reports of utilizing the ascending aorta for inflow cannulation and the descending aorta for outflow cannulation.

12. The inflow cannula position in the left ventricle should be directed posteriorly towards the mitral valve to maximize inflow and reduce turbulent flow as much as possible.
13. After LVAD insertion TEE examination should be performed. Flow into the inflow cannula should be assessed to make sure it is not turbulent. The heart valves should be assessed again to ascertain there is no mitral stenosis or aortic regurgitation. Special attention should also be paid to the right ventricle to make sure it is not dilating and in volume overload or possible failure. It should also be noted that the left atrium and left ventricle are decompressed and the interventricular septum is bowed slightly toward the left ventricle.

14. The flow into the inflow cannula should be assessed with color flow Doppler. Qualitatively, the flow should be laminar and unidirectional from the ventricle into the cannula. Quantitatively, flow should be assessed using pulsed wave Doppler and should be between 0.7 and 2 m/s. The flow should not exceed 2.5m/s into the inflow cannula.

15. The inflow cannula should be positioned in the apex of the LV directed posteriorly towards the mitral valve.

16. Heparin should be reversed with protamine to reduce bleeding in an already high-risk patient population.

17. The usual dose of protamine is 1mg for every 100units of heparin, however point of care testing should be utilized to optimize the protamine dose as too much protamine has been shown to increase bleeding and coagulopathy.


18. Anticoagulation is necessary as blood is passing over a foreign surface and is thus prone to clot formation. Patients are usually given aspirin 81mg for platelet inhibition and started on warfarin. Patients are managed with the warfarin and aspirin therapy as outpatients with goal INRs of 1.5-2.5 to prevent thromboembolism and also decrease the risk of hemorrhagic stroke and bleeding.

19. Patients with LV failure requiring an LVAD typically also have a degree of RV dysfunction. This can be exacerbated when LVAD takes over all the work of the left ventricle, which eliminates the contribution of the septum to RV contractility. This may result in severe RV dysfunction after placement of an LVAD. Volume overload may also be a problem in this patient population leading to RV failure.

20. Risk factors for RV failure include female gender and heart failure from a nonischemic etiology.


21. Patients are at risk of right heart failure after LVAD insertion because the right heart loses the contractility of the septum since the LVAD takes over all the work of the left heart. Also, prior to insertion venous return was extremely low due to poor LV function. After placement of the LVAD, venous return will be back to normal, however the right heart may not be able to handle the sudden increase in flow.

22. Typical pump speed in the Heartmate II is 9200 RPMs. Depending on the patient, pump speed is adjusted to provide an adequate cardiac output.

23. Pump speed is determined by either fixed settings set by the physician, or automatic settings in which pump speed will increase with exercise or exertion.

24. The optimal speed at which a pump operates depends on the patient. Typical LVAD speeds are around 9000 RPMs and this is optimized in order to provide adequate oxygen delivery to tissues. Pump flow should be adjusted in order to maximally unload the left ventricle while preventing leftward shift of the interventricular septum.

Slaughter MS, Pagani FD, Rogers JG, Miller LW, Sun B, Russell SD, Starling RC, Chen L, Boyle AJ, Chillcott S, Adamson RM, Blood MS, Camacho MT,

25. Pulsatility index is a dimensionless number, which describes flow pulse through the pump. It is determined by left ventricular contractility and pump speed. The more the LV is ejecting, the greater the PI will be.

26. PI may suddenly drop from anything that causes a drop in left ventricular contractility including arrhythmias and preload. A sudden drop in the pulsatility index means the LVAD is doing a lot more work than the left ventricle. A PI drop could also be from a decrease in circulating volume, which would then cause a decrease in preload.