

Balloon Pump and Beyond: Echo Assessment of Assist Devices.

Lecture objectives:

At the conclusion of this lecture, participants will understand the utility of echocardiography in assessing patients who may be candidates for circulatory support devices.

Also, participants will understand the role of intraoperative echo in the evaluation of proper assist device function as well as complications that may arise related to the use of these devices.

My goals for achieving the above objectives are as follows:

1. Describe the essential components of an echocardiographic exam in these patients
2. Describe how echo can assist in perioperative anesthetic management of these patients
3. Provide case examples of perioperative echo in patients with assist devices.
4. Review the relevant content for the PTEeXAM (content outline for the PTEeXAM)

Intraaortic balloon pumps (IABP):

IABPs are inserted percutaneously (usually via the femoral artery) and advanced into the aorta 1cm distal to the left subclavian artery. The balloon inflates immediately following aortic valve closure increasing diastolic pressure and thereby increasing coronary perfusion pressure and coronary blood flow. The balloon deflates immediately prior to opening of the aortic valve creating a suction effect that lowers afterload and decreases myocardial wall tension. By improving diastolic coronary blood flow and decreasing myocardial wall tension the IABP increases myocardial oxygen delivery and lowers myocardial oxygen demand. This improvement in the supply-demand relationship can rescue patients suffering from myocardial ischemia. Real time ultrasound can enhance successful femoral arterial cannulation in patients with diminished pulses. Echocardiography allows for visualization of the wire in the aorta and assists in proper positioning of the device 1cm distal to the left subclavian artery. Echocardiography also enhances

diagnosis of problems such as: balloon rupture, aortic dissection, and thrombus formation. Indications for placement include: left ventricular systolic failure, acute hemodynamic collapse post bypass, and unstable angina. It may be helpful when placed preinduction in patients with the combination of severe aortic stenosis and severe coronary artery disease. Contraindications to IABP placement include the following: aortic insufficiency, aortic dissection, prosthetic graft in the thoracic aorta, and severe aortoiliac disease. The presence of an aorto-pulmonary shunt (BT shunt) or a patent ductus arteriosus would also likely preclude placement of an IABP, as diastolic runoff to the lungs would be aggravated. Complications include: aortic dissection and arterial perforation, limb ischemia, thrombocytopenia, thromboembolic complications, balloon rupture with helium embolus, hematoma, pseudoaneurysm, arteriovenous fistula, infection and bleeding. Small balloons have been successfully placed in infants, but its use is uncommon in children.

Ventricular Assist Devices

Surgical treatment of heart failure has been shown to be effective and appropriate in certain settings. For example, end stage heart failure patients (New York Heart Class IV) have a one-year mortality of 75% which decreases to 15% following cardiac transplantation (6), (7).

Unfortunately 16,000 patients could benefit from transplantation and less than 3,000 organs are available each year (7). Ventricular assist device (VAD) therapy may provide an option for those patients who are unable to receive transplants due to a lack of organ availability or because they are not candidates for cardiac transplantation. Ventricular assist devices are currently placed for 3 indications: 1. temporary support as a bridge to transplantation, 2. temporary support until the heart recovers, 3 long-term treatment of patients who are not transplant candidates, and who are not expected to recover ventricular function (destination therapy). When compared with medical therapy, left ventricular assist devices have been shown to double one year survival and triple two year survival (7) (8).

Patients with end-stage heart failure, who are not transplant candidates, have been found to have increased survival and improved quality of life following placement of left ventricular assist devices (LVADS) (1). With the limited availability of organs and with the large number of patients who are not candidates for cardiac transplantation, LVAD therapy will become more common. Increasingly these patients will present for cardiac and noncardiac surgery. Perioperative TEE provides real time diagnostic and monitoring information that is essential in managing these patients during surgery and in the ICU.

This lecture will describe the perioperative use of TEE in patients presenting for assist device placement and will focus on the common echocardiographic features and anesthetic concerns involved in these cases. A detailed discussion of the every specific device and all the individual characteristics and properties of every device will not be addressed and the reader is encouraged to see references at the end of this synopsis. Although it will not be the focus of this lecture, it is of paramount importance that a discussion of the perioperative plan occurs prior to induction of anesthesia. Things that should be discussed include: the patient's current condition, the specific idiosyncrasies of the device to be inserted, and the planned insertion sites of the inflow and outflow cannulae. As with all cardiac surgical procedures, good communication between anesthesiologists, surgeons, perfusionists, and device representatives helps improve patient care.

Left ventricular assist devices (LVADS) represent the bulk of the assist devices placed in cardiac patients in the operating room. In the next section I will provide an outline followed by a more detailed narrative discussing the most important components of the echocardiographic assessment of these patients. The discussion will be divided into 5 segments or periods and the important echocardiographic components of each period will be discussed. The 5 periods are as follows: prebypass, intraoperative (on bypass), weaning from bypass, postbypass, and postoperative(ICU).

In every case of LVAD placement the following essential components of a TEE exam must be performed:

Prebypass examination:

1. Aortic valve insufficiency (If significant AI exists the AV must be replaced or over sewn)
2. Intracardiac shunts (interatrial communications will result in shunting → hypoxia)
3. RV function (TR? The RV must supply the preload to the LV and the VAD)
4. Intracardiac thrombus (left atrial appendage, left ventricular apex)
5. Aortic atherosclerosis (epiaortic scan of outflow insertion site)
6. Mitral valve exam (rule out MS)

Aortic valve insufficiency reduces effective systemic flow. LVAD flow into the aorta reenters the left ventricle via the regurgitant aortic valve diminishing effective systemic flow and oxygen delivery. AI will decrease effective systemic device output by causing a recirculation of flow:

LV → LVAD → Ao → AV → back to LV

Prebypass AI can be underestimated because heart failure patients have elevated LV diastolic pressures and decreased aortic diastolic pressures. Significant (greater than mild) AI during a prebypass exam should prompt the surgeon to seriously consider replacing or oversewing the regurgitant aortic valve. (12) Replacement is indicated if the patient's intrinsic left ventricular stroke volume contributes significantly to the overall cardiac output and/or the patient is expected to recover and ultimately be weaned from the device. AI may be increased following LVAD placement because the AV is exposed to systolic (rather than diastolic) pressure. If the valve is to be replaced, use of a bioprosthetic valve is recommended because the low antegrade flow across a mechanical aortic valve increases the risk of systemic thromboembolism.

Intracardiac shunts (especially a PFO) must be excluded as these allow systemic venous blood from the right heart to bypass the lungs by flowing directly through the defect to the LVAD and

into the systemic circulation. This right to left shunt lowers systemic oxygen saturation, decreases oxygen delivery, and also provides a route for paradoxical embolization.

RV function is of paramount importance in patients receiving LVADs. If the RV does not provide adequate flow through the lungs to the LV and the VAD, the device will subsequently be unable to provide effective perfusion to the systemic circulation. Frequently these patients suffer from a disease that affects both ventricles and ensuring adequate RV function is challenging. A prebypass evaluation of the RV attempts to answer the following questions: 1. Can this patient come off pump without both an RVAD and an LVAD? 2. Would this patient benefit from a TV repair prior to coming off pump? Although the LVAD should decrease RV afterload, TR has not been shown to consistently improve following LVAD placement (9). Rao et al (12) and Chumnanvej et al (9) recommend an annuloplasty ring in patients with greater than moderate TR and this has been shown to decrease post insertion TR (9).

Intracardiac Thrombi are likely in these patients given their miserable systolic function. The heart must be carefully interrogated for thrombi. Locations especially concerning include the LV apex and the left atrial appendage. Thrombi can obstruct the inflow cannula and can become embolic following VAD insertion.

Aortic Atherosclerotic disease causes concern in all cardiac patients. Atheromata encroaching on the aortic lumen with thickness of greater than 5 mm or mobile components are associated with increased risk of cerebroembolic events during cardiac surgery (13, 14). The aortic insertion site for the outflow cannula should be interrogated with epiaortic ultrasound for the presence of atheromata.

Mitral valve stenosis prevents adequate LV and LVAD filling. Mitral stenosis is uncommon in patients presenting for LVAD therapy. Mitral regurgitation is a common finding, and does not usually present a problem in patients undergoing LVAD placement. MR usually improves following LVAD placement and the need for mitral valve intervention is rare (9). Pulmonary vein

stenosis, and pulmonic valve stenosis would also decrease LVAD preload, but are not commonly seen in these patients.

Intraoperative (while on cardiopulmonary bypass):

1. *Assist surgical positioning of cannulae*

The specific device implanted and the location of the inflow and outflow cannula will influence this part of the echocardiographic exam. Most often (conventional) cannulation involves an inflow cannula located in the LV apex and an outflow cannula located in the ascending aorta. The cannula should be positioned to avoid obstruction by the septal wall, and/or valvular or subvalvular apparatus.

Inflow cannula sites include:

1. LV apex (ensure no obstruction by ventricular septum) (conventional, most devices)
2. Trans-aortic valve (Impella) (possible anterior mitral leaflet obstruction)
3. Trans-atrial septum (TandemHeart)
4. LA

Outflow cannula sites include:

1. Ascending aorta (conventional, most devices)
2. Trans-aortic valve into ascending aorta (Impella)
3. Descending Aorta (Jarvik 2000)
4. Femoral Artery (TandemHeart)

Inflow cannula positioning: Regardless of the site of the inflow cannula, laminar unidirectional flow into the cannula should be observed. Color flow Doppler should indicate unobstructed

inflow. Turbulent high velocity flow is suspicious for inflow obstruction. Pulsatile devices (Heartmate I, Novacor, Thoratec) show a pulsatile flow pattern and usually have an inflow cannula diameter of 16 mm and a stroke volume of around 65 ml thus a peak velocity by continuous wave Doppler of greater than 2.3 m/s indicates device obstruction. Axial flow devices (HeartMate II, DeBakey, Jarvik 2000, Impella) show a nonpulsatile flow pattern and have a peak velocity between 1.0-2.0 m/s depending on preload and the patients intrinsic stroke volume. A peak velocity of greater than 2 m/s with an axial flow device is suspicious for device obstruction. The TandemHeart device can be inserted transcutaneously with the inflow cannula inserted in the femoral vein up to the SVC and across the interatrial septum and the outflow cannula present in the femoral artery. TEE is useful in guiding transeptal positioning (usually through the fossa ovalis) of the inflow cannula.

Outflow cannula positioning: Significant atheromata should be excluded from the outflow cannula insertion site by an epiaortic exam if possible prior to placement of a “side biting” partially occlusive aortic clamp.

Weaning from Bypass:

1. LV inflow cannula must not be obstructed.
2. Adequate flow (appropriate LV end diastolic dimension, adequate mean arterial pressure)
3. Inspection of interatrial septum (IAS) to ensure absolutely no patent foramen ovale (PFO)
4. Inspection of aortic valve [evaluation for aortic insufficiency (AI)]
5. Right ventricular function and TR (need for nitric oxide, phosphodiesterase inhibitors, β -agonists, levosimendan)
6. De-airing

During weaning from bypass TEE allows confirmation of unobstructed VAD inflow (and if possible outflow) cannula, adequate unloading of the ventricle, adequate perfusion pressure as bypass support is decreased, absence of significant AI, adequate RV function and absence of intracardiac air. RV function is often tenuous and TEE assists in determining the need for inhaled NO, phosphodiesterase 3 inhibitors (milrinone) beta agonists and calcium sensitizers (levosimendan). Air embolus down the anteriorly located right coronary artery can aggravate efforts to support RV function. Assuring adequate oxygenation and ventilation to avoid increases in pulmonary vascular resistance due to hypoxia and respiratory acidosis is paramount.

Post Bypass:

1. Right ventricular function
2. Doppler of inflow cannula (look for occlusion)
3. Intact interatrial septum (no patent foramen ovale)
4. Volume status

Post bypass right ventricular function continues to be a significant concern. TEE allows rapid assessment and monitoring of RV function. Recalcitrant RV failure unresponsive to aggressive measures (adequate oxygenation and ventilation, inhaled NO, Milrinone, Dobutamine) may prompt the surgeon to consider returning to bypass and placing a RVAD.

Also at this time, the inflow cannula should be interrogated to ensure no obstruction is present.

An adequately unloaded LV should be seen and the interatrial septum should be reexamined prior to chest closure to ensure that the newly decreased LA pressure did not facilitate right to left flow across a previously missed PFO. Assessment for aortic regurgitation and iatrogenic aortic dissection (from cannulation) should also be quickly performed prior to chest closure.

Post OP (ICU):

1. Hypoxia → look for patent foramen ovale, right ventricular failure

2. CVA → look for intracavitary thrombus, patent foramen ovale, air
3. Hemodynamic instability → look for hypovolemia (bleeding), Tamponade, Right ventricular failure.

In the intensive care unit (ICU) TEE often provides valuable information when a patient is decompensating. Hypoxia should provoke reexamination of the interatrial septum for possible right to left shunts. Also, hypoxia from any cause will provoke hypoxic pulmonary vasoconstriction which increases pulmonary vascular resistance and can illicit RV failure. Patients who suffer cerebrovascular events should be examined for thrombi, patent foramen ovale, and intracardiac air (air can sometimes be entrained by certain devices). Transeptal and transaortic devices may predispose patients to thrombus formation in the LV apex (9). Infection and device failure (regurgitation) are frequently late complications of these devices. Bidirectional flow on Doppler examination of the inflow cannula is suspicious for inflow valve regurgitation. Device failure may be less common in newer axial flow devices with fewer moving parts and no valves.

New Advances / technology:

Although successful weaning from left ventricular assist devices is difficult, (2) (10) new technology may assist in identifying candidates for weaning and explantation. Pressure area loops may be generated using automated border detection (TG SAX view) and high-fidelity intraventricular pressure recording (4). In addition tissue Doppler imaging may predict myocardial recovery during circulatory support with left ventricular assist devices (3). Also, 3-dimensional echocardiography may improve accuracy of volume measurements in these patients (8). Recently, a small study suggested that medical treatment combined with LVAD therapy may help reverse the remodeling process and enable successful weaning and explantation (10).

Summary:

With the limited availability of organs and with the large number of patients who are not candidates for cardiac transplantation, circulatory assist device therapy will become more common. Increasingly, these patients will present for cardiac and noncardiac surgery.

Perioperative TEE provides real time diagnostic and monitoring information that is essential in managing these patients during surgery and in the ICU.

As these devices become more prevalent, it is imperative that the perioperative echocardiographer become familiar with these patients, and their unique concerns.

Practice Questions:

1. Which of the following is an essential component of the prebypass exam in patient's undergoing LVAD placement?
 - A. Evaluation of RV function
 - B. Evaluation for septal defects
 - C. Evaluation for intracardiac thrombi
 - D. Evaluation for aortic insufficiency
 - E. All of the above

2. A high (>4 m/sec) continuous wave Doppler LVAD inflow velocity most likely indicates which of the following?
 - A. Thrombus obstructing device outflow
 - B. Device malfunction
 - C. Septal obstruction of device inflow
 - D. Hypovolemia
 - E. Right ventricular failure

3. Which of the following would be expected to be the next cardiac surgery an LVAD patient requires?
 - A. Tricuspid valve repair
 - B. Myomectomy for septal occlusion of LVAD inflow
 - C. Cardiac transplantation
 - D. Mitral valve repair
 - E. Pulmonary thromboendarterectomy

4. Which of the following Prebypass valvular abnormalities is most concerning in a patient undergoing LVAD placement?

- A. Tricuspid insufficiency
 - B. Pulmonic insufficiency
 - C. Aortic insufficiency
 - D. Mitral insufficiency
 - E. All of the above are concerning
5. Which of the following is an indication for LVAD placement?
- A. 25 year old with post partum dilated cardiomyopathy awaiting transplantation
 - B. 69 year old with ischemic cardiomyopathy who is not a transplant candidate due to elevated pulmonary vascular resistance.
 - C. 17 year old with idiopathic dilated cardiomyopathy in whom it is hoped the myocardium will recover.
 - D. 3 year old with post viral cardiomyopathy
 - E. All of the above are candidates for LVAD therapy
6. Which of the following best describes the diastolic function that would be expected in a patient undergoing LVAD implantation?
- A. normal diastolic function
 - B. Grade 1 (impaired relaxation)
 - C. Grade 2 (pseudonormal diastolic dysfunction)
 - D. Grade 3 (reversible restrictive diastolic dysfunction)
 - E. Grade 4 (irreversible restrictive diastolic dysfunction)
7. Which of the echocardiographic findings would be consistent with a patient undergoing LVAD implantation?
- A. Lateral mitral annular tissue Doppler $E_M = 8.6$ cm/sec
 - B. Ratio of $E/E_M > 15$
 - C. Transmitral Color M-mode propagation flow velocity (VP) = 53 cm/sec
 - D. Left atrial diameter = 39 mm
 - E. Isovolumetric relaxation time = 100 msec
8. Which of the echocardiographic findings would be consistent with a patient undergoing LVAD implantation?
- A. LV free wall thickness = 22 mm
 - B. $dP/dt = 1600$ mmHg/sec
 - C. FAC = 50%
 - D. FS = 28%
 - E. LV end diastolic diameter = 70 mm

Dp/dt = change in pressure with respect to time during isovolumetric left ventricular contraction, FAC = fractional area change, FS = fractional shortening, LV = left ventricle, E = early transmitral inflow velocity as determined using pulse wave Doppler, E_M = early lateral mitral annular tissue Doppler velocity.

Answers:

- 1. E
- 2. C
- 3. C
- 4. C

5. E
6. E
7. B
8. E

Explanations:

1. *Answer = E*, all of the above are essential components of the prebypass exam. RV function is important, because if the RV does not deliver blood to the LV then the device cannot pump blood from the LV to the systemic circulation. Optimize ventilation to avoid elevated pulmonary vascular resistance due to hypoxia, acidosis and hypercarbia; add phosphodiesterase inhibitors, beta agonists, and inhaled nitric oxide if needed. A septal defect will result in a right to left shunt causing hypoxemia and potentially a paradoxical embolus. Intracardiac thrombi can also be a source of embolus or device occlusion. AI will decrease effective systemic device output by causing a recirculation of flow:
 LV→LVAD→Ao→AV→ back to LV. Prebypass AI can be underestimated because heart failure patients have elevated LV diastolic pressures and decreased aortic diastolic pressures.
References: 1, 7, 9
2. *Answer = C*, Septal obstruction as indicated by a high peak inflow velocity can occur following LVAD insertion. A peak velocity of 230 cm/sec is frequently quoted (9), and this is for a device with a stroke volume of 65 ml and an inflow cannula diameter of 16mm. Obviously the specific hemodynamics will depend upon the device, but in general a high peak inflow velocity on CW Doppler or turbulent inflow on color flow Doppler is concerning for obstruction. A thrombus obstructing the ***Inflow*** (NOT the outflow) cannula could cause elevated inflow velocities. References: 1, 7, 9
3. *Answer = C*, cardiac transplantation is the most likely next surgery. One of the primary indications for LVAD placement is as a bridge to cardiac transplantation.
References: 1-10
4. *Answer = C*, Aortic insufficiency is a huge problem for a patient undergoing LVAD placement. As explained in answer 1 above, AI decreases LVAD output, lowers systemic perfusion, and causes LV distention. In these patients the valve needs to be replaced or oversewn. If it is hoped that the patient might ultimately be weaned and explanted, (temporary support) the valve should be replaced. References: 1, 7, 9
5. *Answer = E*, All of the above are candidates for LVAD therapy
References: 1-10
6. *Answer = E*, Grade 4 (irreversible diastolic dysfunction) is characteristic of end stage heart failure which is likely present in all patients undergoing LVAD therapy.
Reference: 11
7. *Answer = B*, A Ratio of $E/E_M > 15$ is indicative of high left atrial filling pressures. This would be consistent with end stage heart failure. The other choices listed would be indicative of normal diastolic function and normal left atrial filling pressures.
Reference: 11
8. *Answer = E*, A LV end diastolic dimension of 70 mm would be consistent with severe LV dilation. A LV free wall thickness of 22 mm is severely hypertrophied; unlikely in a

patient with end stage heart failure requiring an LVAD. The other measurements are consistent with normal systolic function which is also inconsistent with end stage failure.

References: 1, 7, 9

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