Standard of Care:
Physical Therapy Management of the Patient with a Ventricular Assist Device

ICD 10 Codes:
- I 21- I 25 Ischemic Heart Disease
- I 40 – I 41 Acute Myocarditis
- I 42- I 43 Cardiomyopathy
- I 46 Cardiac Arrest
- I 50 Heart Failure

Case Type / Diagnosis:

This standard of care applies to patients who have undergone placement of a ventricular assist device (VAD) for end-stage heart disease. End stage heart disease is a growing problem in America and advanced disease has a mortality rate of one in five persons in the first year. Seventy-five percent of people with symptomatic heart failure have moderate to severe diastolic dysfunction and one in eight death certificates list heart failure as the reason of death. There were over 1.1 million hospital discharges related to heart failure in 2006 and the estimated cost of heart failure in 2009 is 37.2 billion dollars in the US alone. Despite advances in medical management, heart transplantation remained the only option for many patients. Due to long waiting lists for organs, the National Heart, Lung and Blood Institute urged the development of cardiac mechanical assist devices in the 1970’s. Since then, many devices have been developed and can be used for short or long term support.

VADs are used for refractory heart failure or cardiogenic shock, both of which can result from acute or chronic health conditions, including acute myocardial infarction, myocarditis, or progressive end stage heart failure. A VAD can be used to support the left ventricle (LVAD), the right ventricle (RVAD) or both ventricles (BIVAD). These devices can be described in many ways. Intracorpeal devices have a pumping chamber inside the patient’s body. Extracorpeal (Paracorpeal) devices have a pumping chamber outside the patient’s body. VADs are further categorized by their mechanism of pumping.

A pulsatile device has a sac and diaphragm which creates a compressible blood chamber. The chamber expands to fill when blood enters, and is emptied by the compression of the diaphragm. This type of device has valves which control blood flow to maintain blood flowing forward. Pulsatile VADs can be controlled by an electric motor or a pneumatic pump, in the case of VAD electrical malfunction. Non-pulsatile VADs are divided into axial flow pumps in which a propeller propels blood unidirectionally, and centrifugal pumps in which blood comes into the center of the pump, and is spun and accelerated out to the periphery of the plate. For all devices, the inflow cannulae bring blood from the peripheral circulation of the body to the VAD. Inflow cannulae remove blood from the atria or ventricle and decrease preload. The outflow cannulae bring blood from the VAD back to the body. In the case of the RVAD the...
blood returns to the body via the pulmonary artery. In the case of an LVAD the blood returns to the body via the aorta and provides cardiac output.

The indication for which design and brand of VAD is placed is patient or surgeon specific. In general, short term devices are placed for patients who are likely to have a rapid recovery, termed “bridge to recovery” or to stabilize them for another intervention to increase heart function, termed “bridge to decision”. These devices are used for a few days to a few weeks. Long term devices can be used for several months to years. These devices are often used as a “bridge to cardiac transplantation”, or as an alternative to cardiac transplantation as end of life care, called “destination therapy”. Brigham and Women’s Hospital currently uses VADs made by Thoratec Corporation (PVAD®, IVAD®, Heartmate I®, Heartmate II®, Centrimag®) and by CardiacAssist, Inc. (TandemHeart®). For specific information about each device, please see appendixes I through V.

**Indications for Treatment:**

The following structural and functional changes may be present after VAD placement

1. **Body Structures**
   a. Heart (s4100)
   b. Arteries (s4101)
   c. Veins (s4102)
   d. Capillaries (s4103)
   e. Trachea (s4300)
   f. Lungs (s4301)
   g. Thoracic Cage (s4302)
   h. Muscles of Respiration (s4303)
   i. Skin Of Trunk And Back (s8105)
   j. Skin of Upper Extremity (s8102)
   k. Skin Of Lower Extremity (s8104)

2. **Body Functions**
   a. Heart Functions (b410)
   b. Blood Vessel Functions (b415)
   c. Blood Pressure Functions (b420)
   d. Respiratory Functions (b440)
   e. Respiratory Muscle Functions (b445)
   f. Additional Respiratory Functions (b449)
   g. Exercise Tolerance (b455)
   h. Energy and drive functions (b130)
   i. Immunological system functions (b435)
   j. Ingestion functions (b510)
   k. Urinary excretory functions (b610)
   l. Mobility of joint functions (b710)
   m. Muscle power functions (b730)
   n. Repair functions of the skin (b820)

3. **Activity And Participation**
   a. Carrying out daily routine (d230)
      i. Managing one’s own activity level (d2309)
b. Handling stress and other psychological demands (d240)
c. Speaking (d330)
d. Change basic body position (d410)
e. Maintaining a body position (d415)
f. Transferring oneself (d420)
g. Walking (d450)
h. Caring for body parts (d520)
i. Dressing (d540)
j. Intimate relationships (d770)
k. Work and employment (d845)
l. Community life (d910)
m. Recreation and leisure (d920)
n. Sound (e250)
o. Air quality (e260)
p. Support and relationships
   i. Immediate family (e310)
   ii. Friends (e315)
q. Individual attitudes of friends (e420)

Contraindications / Precautions for Treatment:

The most common medical and surgical complications associated with VAD therapy include hemorrhage, hemolysis, thrombosis, infection, device malfunction, arrhythmias, renal dysfunction and hepatic dysfunction. When only one ventricle of the heart is supported (i.e. LVAD) there is the potential for contralateral ventricular failure. Please refer to the cardiac standard of care for general precautions and contraindications for treatment of the cardiac surgery patient.

General Precautions:

Sternal precautions apply for all patients who have had a midline sternotomy. Current recommendations for sternal precautions are considered best practice. Current literature does not support all the imposed restrictions. Clinical judgment should be used to allow for safe mobility and return of function. Special situations should be discussed with the medical team and a mentor therapist. Consideration should be taken to identify those patients who have multiple risk factors for sternal wound dehiscence and these patients should be encouraged to adhere strictly to the following sternal precautions. Surgeons may also identify patients at high risk for sternal wound dehiscence in the operating room and either use a modified closure (Robicsek weave) or write orders for strict sternal precautions during the postoperative course. Patients who may be at high risk for sternal dehiscence include:

a. Use of internal mammary artery (IMA) in the bypass graft
b. Females with pendulous breasts
c. Morbid obesity
d. Barrel chest
e. History of poorly controlled diabetes mellitus
f. Osteoporosis
g. Redo operation for bleeding or repeat cardiothoracic surgery

- Patient’s s/p full sternotomy without signs of sternal infection should follow sternal precautions, as listed below, for 12 weeks, or until surgeon clearance.
  - Avoid simultaneous bilateral shoulder flexion, abduction greater than 90 degrees.
  - Encourage unilateral upper extremity (UE) active range of motion (ROM) as tolerated to facilitate functional mobility gains and reduce the risk of shoulder ROM impairments and muscle performance changes.⁷-¹¹
  - Log rolling for bed mobility to avoid strong contraction of the abdominal muscles pulling on their superior sterna or costal attachment. Consider trunk stabilization activities.¹²
  - Avoid activities that may cause excessive Valsalva maneuver.¹³
  - Encourage chest splinting with pillow when coughing.
  - UE strength/ROM testing for strength grades greater than 3/5 should be performed only if neurological changes are suspected to have occurred.
  - Avoid full weight bearing through upper extremities (e.g., gait training must be at least partial weight bearing for ambulation)
  - Avoid lifting, pushing, and pulling greater than 10 lbs. for 3 months (no use of bed ladder or trapeze).
  - No driving and no sitting in passenger seat behind an airbag for 4 weeks.

Physical therapy (PT) intervention may need to be modified in the following situations:

- Infections tend to occur early in the VAD course, generally developing in the first 2 months after implantation. Studies have reported drive line infections in 13-52% of patients, pocket infections in 17-38% of patients, and VAD-related bloodstream infections in 16-33% of patients¹⁴. The most common organisms found in VAD related infections include coagulase-negative staphylococci, S. aureus, Enterococcus species, gram-negative bacilli and Candida¹⁴. Infections are evidenced by fevers, increased white blood cell counts and radiographic evidence on chest or abdominal CT scan. Infections may be difficult to diagnose and may lead to increased bleeding and thromboembolic events¹⁵.

- Arrhythmias, specifically atrial fibrillation and ventricular tachycardia, may not be an absolute contraindication to PT treatment. Ventricular tachycardia may be treated with antiarrhythmic medications in the case of an LVAD. In the case of a biventricular assistive device, arrhythmia may be well tolerated by the patient¹⁶.

- Conversations regarding the physiologic and hemodynamic status of the patient with the supervising PT or medical staff are necessary. Staff should monitor for symptomatic response to arrhythmia or hemodynamic instability/intolerance.

- Orthostatic hypotension will often manifest itself through 1) a rise in native heart rate or VAD rate, and 2) a drop in systolic BP and a drop in VAD flow. Treatment considerations are similar to any patient with hypotension and include the use of lower extremity compression garments (i.e. antiembolism stockings, elastic wrap bandages), abdominal binders, deep breathing, lower extremity exercise and supine repositioning with lower extremity elevation.

- Any new VAD alarms or VAD malfunction

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• Anticoagulation during long term VAD therapy is essential for prevention of thromboembolic and bleeding complications. The International Normalized Ratio (INR) goal will depend on the type of device and the patient’s past medical history, and should be discussed with the VAD healthcare team.

Cardiopulmonary resuscitation (CPR) may or may not be effective in the patient with a VAD. Please refer to appendices I through V for device specific emergency procedures.

Many device-specific precautions and contraindications also exist within the VAD population. Please refer to appendices I through V for device-specific precautions and contraindications.

**Evaluation:**

1. **Medical History:**
   a. Cardiac risk factors
   b. Onset and duration of cardiac symptoms
   c. Cardiac Diagnosis
   d. Length of cardiac history
   e. Extent of prior cardiovascular interventions

2. **History of Present Illness:** Include if the VAD was placed emergently or electively, the type of VAD placed, which ventricle(s) is/are supported, manufacturer, goal of VAD therapy (i.e. destination therapy, bridge to transplantation), complications during the perioperative or postoperative period, pertinent lab values, significant diagnostic tests, dates of physical and occupational therapy (OT) consults, date of abdominal binder fitting by OT, and any response to activity with RN/medical staff (i.e. flows drop with bed mobility, etc.)

3. **Social History:** Patient’s prior level of function, prior use of an assistive device, level of endurance, home environment, barriers, family/caregiver support available, patient’s expectations of returning to home and their life goals.

4. **Medications:**
   a. Medications on admission (i.e. home inotropic support)
   b. Medication requirements perioperatively, including vasopressors, beta blockers, ACE inhibitors, calcium channel blockers, diuretics, and pain medications
   c. Current medications
   d. Medication effects on rehabilitation therapies
**Examination**
This section is intended to capture the most commonly used assessment tools for this case type/diagnosis. It is not intended to be either inclusive or exclusive of assessment tools. Please refer to the Cardiac Medicine & Surgery Standard of Care for all examination techniques related to the general cardiac patient.

1. **Observation**
2. **Hemodynamics**: A patient’s native heart rate will be demonstrated on telemetry. The therapist should note this rate, but be aware that the VAD rate will be different and is a more reliable rate for the patient’s status as it directly controls all peripheral flow and cardiac output. Taking a radial pulse will monitor peripheral flow, and will therefore be a reflection of VAD rate. A pulse oximeter will also reflect VAD rate, not the native heart rate. A pulse oximeter will not be able to detect VAD rate or oxygen saturation in a patient with a pulseless device. In axial flow pumps, blood pressure (BP) is often difficult to auscultate. In the ICU BP can be monitored with an arterial line, however once the arterial line is discontinued, the standard of care is to monitor mean BP by Doppler\(^{18}\)
3. **Current Lab Values**
4. **Abdominal Binder**: All patients should be fitted with a binder by OT prior to initiation of out of bed activities. This binder may be custom made, or a prefabricated binder issued by the Thoratec Corporation can be used. The binder provides immobilization of the percutaneous drive line to promote wound healing between the epithelium and the fabric of the driveline, and prevent infection\(^{19}\). The binder should be worn at all times, including during sleep\(^{19}\). Ensure proper binder fit and adequate security of drivelines prior to mobility.
5. **Power Source**: The patient’s VAD may be connected to a power based unit (i.e. AC power from wall source) or may be reliant on battery support. It is important to know the current battery life of the VAD prior to initiation of physical therapy services
6. **Pain** (location, duration, intensity), use of Visual Analog Scale 0-10\(^{20}\), and any action taken (i.e. RN notified of patient’s pain, patient pre-medicated)
7. **Posture**
8. **Sensation**
9. **Strength**
10. **Range of Motion**
11. **Functional Mobility**
    a. Patient should be progressed as with any acute care patient, beginning with bed mobility and transfers and progressing to ambulation on level and stairs when tolerated by the patient.
    b. Current recommendations suggest that patients with VADs should be out of bed to chair and beginning ambulation with assistance by postoperative days 3-5\(^{21}\). It is suggested that patients with VADs should progress to independent ambulation and stair climbing with physical therapy by postoperative days 12-14\(^{21}\).
12. **Gait**: Note if the patient is ambulating on battery support or with a AC power based unit, and note if the patient is pushing their own VAD or if they need assistance
13. **Endurance**
    a. **Rate of Perceived Exertion**\(^{16}\)
    b. **Six Minute Walk Test**\(^{22,13}\) can be initiated in the patient with a VAD, during postoperative days 6-8, as medically appropriate. The percent of age predicted walking distance per Enright et.al. or Gibbons et.al. should be recorded in the medical record\(^{8,23}\)
c. Current literature suggests that an endurance program for a patient with a VAD should include the following:
   i. Interval ambulation (i.e. 2 min x 5) initiated by postoperative days 9-11\textsuperscript{21}
   ii. A treadmill walking program by days 12-14 prescribed by modified treadmill ramp protocol\textsuperscript{21,24}
   iii. Cycling, which may begin by postoperative week 3, should begin with 50 watts and increased by 25 watts as tolerated by patient\textsuperscript{21}
   iv. Exercise should be progressed by 5 minutes each week for a total of 50 minutes of exercise 4-5 times per week by postoperative week 6\textsuperscript{21}

14. Balance: Note alterations in balance when on battery power or when pushing a portable driver

15. Positioning: Including drive lines and abdominal binder\textsuperscript{19}

16. Skin Integrity: Including VAD drive lines\textsuperscript{19}

17. Cognitive-Perceptual and Psychological Considerations: If the patient has undergone elective VAD placement, a pre-operative cognitive evaluation is often completed by the occupational therapist, and can be helpful in post-operative management and education\textsuperscript{25}
   a. The psychological implications of VAD placement: note the patient’s ability to cope with body image changes, altered functional status, fear or anxiety regarding the mechanical device, fear of upcoming transplant, fear or anxiety around retuning to previous life roles, and end of life issues.
   b. Consider the patient’s goals and motivators, the patient’s learning style and preferred method of information delivery. There are many forms of VAD education including videos, books, one-on-one conversation with the VAD Nurse practitioner and hands-on practice with supervision from the nurse or nurse practitioner.
   c. Family stress, major depression, organic mental syndromes and serious adjustment disorders occur more frequently in patients with medical complications and significantly impairs rehabilitation. Aggressive treatment of depression in the VAD patient may improve functional status\textsuperscript{3}

Assessment:

The primary goal for inpatient physical therapy for a patient status post VAD placement is to maximize the patient’s functional independence and safety prior to discharge from the hospital. If discharge home is not feasible, the goal of inpatient physical therapy intervention is to maximize their independence and endurance while on VAD at Brigham and Women’s Hospital prior to discharge to discharge to a local extended care facility specifically trained to care for patients with VADs. Brigham and Women’s Hospital has partnered with Youville Hospital and Rehabilitation Center to provide continued rehabilitative services after discharge from the acute care setting.

Body Changes

Potential body structure changes include, but are not limited to: median sternotomy, integumentary incisions, and cardiovascular and pulmonary system deconditioning. Potential body function changes may include, but are not limited to, cardiac and pulmonary pumps, aerobic capacity/activity tolerance, muscle performance, balance, and knowledge related to incisional precautions as well as knowledge regarding the operations of the VAD, and recommendations regarding mobilizing and exercising with the new VAD.
**Prognosis**

The predicted optimal level of improvement for these patients is to return to their home environment demonstrating independence in all areas of function including gait with the VAD, with assistive devices as needed, and independence with management of their VAD device at rest and during daily activities and exercise. Patients should be able to return to their previous roles & lifestyles, although some modifications will likely be necessary because of the VAD. It is reasonable to expect patients to be at their maximum level of independence within 6-8 weeks of VAD placement. This prognosis may be altered in the event of any comorbidities, complications or secondary impairments. Environmental factors such as home set up, and psychosocial consideration such as their available support network will also impact home management of the VAD, and may alter functional capacity and participation. At Brigham and Women’s Hospital the post-VAD median length of stay was 20 days in 2008. A recent study published in Germany reported data on over 1000 VAD patients who received 15 different devices\(^1\). Researchers reported that 114 patients were discharged home and patients were able to spend a mean of 301 days at home with a readmission rate of 3.1% which is similar to other centers\(^1,2\). Fifty-six percent of the hospital re-admissions in Potapov’s study were unrelated to the VAD, 20.9% were for wound infections, 10.9% for coagulation disorders and 7.7% were for cerebral embolism\(^1\).

**Unique considerations in this population:**

The ages of VAD recipients are varied at Brigham and Women’s Hospital, and have on occasion included adolescent patients. A local pediatric teaching hospital, Children’s Hospital Boston, has a limited VAD program. When the adolescent patient is of adult body size (determined by body surface area (BSA)) their care may be transferred to Brigham and Women’s Hospital. There is no specific age limitation for VAD implantation; rather specific devices may have BSA limitations. Adolescent patients require special considerations. Their family is typically closely involved in their care, and PT treatment will include educating the family as well as the patient.

Peripartum cardiomyopathy (PPCM) is defined as the development of cardiac failure in the last month of pregnancy or in the first five months after delivery. Patients must also meet the criteria of having no identifiable cause for the heart failure, the absence of heart disease prior to the last month of the pregnancy and LV systolic dysfunction with a left ventricular ejection fraction of less than 45%. PPCM is present in 1 in 15,000 deliveries in the United States. Inflammatory cytokines may play a role in the progression of the cardiomyopathy but no distinct etiology has been discovered. Researchers do know that tumor necrosis factor and interleukin-6 are both elevated in patients with PPCM and an apoptosis signaling receptor and C-reactive protein are both associated with more severe disease. There is a varying opinion on whether or not myocarditis is associated with PPCM. There are several identified risk factors which include: age greater than 30 years, multiparity, African descent, history of preeclampsia, eclampsia or postpartum hypertension, and maternal cocaine abuse. Most commonly, patients present with dyspnea, cough, orthopnea and hemoptysis. Nonspecific complaints of chest discomfort, abdominal pain and fatigue are also common, but can be mistaken for normal postpartum symptoms. If PPCM is suspected, the patient may undergo the following tests\(^2\):
• ECG which may show sinus tachycardia, nonspecific ST and T wave changes, and prolonged PR and QRS intervals
• Echocardiography may show global reduction in contractility and LV enlargement without hypertrophy
• Chest X-ray may show enlargement of the cardiac silhouette and pulmonary venous congestion.
• Endomyocardial biopsy may show myofiber hypertrophy

The treatment for PPCM is similar to the treatment of patients with heart failure of other causes. The main goals are to optimize hemodynamic status and relieve symptoms. These patients may require anticoagulation and arrhythmia treatment as well. Special considerations in this population include avoiding angiotensin inhibitors due to the high risk of adverse fetal effects, and avoiding diuretics in the pregnant woman due to the risk of bleeding and hyponatremia. Digoxin, hydralazine and beta blockers are all considered to be safe alternative medications during pregnancy. Implantation of a ventricular assist device may be necessary to support heart function during PPCM, and patients with PPCM may eventually require cardiac transplantation, depending on the degree of myocardial recovery.

Considerations related to the prognosis of a patient with PPCM include maternal, neonatal, and obstetrical outcomes. Subsequent pregnancy should be carefully considered, as the risk of increased heart failure has been shown to occur in 53% of women. Recent studies have shown a cardiac transplantation rate of 4-7% and a mortality rate of 6-10% as a result of PPCM. Higher New York Heart Association classification, being of African American descent, and multiparity are all indicative of higher mortality in PPCM. Recovery can occur, and left ventricular ejection fraction has been shown to increase from a mean of 28% at diagnosis to 46% in 2 years. Also, the degree of recovery was greatest in patients with an LV EF baseline of greater than 30%. Two to three percent of patients require an implantable cardioverter-defibrillator or a permanent pacemaker.

Goals
Potential goals for safe discharge home:

Body Structure/Function:
The patient will demonstrate range of motion within functional limits in bilateral upper extremities and lower extremities.
The patient will demonstrate upper extremity strength of 3/5 or greater

Activity:
The patient will be independent in all functional mobility including bed mobility, transfers, ambulation and stair training with their VAD
The patient will be independent in all VAD management and monitoring during functional activities
Participation:
The patient will be independent in all VAD management and monitoring during an independent exercise program
The patient will utilize VAD support group for support with community reintegration

Treatment Planning / Interventions

Established Pathway
___ Yes, see attached.  _X_ No

Established Protocol
___ Yes, see attached.  _X_ No

Interventions most commonly used for this case type/diagnosis.
This section is intended to capture the most commonly used interventions for this case type/diagnosis. It is not intended to be either inclusive or exclusive of appropriate interventions.

Physical Therapy is typically consulted to see the VAD patient immediately post-operatively. It is the therapist’s responsibility to assess each patient’s appropriateness for beginning a PT program. Patients who have undergone VAD placement are typically seen for the following interventions:

Therapeutic Exercises: Physical Therapy with a VAD patient often begins in the ICU with passive or active assisted ROM exercises, advancing to active ROM exercises as the patient’s strength improves. Exercises typically progress from supine, to sitting, to standing. Patients are issued a Phase One Cardiac Rehab Exercise program which includes a daily walking and therapeutic exercise program.

Endurance Training: Systemic cardiac output has been shown to increase because the left ventricle is able to eject blood through the native aortic valve and increase blood output in parallel with the VAD. Endurance training is accomplished by gradually increasing the time patients are able to participate in an activity. This is usually addressed initially through the progression of functional activities, gradually increasing the time the patient is out of bed to a chair or the distance a patient is walking. Stationary biking is also an option; however the position of the VAD may interfere with the ability to perform full hip flexion to allow for comfortable pedaling. Use of a restorator may be more practical in the VAD patient. Interval training is often utilized with exercises, functional activities or ambulation to increase endurance.

Functional Mobility Training: Patients are progressed from bed mobility, to sit to stand and bed to chair transfers, to ambulation weaning assistive devices as appropriate, and finally to steps/stairs.

Ventricular Assist Device Management: During the course of physical therapy interventions, the patient and therapist should focus on increasing the patient’s independence with the mechanical features of the VAD. The patient should progress to efficiently changing from AC to battery power, performing system checks, packing their “emergency” bag for ambulation and monitoring VAD hemodynamic response to activity. The patient may have to learn special techniques for maneuvering the VAD on the stairs and monitoring their exercise tolerance when...
conventional techniques do not apply. The patient will review hand pumping techniques with the nurse or nurse practitioner and should be proficient in these techniques with appropriate clinical documentation before being encouraged to ambulate independently by the therapy staff.

**Frequency & Duration:**

Frequency may vary during the patient’s hospital course. Initial treatment in the ICU is often 3-5x/wk with frequency progressing to 5-7x/wk as discharge approaches. If the patient remains at BWH until transplant, their frequency of treatment may lessen as they achieve their PT goals. They may be discharged from acute PT services and perform an independent program daily, with supervision as needed from the nursing staff or their family while they remain at BWH.

**Patient / family education**

- Instruct patient in appropriate pacing techniques
- Patients should be taught to understand their own VAD numbers at rest, and how they should respond to daily activities, self care and exercise
- In conjunction with the VAD team, review with the patient how to check their battery life prior to mobilization
- In conjunction with the VAD team, review emergency equipment and procedures
- Review equipment that should be carried with them during ambulation or time out of their room
- Instruct patient in independent therapeutic exercise program
- Instruct patient in home exercise/activity program including a therapeutic exercise program and a cardiopulmonary endurance program (walking, biking)
- VAD patients who experience abdominal discomfort related to the VAD may benefit from education regarding stretching, positioning, and bracing in the abdominal region

**Handouts**

*BWH Guidelines after Cardiac Surgery*
*BWH VAD Handbook (created by VAD Nurse Practitioners, supplemented by PT and OT)*

**Recommendations and referrals to other providers**

Treatment of the VAD patient is a multidisciplinary approach with a specialized group of cardiologists, cardiac surgeons, and nurse practitioners. Referrals to other disciplines at BWH often include:

**Occupational Therapy (OT):** OT is consulted pre-operatively to assess cognitive function and ability to learn in the case of elective VAD placement. Long term low cardiac output in the heart failure patient impacts end organ function through decreased blood flow. Studies have shown moderate to severe cognitive and neuromotor impairment in up to 60% of patients with heart failure. These patient show impairments in mental processing speed, memory, motor speed and grip strength. More pronounced levels of these impairments were noted in the patients who required mechanical assist devices.25 Hand weakness and dyseoordination may lead to difficulty in independent manipulation of VAD parts. This can often be identified and treated by an
occupational therapist prior to elective VAD surgery with an independent exercise program. OT is also consulted immediately post-operatively for all VAD patients to measure the patient for a custom made or prefabricated abdominal binder. A full OT evaluation is completed once the patient is medically stable to assess upper extremity motor skills and cognitive skills. In a recent study, VAD patients have reported difficulties performing self-care activities which OTs at Brigham and Women’s Hospital routinely assess during evaluation.

Social work: At BWH there is a specific social worker who specializes in the care of patients in the heart failure program. The social worker follows these patients during admissions for heart failure, admissions for VAD placement and any subsequent admissions, up to and including admissions around cardiac transplantation if applicable.

Chaplaincy and/or Psychiatry may need to be involved in the treatment of this patient population due to the severity of the patient’s illness, the effect on family dynamics, body image, life roles and potential end of life issues. Shapiro, et al noted that psychiatric problems most often occurred in patients who had complications following VAD placement, and that aggressive treatment of depression may help improve functional status.

Speech and Swallow Services: Speech and swallow therapy may be involved in patients who present with significant weakness related to preoperative heart failure, long intubations and bed rest. A bedside speech evaluation will be completed to determine appropriateness of a video swallow evaluation, prior to initiating food/liquid by mouth. Speech Therapy can also provide assistance with speech and language in the event of a perioperative CVA.

Care Coordination: The cardiac surgery care coordinators aid in setting up home care services when the VAD patient nears discharge home. Generally home nursing services are needed for dressing changes. The care coordinators can also set up transfer to Youville Hospital and Rehabilitation Center if indicated.

VAD Support Group: Support group meets twice a month. Patients generally come to the BWH VAD clinic and meet with their doctors and nurses in the morning, followed by support group in the early afternoon. The social worker runs the support group, and the VAD Nurse Practitioners are generally present. Many current VAD patients, and occasionally some heart transplant patients who have had VADs in the past, are involved in the support group. The group is open to all current VAD patients, whether inpatient or outpatient, and their families. Often times a patient may still be in the ICU, but the family members are able to begin participating in support group. All inpatients are encouraged by the VAD team to attend when hemodynamically stable. Rehab therapists schedule treatment sessions around the meeting of support group, as attending support group is considered a vital part of the VAD program and the patients overall recovery process. Supportive care by social workers and mentoring by prior VAD patients in a support group has been suggested as a way to improve quality of life in the weeks following VAD implantation.
VAD and Cardiac Transplant Rounds: A multidisciplinary group of providers meet daily to discuss the patients who are currently admitted to the hospital with a VAD or status post cardiac transplantation. The goal of multidisciplinary rounds is to discuss the patient’s current status and the treatment plan. This allows for team communication and consistency among all healthcare providers. Rounds are generally attended by the cardiology fellow, cardiac surgery fellow or physician assistant, nurse practitioners, nurse educator, nurse, physical therapist, occupational therapist, social worker, care coordinator, and nutritionist. Speech Therapy and Chaplaincy are involved as needed.

Re-evaluation

Reassessment will occur every 7-10 days following initial evaluation or most recent assessment, but may also occur due to any of the following circumstances: all physical therapy goals are met, there is a significant change in the patient’s medical status, the patient is discharged from acute PT services, or the patient is discharged from Brigham and Women’s Hospital.

Discharge Planning

Discharge planning for the VAD patient is a multidisciplinary approach. The patient going home with a new VAD has to demonstrate knowledge of handling the VAD on a daily basis and in emergency situations to the Nurse Practitioners. Their family members/caregivers must also be able to demonstrate these procedures before the patient can safely be discharged from BWH. The nurse practitioners provide education regarding operation of the VAD, troubleshooting alarms, exit site wound care and post discharge follow up care. Community support for medical or power failure emergencies is necessary when a VAD patient goes home. The patient’s local fire departments, emergency medical technicians (EMTs), and emergency room physicians are trained in emergency procedures of the VAD by the Nurse Practitioners. The local power company is also alerted to the need for early return of power in the case of power loss. VAD patients’ perceptions of being unable to care for themselves after surgery may be alleviated with educational programs as mentioned above 33,34.

The uncomplicated VAD recipient is discharged to home within weeks of VAD placement, however many times their hospital course may be extended due to complications. Upon discharge from BWH, most individuals do not require follow-up physical therapy. Patients have been instructed in their individualized home exercise program, including a cardiopulmonary endurance training program. They have also been instructed in the correct way to advance their own program, and will therefore be able to progress on their own. The VAD team is readily available to these patients if they have any questions. The services of home physical therapy can be available through our hospital’s home care company, Partners Home Care, if prior arrangements are made through the care coordinator.

In the event that a patient with a VAD is unable to be discharged home due to functional limitations and/or medical complexity, Brigham and Women’s Hospital has a working relationship with Youville Hospital and Rehabilitation Center in Cambridge, Massachusetts. Youville Hospital has taken patients with certain VADs in the recent past. This is reserved for those patients with extended length of stay and medical complications. It should be discussed as
early as possible with the healthcare team should the need for a rehab stay be anticipated. In the case of discharge to Youville Hospital, the Nurse Practitioners on the VAD service coordinate staff education at the receiving hospital, and the Cardiac Surgery Care Coordinator facilitates discharge arrangements. Complex VAD discharge situations should be discussed with a mentor therapist and the VAD nurse practitioners.

**Patient’s discharge instructions**

Patients are discharged from physical therapy services when they have met all short term goals for safe discharge home. Patients often require assistance from their families or caretakers with VAD management on stairs, and physical therapy goals should take this into consideration. A family teaching session prior to discharge from physical therapy services is generally warranted for patient and family safety. VAD patients must also demonstrate competence in monitoring the VAD during exercise and demonstrate appropriate modifications of their exercise program based on their response to exercise. The patient should be independent in a daily exercise and walking program.

Patients and their families are discharged home after extensive teaching with the VAD team. The Nurse Practitioners will complete the majority of discharge teaching, and the nursing staff will reinforce the teaching on a daily basis. Some discharge teaching may be done with the Physical Therapist, but great care should be taken to ensure accuracy and consistency of information. The patient will receive a VAD Log Book prior to discharge home. This is provided by the Nurse Practitioner. Each Log Book is device specific and includes emergency contact information, a troubleshooting guide, the device manual, flow sheets for tracking VAD numbers, a medication flow sheet, flow sheets for tracking weight, blood pressure and temperature, and wound care information. Information from other disciplines (i.e. Physical Therapy, Occupational Therapy and Nutrition) will be included as needed. The log book also includes a discharge checklist which should be completed by the nurse practitioner prior to discharge to ensure that all necessary information is covered. Physical Therapy should provide any necessary exercise and sternal precaution handouts and their pertinent contact information.

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Indications for use

- Biventricular failure
- Lethal arrhythmias
- Bridge to transplant
- Small body habitus – less than 1.5m² body surface area
- Mechanical Aortic Valve
The Pumps

- Two versions
  - Paracorpeal VAD (PVAD®) Fig. 1
    
    ![Fig. 1 Thoratec PVAD®](image)
    
    Reprinted with permission from Thoratec Corporation
  
  - Intracorpeal VAD (IVAD®) Fig. 2
    
    ![Fig. 2 Thoratec IVAD®](image)
    
    Reprinted with permission from Thoratec Corporation
Both versions provide
- A prosthetic ventricle with smooth chamber enclosed in a hard case
- Two mechanical valves maintain unidirectional flow
- The pumping chamber is separated from an air chamber by a polyurethane diaphragm
- The fill switch determines when the VAD is full of blood and sends the fill signal to the drive console

Support & Cannulation
- Can provide left, right or biventricular support (See Figure 3)
- In left heart support the inflow cannula connects the left atrium or the left ventricle to the pump, and the outflow cannula connects the pump to the aorta
- In right heart support the inflow cannula connects the right atrium to the pump, and the outflow cannula connects the pump to the pulmonary artery

With atrial cannulation there is minimal myocardial damage and cardiopulmonary bypass is not necessary, but lower VAD flow are achieved
With ventricular cannulation there are higher VAD flows and lower risk of thromboembolism

Fig. 3 Examples of Cannulation
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Dual Driver Console (DDC) (Figure 4)

- Contains two identical, independent drivers
- Labeled LVAD and RVAD
- Mode is “asynchronous” or “volume”
  - “Asynchronous” mode allows a set rate
  - “Volume” mode allows VAD to empty only when completely filled with blood
- % systole is the ejection time (in milliseconds) the VAD takes to eject the blood (i.e. 300 milliseconds)
- Drive Pressure: Ejects blood from the VAD
  - LVAD 230-345mmHg
  - RVAD 140-160mmHg
- Vacuum: Assists with VAD filling, generally -25 to -40 mmHg

Fig. 4 Dual Driver Console
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Standard of Care: Ventricular Assist Device
DDC Alarms

- **Pressure Alarm**
  - Occurs when ejection pressure is below 100mmHg or above 250 mmHg
  - If alarm sounds during PT treatment, notify VAD team

- **Vacuum Alarm**
  - Occurs when vacuum is less than +4 mmHg or greater than -90mmHg
  - If alarm sounds during PT treatment, notify VAD team

- **SYNCH Alarm**
  - When alarm occurs, -E- is displayed on dual drive console instead of the VAD output
  - VAD rate drops to the back-up rate
  - **Potential Causes**
    - Poor VAD filling (hypovolemia, RV failure, tamponade, vacuum too low, cannula or pneumatic hose kinked)
    - Rate set too high
    - Drive pressure <100mmHg
    - Ejection time <250msec
    - % systole too high, resulting in too short filling time
    - Fill cable (grey) malfunction or disconnection
    - Fill switch or module failure
  - When the outflow cannula is in the right atria, -E- may occur with standing as gravity sends blood to the right ventricle rather than through the right atria to the VAD
  - VAD team should be notified of alarms during PT and mobility

- **Low Battery Alarm**
  - Battery life is about 40 minutes
  - Charge indicated by the 5 lights on the front of the console
  - Alarms when batteries have less than 30 minutes of power
  - Intermittent alarm, beeps once per second when unplugged
  - Red light alarms when less than 5 minutes of battery life remains
  - DDC requires 24 hours to fully recharge the battery
TLC II® Portable Driver (Fig. 5)

- Small, portable, lightweight (9.8kg)
- Uses Lithium Ion (Li-Ion) Rechargeable Batteries
  - 80 minutes of power per battery when used in BIVAD®
  - 120 minutes of power per battery when used as left or right VAD
  - Batteries have 5 green lights indicating amount of charge left
  - Battery status is continually monitored
  - When either battery is depleted the TLC II control panel will display “CHANGE BATTERY A” or “CHANGE BATTERY B” with an >>> arrow
  - An audible alarm occurs in 30 second interval if only one battery source is available
  - A continuous alarm occurs when there are 10 minutes or less of battery life remaining and the control panel will display “< 10 MINUTES LEFT”
  - Battery Charger can fully recharge batteries in 2 hours
- Use of the TLC II® requires a drive pressure setting of less than 170 mmHg on the RVAD. Medication adjustments by the medical team may be necessary to achieve this.

Fig. 5 TLC II® Portable Driver
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Modes of Operation on TLC II®

- **Fixed mode** sets the ejection frequency at a fixed rate
  - Asynchronous from the native heart rate
  - Used for initializing settings after surgery
  - Used for weaning from the device if explantation may be possible

- **Volume mode** sets ejection frequency by filling of the blood chamber
  - Rate automatically responds to the changes in physiologic conditions
  - Once the pump fills completely, the fill switch signals to the drive console to eject the blood
  - As preload (atrial pressure) increases, the pump fills faster and the rate of output increases
  - As preload decreases, the pump fills more slowly, and the rate decreases

**Flash Test (Figure 6)**

- This is only way to determine if the pump is emptying completely with each beat
- In a patient with a PVAD®, the pump is lifted slightly, flashlight is shined through the pump, and should illuminate a “flash” on the surface below

![Fig. 6 Flash Test](image)

Photo courtesy of Catherine Saniuk RN, MS, CCRN
Brigham and Women’s Hospital
IVAD® Flash Test (Figure 7)

- In a patient with an IVAD®, emptying is verified by a flashing green fill light on the signal indicator

Hand Pumping
- In the event of pump failure and the pump stops
- Assess the patient
- Connect drive lines to hand bulbs (blue)
- Squeeze bulbs manually at approximately 60 bpm
- In the case of biventricular support, always empty (squeeze) LVAD first to avoid pulmonary hypertension
- Never pump the RVAD faster than the LVAD

Fig. 7 Thoratec PVAD® Signal Indicator
Reprinted with permission from Thoratec Corporation
Binder (Figure 8)

- Fit by OT as soon as medically stable
- Wedges provided to keep warm pump off patient’s skin, avoid kinking of drive lines

![Fig. 8 Thoratec PVAD® Binder with Wedges](Image)

Photo courtesy of Catherine Saniuk RN, MS, CCRN
Brigham and Women’s Hospital

Anticoagulation

- Heparin dosage with goal to maintain PTT 75-80
- Warfarin dosage with goal to maintain INR 2.5-3.5
- May need Plavix if platelet count greater than 300,000

Rehab Considerations:

- When leaving the room with the TLC II®, the patient should carry an extra battery and one or two hand pumps for uni- or bi-ventricular support respectively
- A balance assessment should be completed prior to initiation of ambulation pushing the portable TLC II® driver due to the unstable nature of the TLC II® driver
- The patient should be instructed on how to monitor VAD rates and flows during activity
Indications for use
- End stage CHF with failing medical therapy
- Heart transplantation candidate
- Approved by the FDA for “destination therapy” in patients with Class III-IV heart failure with EF <25%

Patient Selection Considerations
- Body Surface Area >1.5cm²
- Adequate right heart function
- Psychosocial and physical abilities
- Co-morbidities (Diabetes Mellitus, HIT positive etc.)
- Prior cardiac surgery or sternotomy
- Contraindications include irreversible pulmonary hypertension, right heart failure and mechanical aortic valve
The Pump
- Pulsatile pump with one blood and one air chamber
- Implanted in the left upper quadrant of the abdomen
- The inflow cannula connects the apex of the left ventricle to the blood chamber
- The outflow cannula connects the blood chamber to the ascending aorta
- The membrane between the two chambers is a flexible polyurethane diaphragm which reduces the need for anticoagulation as the body lays down a pseudo-endothelium
- The pump holds 83 ml of blood and pumps up to 10L per minute
- The maximum pump rate is 120 bpm
- The pump weighs about 5 pounds
- The motor requires electricity or manual (pneumatic) compression
- The pump fills passively

The Modes
- Fixed
  - The rate is set 50-120 bpm and the pump ejects at that rate
  - The pump may not fill completely
  - Stroke volume and flow will fluctuate with demand
- Auto
  - The pump ejects when filled with about 80 ml of blood
  - The rate will fluctuate with demand
The System Controller (Figure 2)

- Delivers power to the pump
- Controls the operating modes (fixed vs. auto)
- Computes rate, flow and stroke volume
- Provides visual and audio alarms
- Two operating buttons
  - Mode Button: changes from fixed (one beep) to auto (two beeps) and completes system check
  - Alarm Silence: silences alarms for 24 hours during yellow wrench alarm, provides a battery fuel gauge when on battery power. Red heart alarm cannot be silenced.

Power Based Unit (PBU) (Figure 3)

- Provides AC power to the LVAD when connected by the 20' PBU cable
- Color coded connections (white and black)
- Tests and charges up to six batteries in eight hours
- Indicates battery charge status
- Interfaces with the display module
- The display module provides pump rate, flow and stroke volume
- The patient should be on the PBU any time they are sleeping

Standard of Care: Ventricular Assist Device
Batteries (Figure 4)

- Two 12 volt batteries provide 4-6 hours of power
- Battery clips are required to connect to the system controller
- Fuel Gauge
  - 4 green lights = 75-100% power
  - 3 green lights = 50-75% power
  - 2 green lights = 25-50% power
  - 1 green light = <25% power (replace batteries one at a time)
- Yellow Battery Alarm occurs when less than 15 minutes of power remains
- Red Battery Alarm (CRITICAL)
  - Less than 5 minutes of power remains
  - Pump will default to power saver mode and a fixed rate of 50 bpm
  - Device will stop working if no other power source is attached

Fig. 4 Batteries and Battery Clips
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Alarms

- **Yellow Wrench Alarm**
  - Beeps once per second
  - Potential causes
    - Power cable/battery disconnect
    - Controller malfunction
    - Power limit advisory
    - Rate control fault
  - Troubleshooting
    - Check all connections
    - Change vent filter
    - Replace system controller
    - Replace PBU cable or PBU
    - Call the VAD team

- **Red Heart CRITICAL**
  - Continuous alarm
  - Potential causes
    - Low beat rate (<35bpm)
    - Low flow (<1.5 L/min)
    - Low stroke volume (<25ml)
    - Pump is not functioning
  - Troubleshooting
    - Check all connections
    - Remove vent filter
    - Disconnect power and initiate hand pumping
    - Seek immediate help
Hand Pumping (Figure 5)

- Used in the event of red heart alarm when the device stops pumping
- Remove the vent filter
- Disconnect the controller from power
- Disconnect controller from patient (alarms stop)
- Connect the hand pump to the vent pump
- Depress and hold the white purge valve
- Collapse and hold the black bulb
- Release the white purge valve
- Release the bulb
- Count to 10 and depress the white purge valve again to allow bulb to inflate
- Swing handles around bulb to depress bulb
- Fully compress and release the bulb at 60-90 bpm
- If the hand pump does not seem to be moving the pump and the patient is unresponsive, do CPR

**HEARTMATE HAND PUMPING**

Remove the air filter. Disconnect the System Controller from power source (both cables). Attach the hand pump into the vent port (the system controller will emit a steady audible tone unless the controller is disconnected from the patient)

1) PRESS and HOLD the WHITE BUTTON
2) PRESS (collapse) and HOLD the BLACK BULB
3) RELEASE the WHITE BUTTON
4) RELEASE the BLACK BULB (it will stay collapsed)
5) Count to 10 and PRESS WHITE BUTTON AGAIN (this re-expands the bulb)
6) Begin pumping using the handles at 60-90 times per minute.
   Assure bulb fills – press white button again if bulb is collapsed

Fig. 5 Hand Pumping Room Sign
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Pneumatic Console:
- Used in the event of device failure
- The patient must stay in the hospital
- The battery life is 45 minutes and the device requires 24 hours to fully recharge
- Has a stroke volume limiter which must be vented by nursing every 4 hours

Changing from PBU to Battery Power
1. Ensure that the connections between the LVAD lead and the controller are intact
2. Connect the batteries to the right and left battery clips until the battery clicks into place (align arrows)
3. Disconnect **white** controller cable from power based unit and connect to battery and clip (figures 6 and 7)
4. Ensure connections are “hand tight”
5. Disconnect **black** controller cable from power based unit and connect to battery and clip
6. Ensure connections are “hand tight”
7. Never disconnect both cables at the same time. The pump will STOP!
8. Repeat procedure when returning to power based unit

---

Fig. 6 HeartMate XVE® White Controller Cables Disconnected

Photo courtesy of Catherine Saniuk RN, MS, CCRN Brigham and Women’s Hospital

Fig. 7 HeartMate XVE® White Controller Cable Connected to Battery Clip

Photo courtesy of Catherine Saniuk RN, MS, CCRN Brigham and Women’s Hospital
Anticoagulation
- Does not require systemic anticoagulation due to pseudo-endothelium
- Aspirin a day (81mg)

Daily Routines
- System self test every morning
- Exit site wound care performed daily by nursing
- Custom abdominal binder (made by OT) or binder provided by Thoratec is worn at all times
- Physical and Occupational therapy
- Nutrition
- Discharge teaching with Nurse Practitioners

Rehab Considerations

- Ambulation Checklist
  - Fresh batteries are inserted prior to ambulation
  - The patient carries a travel bag with emergency equipment (any time the patient leaves their hospital room)
    - Hand pump
    - Spare controller
    - Vent filters
    - Spare controller battery
    - Spare LVAD batteries
  - The battery fuel gauge should be checked periodically on the controller

- Response to Exercise
  - Flow increase of up to 2.0 liters per minute
  - Rate increase of up to 20 bpm
  - Stroke Volume should remain between 78 and 83 ml
  - Systolic BP may elevate up to 20 mmHg
  - Watch native heart function on the telemetry and note any increase in ectopy
  - Oxygen saturation monitoring
  - The patient should be instructed to monitor his or her own radial or carotid pulse during exercise which reflects pump rate
Clinical Trial
- Multicenter clinical evaluation of the HeartMate® II axial flow device for advance stage heart failure patients
- 2 study arms (bridge to transplant, destination therapy)
- Goal is for discharge home
- Must have BSA >1.5m²
The Pump (Figure 2)
- Valveless
- Preload and afterload sensitive
- Follows native pulse
- Pump output varies over the cardiac cycle
- The pump weighs about 400 grams
- Flexible inflow cannula inserted in the LV apex
- Outflow graft connects to aorta via flexible “bend relief” tubing
- Inflow and outflow cannulae have textured, thrombo-resistant surfaces

![External View](image)

**Fig. 2** The HeartMate® II Pump
Reprinted with permission from Thoratec Corporation

The Rotor
- The only moving part
- Spins on blood-lubricated bearings
- Driven by integrated electric motor which is outside the pump
The Flow Path (Figure 3)
- Inflow comes from the left ventricle
- Inlet stator has 3 guide vanes shaped like airplane wings to “straighten” the blood before it enters the rotor
- The rotor propels blood forward and spins it radially
- When leaving, the flow is straightened by the outlet stator and pressure is increased

Flow Principles
- Flow is set by the speed of the rotor and the difference between the pressure in the ventricle and the aorta
- Even a severely depressed heart will have some residual contraction
- With increased speed the pump offloads the ventricle further
  - This will cause more LV contraction
- Any contraction of the heart creates a pressure pulse
- An increase in pressure at the pump inlet (LV) will cause an increase in flow at the outlet (aorta)
- As speed increases, flow will increase
- As the pressure gradient increases, flow will decrease
- A large difference in pressure gradient will cause low flow
- A small difference in pressure gradient will cause high flow

Fig. 3 The Flow Path
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Pulsatility Index (PI)

- A measure of the flow pulse through the pump
  - Ventricular contraction increases flow across the pump
- In normal cardiac physiology, when preload increases in the LV, the force of contraction increases as described in the Frank-Starling relationship. In heart failure, the myocardium is overloaded such that the myocardial sarcomeres are overstretched to the point that they produce a less forceful contraction. As the VAD unloads the ventricle of a heart in failure, the length tension relationship improves and subsequently the force of contraction increases and PI increases. As the VAD continues to further unload the ventricle, the length tension relationship becomes sub-optimal and the force of contraction decreases, along with the PI of the ventricle (Figure 4)
- Pump speed determines the amount of LV unloading and therefore the pulsatility of the ventricle (Figure 5)
  - As speed increases, the PI decreases, indicating more LV unloading
  - As speed decreases, the PI increases, indicating less LV unloading
  - Goal PI 4.0

Fig. 4 Pressure Flow Curve
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Pulsatility Index-speed ramp

Schematic of events as pump speed is steadily increased (failing heart)

Flow, PI

Pump Flow

LV Unloading

Fig. 5 Pulsatility Index-Speed Ramp
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Suction Event

- The system monitors sudden changes in pump flow pulsatility (PI event)
- The PI event (low flow) is detected, the speed of the pump automatically reduces to the low limit setting to avoid suction
- The pump will slowly return to the set speed
- May cause ectopic beats
- Potential causes:
  - Dehydration
  - Pump speed too high
Typical Hemodynamics

- Fixed Speed = 6,000-15,000 rpm
- The flow estimator provides an estimate of pump flow, generally 3.0-6.0 L/min; flow should not be used to monitor the patient’s status
- Power in watts
- Pulsatility Index generally 3.0 to 6.0 with goal of 4.0
- Blood Pressure will usually not be pulsatile enough to detect with direct auscultation or with an automatic sphygmomanometer. The clinician must use a manual sphygmomanometer with a doppler to obtain a SBP
- SBP should generally be 100-120 mmHg
- MAP should be maintained less than 90
- CVP generally should be between 12-15
- Generally no O2 Saturation can be detected as blood flow is not pulsatile
System Controller (see Figure 6)
- Controls pump speed and power
- Monitors and interprets data and responds to system performance
- Hazard and advisory alarms
- Fully redundant back-up system
- Automatic event recording
- Has a percutaneous lead connection which should be inserted all the way into the controller
- Latch guard should be in place to protect against accidental disconnect of percutaneous cable from system controller (pump would stop)

Power Based Unit (PBU) (See Figure 6)
- Provides AC power to the LVAD when connected by the 20' PBU cable
- Color coded connections (white and black)
- Tests and charges up to six batteries in eight hours
- Indicates battery charge status
- Interfaces with the display module
- The display module provides speed (RPMs), flow (L/min), power (watts) and PI
- The patient should be on the PBU any time they are sleeping
- Provides 30 minutes of back up power

Batteries (see Figure 6)
- Two 12 volt batteries provide 3-5 hours of power (as a pair)
- Battery clips are required to connect to the system controller
- Fuel Gauge
  - 4 green lights = 75-100% power
  - 3 green lights = 50-75% power
  - 2 green lights = 25-50% power
  - 1 green light = <25% power (replace batteries one at a time)
- Battery Alarms
  - Less than 15 minutes of power remains, beeps once every 4 seconds
  - Less than 5 minutes of power remains, continuous tone, defaults to power saver mode and set speed of 8000 RPMs
Changing from PBU to Battery Power
1. Ensure that the connections between the LVAD lead and the controller are intact
2. Connect the batteries to the right and left battery clips until the battery clicks into place (align arrows)
3. Disconnect white controller cable from power based unit and connect to battery and clip (See Figures 7 and 8)
4. Ensure connections are “hand tight”
5. Disconnect black controller cable from power based unit and connect to battery and clip
6. Ensure connections are “hand tight”
7. Never disconnect both cables at the same time. The pump will STOP!
8. Repeat procedure when returning to power based unit

Fig. 7 HeartMate II® White Controller Cables Disconnected
Photo courtesy of Catherine Saniuk RN, MS, CCRN Brigham and Women’s Hospital

Fig. 8 HeartMate II® White Controller Cable Connected to Battery Clip
Photo courtesy of Catherine Saniuk RN, MS, CCRN Brigham and Women’s Hospital
Alarms
- Power Cable Disconnect
- System Controller Cell Low Voltage (low battery)
- Low Speed Alarm
- Replace System Controller
- Low Flow Alarm
- Red Heart Hazard Alarm
  - Red heart symbol on controller, continuous alarm
  - Potential Causes
    - Low flow
    - System controller disconnect

Special Situations
- In the case of backflow through the device, PT would note low flow or low speed alarm, likely due to dilated ventricle
- In the case of ventricular recovery, an increase in PI would be noted and, on ECHO, the aortic valve would open with every beat
- During exercise the PT should note an increase in PI due to increased venous return and increased ventricular contractility

Daily Routines
- System self-test every morning
- Exit site wound care completed daily by nursing
- Custom abdominal binder or binder provided by Thoratec is worn at all times
- Physical and Occupational therapy
- Nutrition
- Discharge teaching with Nurse Practitioners

Ambulation Checklist
- The patient carries a travel bag with emergency equipment (any time the patient leaves their hospital room)
  - Spare controller
  - Spare controller battery
  - Spare batteries
- Fresh batteries are inserted prior to ambulation and the battery fuel gauge should be checked periodically during ambulation, on the controller

Anticoagulation
- Warfarin and Aspirin 81mg for goal INR 2-3

Standard of Care: Ventricular Assist Device
Standard of Care: Ventricular Assist Device
Appendix D
Centrimag® (Figure 1)

CentriMag®
System Components

Pump  Motor  Console

Fig. 1 Reprinted with permission from Thoratec Corporation

Description
- Extracorporeal short term blood pump
- Magnetically levitated

System Components
- Polycarbonate pump with impeller spinning in the “contact-free” chamber
- Motor which applies both levitational and rotational magnetic force (bearing-less)
- Console

Consoles
- Primary console used at the bedside daily
- Backup console available to provide temporary life support should the primary console malfunction, this console does not have flow or pressure sensing capabilities, and the patient should be returned to a primary console as soon as possible.
- Has digital read out of speed (RPM) and flow (Liters per minute [LPM])
- Fuel gauge for battery lift
- 2 lines of text which indicate the “high flow” and “low flow” states

Standard of Care: Ventricular Assist Device

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Flow Probe (Figure 2)

- Ultrasonic flow probe
- Can detect flows from 0.9 to 9.9 LPM
- Clip on design
- Does not need calibrating
- Repositioned once per shift to avoid memory kink on the tubing
- Can detect retrograde flow of >40cc/min, displayed as “---” instead of LPM on console

![Flow Probe Image]

Fig. 2 Ultrasonic Flow Probe
Photo courtesy of Catherine Saniuk RN, MS, CCRN
Brigham and Women’s Hospital

Battery Life
- Primary Console has a one hour rechargeable battery, alerts when “ON BATTERY” and battery gauge indicates level of battery charge
- Backup Console is not rechargeable

Clot Check
- Performed by nursing every 4 hours by shining a flashlight on the pump, looking for clot (white specs or streaks) especially at the inflow cannula connection to the pump

Standard of Care: Ventricular Assist Device
Normal Ranges
- **Pump Speed**
  - Goal is for RPMs to maintain adequate blood flow without causing excessive emptying of the ventricle leading to “chugging”
  - If RPMs are increased, flow should also increase
  - Generally 2,500-3,500 RPMs
- **Flow**
  - Generally 3.0-6.0 LPM
  - Usually non-pulsatile
  - When it is pulsatile, trend pulse pressure (goal 10-15 mmHg)
- **MAP**
  - Trended in the ICU via arterial line
  - Goals is for MAP less than 90
- **Pump** is preload dependent therefore goal is for CVP 10-15

Alarms
- “ON BATTERY” Alarms once every 15 minutes until reconnected to AC power
- “LOW BATTERY” Alarms once every 10 minutes until reconnected to AC power
- “BATTERY BELOW MINIMUM” will appear with only 10 minutes of battery life remaining, and cannot be silenced until the battery is depleted or returned to AC power.
- “SYSTEM FAULT” the screen goes blank and alarm sounds continuously, CPR can be performed if unable to restart pump

Anticoagulation
- Heparin begun after surgery
- Goal PTT 60-80

“Chugging”
- Inflow cannula to the pump will begin to sway or move violently
- Minimum flow alarm will alarm, the pump is likely experiencing inadequate filling
- RN should decreased RPMs in 100 rpm increments until chugging ceases
- Team will assess volume status to determine if the patient is dehydrated, has RV failure, cardiac tamponade, etc.
  - “---” on the LPM screen
- Indicates retrograde flow of >40 ml/min
- If occurs during mobility with PT, the VAD team should be notified
Cardiac Assist TandemHeart® (Figure 1)

Overview and Indications for Use

- Extracorporeal temporary centrifugal ventricular assist device
- Provides rapid ventricular off-loading and increased systemic perfusion
- Can provide at least 4 liters per minute of flow at 7500 RPMs
- Can be placed percutaneously in the femoral vein and advanced to the right atria in the catheterization lab to provide right ventricular support in patients with a mechanical left ventricular assistive device in place
- Can be surgically secured in the operating room to make mobility possible

Contraindications for Use

- Left ventricular failure that is not supported with a ventricular assist device
- Severe peripheral vascular disease
System Components
- Polycarbonate pump with impeller spinning in the “contact-free” chamber
- Motor which applies both levitational and rotational magnetic force (bearing-less)
- System Controller
  - Contains an infusion system and 2 separate controllers
  - Contains a primary and a backup controller
  - Switchover from the primary to the backup controller occurs automatically and without any alert
  - Controller is kept plugged in at all times, except during transport or mobility

Flow Probe (Figure 2)
- Ultrasonic flow probe
- Can detect flows from 0.9 to 9.9 LPM
- Clip on design
- Does not need calibrating
- Repositioned once per shift to avoid memory kink on the tubing
- Can detect retrograde flow of >40 cc/min, displayed as “---” instead of LPM on console

Fig. 2 Ultrasonic Flow Probe

Photo courtesy of Catherine Saniuk RN, MS, CCRN
Brigham and Women’s Hospital
The Pump and Cannula (Figures 3 and 4)
- Inflow cannula transports blood from the patient into the center of the pump
- Outflow cannula transports blood out from the side of the pump to the patient
- Upper Housing Chamber: blood flows into the center of the upper housing chamber via the inflow cannula and is rotated by the impeller at the set speed and sent via the outflow cannula back to the patient’s circulation
- Lower Housing Chamber: includes the motor and the infusate solution, providing cooling and a local anti-coagulation effect

**Infusate System**
- Provides 10 ml/hour IV solution (normal saline, heparin or bivalirudin solution)
- Infused directly into the pump under pressure
- Goals is are to cool and lubricate the rotor

**Battery Life**
- System Controller has a 60 minute rechargeable battery, and alerts when “ON BATTERY”
- The battery gauge indicates level of battery charge
- The battery requires 4 hours to recharge

**Clot Check**
- Performed by nursing every 4 hours, by looking for clot (white specs or streaks) especially at the inflow cannula connection to the pump

Photos courtesy of Catherine Saniuk RN, MS, CCRN Brigham and Women’s Hospital

Standard of Care: Ventricular Assist Device

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Typical Hemodynamics

- **Pump Speed**
  - Goal is for RPMs to maintain adequate blood flow without causing excessive emptying of the ventricle leading to “chugging”
  - If RPMs are increased, flow should also increase
  - The pump is capable of generating speeds of 3,500-7,500 RPMs

- **Flow**
  - Detected via the flow probe and is generally a “real” flow
  - Generally 3.0-6.0 LPM

“Chugging”

- Inflow cannula to the pump will begin to sway or move violently
- Minimum flow alarm will alarm, the pump is likely experiencing inadequate filling
- RN should decrease RPMs in 100 rpm increments until chuffing ceases
- The VAD team should be notified
- The team will assess volume status, potential causes include
  - Dehydration
  - Right ventricular failure
  - Cardiac tamponade

Anticoagulation

- Heparin begun after surgery
- Goal PTT 60-80

Considerations

- The pumps should be kept visible at all times and should never be covered with bed linen
- The patient should logroll for all bed mobility and care
- Daily dressing changes are conducted by the nursing staff per VAD guidelines
- The pump should be secured with a binder or holster at all times
- The pump should not be touching the skin at any time due to the risk of burns
- Products with acetone (e.g. a permanent marker or nail polish remover) should not ever be used near the site due to the risk of cannula degradation.
Bibliography


**Standard of Care: Ventricular Assist Device**


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