

The 2013 International Society for Heart and Lung Transplantation Guidelines for Mechanical Circulatory Support: Executive Summary

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The field of mechanical circulatory support (MCS) has made tremendous progress in the past 15 years. Thousands of patients worldwide have undergone implantation of long-term MCS devices (MCSDs). Currently, management of patients with MCSDs has been guided by individual clinicians and center-specific protocols. There have been few randomized studies to guide patient selection and care of the MCS patient. Short-term success with MCS therapy largely depends on patient selection, surgical technique, and post-operative management. Long-term success depends on physician and patient engagement in excellent care of their device and personal health. The International Society for Heart and Lung Transplantation (ISHLT) has made a commitment to convene an international and multidisciplinary panel of experts in MCS care.

The document results from the work of 5 Task Force Groups:

- Task Force 1 addresses the important issue of patient selection for permanent pump implantation. This section covers (1) the referral of patients for MCSD implantation, (2) evaluation of patients considered for MCSD implantation, which includes clinical assessment of heart failure, heart failure etiology, anatomic considerations, (3) medical and psychosocial evaluation, and (4) assessment of operative risk. Relative vs absolute contraindications are discussed as well as ethical dilemmas associated with this topic.
- Task Force 2 discusses the mechanisms that are important for patient optimization prior to device implantation. This section covers (1) management of cardiac and non-cardiac risk factors, (2) optimizing patients with relative contraindications and (3) informed consent and ethical issues as a continuum from Task Force 1. MCS patients once consented are members of their care team before implantation. Recommendations for multidisciplinary care, education, and psychosocial support are found in this Task Force.
- Task Force 3 discusses the intraoperative considerations and immediate post-operative care in the intensive care

unit (ICU) setting. This section covers (1) anesthesia, (2) implantation techniques, (3) explantation techniques, (4) complex anatomic considerations, and (5) early post-operative management in the ICU.

- Task Force 4 addresses inpatient management during the post-operative phase, once the patient is out of the ICU through discharge, and during readmission to the hospital. This section covers (1) right ventricular (RV) and hemodynamic management, (2) anti-coagulation, (3) adjunct medical therapy, (4) driveline care, (5) psychosocial support and suitability for discharge to home, and (6) common reasons for hospital readmission and approaches to their management.
- Task Force 5 discusses the long-term outpatient care of the MCS patient using a multidisciplinary approach. This section covers (1) the outpatient management of device-related issues, (2) patient medical management and monitoring, (3) psychosocial long-term support, and (4) continued education of the patient and family.

It is important to note that every effort has been made to include as contributing writers cardiologists, cardiac surgeons, MCS coordinators, and other members of the multidisciplinary team. Because the guidelines are international, we also tried to balance perspective from different countries as best possible.

As the reader of these guidelines will observe, most of the recommendations are level of evidence C or consensus agreement. Gaps in evidence are highlighted where appropriate. Because MCS is an evolving field, device availability varies from center to center. We aim to address general issues of long-term use and not to focus on nuances of individual devices. Each manufacturer has recommendations for its specific device. There are also different indications for MCS, depending on patient urgency, and often, short-term MCS is emergently utilized. The focus of this document is long-term device therapy with the goal of patient discharge from the hospital. There is limited mention of short-term MCS support for acute shock patients in Task Force 1, 2, and 3. Lastly, we hope that these guidelines will

provide an impetus for organized dissemination of best practices from various centers with excellent outcomes into the literature to further the field of MCS.

Task Force 1: Selection of candidates for MCS and risk management prior to implantation for fixed comorbidities

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Topic 1: Patient selection

Recommendations for the evaluation process of MCS candidates:¹⁻⁷

Class I:

1. All patients should have any reversible causes of heart failure addressed prior to consideration for MCS.

Level of evidence: A.

2. All patients referred for MCS should have their transplant candidacy assessed prior to implant.

Level of evidence: A.

Recommendations for the clinical classification of MCS candidates:⁷

Class I:

1. All patients being considered for MCS should have their New York Heart Association functional class assessed.

Level of evidence: C.

2. All patients being assessed for MCS should have their Interagency Registry for Mechanically Assisted Support (INTERMACS) profile determined.

Level of evidence: C.

Recommendations for risk stratification for consideration of MCS:⁸⁻³⁰

Class IIa:

1. Long-term MCS for patients who are in acute cardiogenic shock should be reserved for the following:
 - a. Patients whose ventricular function is deemed unrecoverable or unlikely to recover without long-term device support.
 - b. Patients who are deemed too ill to maintain normal hemodynamics and vital organ function with temporary MCSs, or who cannot be weaned from temporary MCSs or inotropic support.
 - c. Patients with the capacity for meaningful recovery of end-organ function and quality of life.
 - d. Patients without irreversible end-organ damage.

Level of evidence: C.

2. Patients who are inotrope-dependent should be considered for MCS because they represent a group with high mortality with ongoing medical management.

Level of evidence: B.

3. Patients with end-stage systolic heart failure who do not fall into recommendations 1 and 2 above should undergo routine risk stratification at regular intervals to determine the need for and optimal timing of MCS. This determination may be aided by risk assessment calculators and cardiopulmonary stress testing.

Level of evidence: C.

4. Heart failure patients who are at high-risk for 1-year mortality using prognostic models should be referred for advanced therapy including heart transplant, or MCS (bridge to transplantation [BTT] or destination therapy [DT]) as appropriate.

Level of evidence: C.

Topic 2: Risk management of comorbidities

Recommendations for patients with coronary artery disease:^{31,32}

Class IIa:

1. Patients being considered for MCS who have a history of coronary artery bypass grafting should have a chest computed tomography (CT) scan to provide the location and course of the bypass grafts to guide the surgical approach.

Level of evidence: C.

Recommendations for patients with acute myocardial infarction:

Class IIb:

1. If possible, permanent MCS should be delayed in the setting of an acute infarct involving the left ventricular (LV) apex.

Level of evidence: C.

Recommendations for the evaluation of MCS candidates with congenital heart disease:

Class I:

1. All patients with congenital heart disease should have recent imaging to fully document cardiac morphology, assess for the presence of shunts or collateral vessels, and the location and course of their great vessels.

Level of evidence: C.

Class IIa:

1. Patients with complex congenital heart disease, atypical situs, or residual intraventricular shunts who are not candidates for LV support should be considered for a total artificial heart.

Level of evidence: C.

Recommendations for aortic valve disease:

Class I:

1. Functioning bioprosthetic valves do not require removal or replacement at the time of implant.

Level of evidence: C.

- Replacement of a pre-existing aortic mechanical valve with a bioprosthetic valve or oversewing the aortic valve at the time of implantation is recommended.

Level of evidence: C.

Recommendations for aortic regurgitation:

Class I:

- More than mild aortic insufficiency should prompt consideration for surgical intervention during device implantation.

Level of evidence: C

Recommendations for aortic stenosis:

Class I:

- Patients with aortic stenosis of any degree that is accompanied by more than mild aortic insufficiency should prompt consideration for a bioprosthetic aortic valve replacement during MCS implant (see Section 3).

Level of evidence: C.

Class IIb:

- Patients with severe aortic stenosis may be considered for aortic valve replacement, regardless of the degree of concomitant aortic insufficiency.

Level of evidence: C.

Recommendations for aortic root disease:

Class IIIa:

- Patients with a history of vascular disease and/or coronary artery disease should have a pre-operative assessment of their ascending aorta for aneurysmal dilation and atherosclerotic burden with a CT scan prior to implant.

Level of evidence: C.

Recommendations for mitral valve:

Class IIb:

- Severe mitral insufficiency is not a contraindication to MCS and does not routinely require surgical repair or valve replacement, unless there is expectation of ventricular recovery.

Level of evidence: C.

Class III:

- Routine mitral valve repair or replacement for severe mitral regurgitation is not recommended.

Level of evidence: C.

Recommendations for mitral valve stenosis:

Class I:

- Valve replacement with a tissue valve should be considered if there is moderate or worse mitral valve stenosis at the time of left ventricular assist device (LVAD) implantation.

Level of evidence: C

Recommendations for mechanical mitral valves:

Class III:

- Routine replacement of properly functioning mechanical mitral valve is not recommended.

Level of evidence: C.

Recommendations for tricuspid valve regurgitation:

Class IIa:

- Moderate or greater tricuspid regurgitation should prompt consideration of surgical repair at the time of implant.

Level of evidence: C.

Recommendations for infective endocarditis:

Class I:

- Device implantation in patients who have been bacteremic should have documented clearance of the bacteremia for at least 5 days on appropriate anti-microbial therapy. This anti-microbial therapy should include a total duration of at least 7 total days prior to MCS implantation.

Level of evidence: C.

Class III:

- Acute valvular infectious endocarditis with active bacteremia is an absolute contraindication to MCS implantation.

Level of evidence: C.

- Active infection of an implantable cardioverter defibrillator (ICD) or pacemaker with bacteremia is an absolute contraindication to MCS implantation.

Level of evidence: C.

Recommendations for intracardiac shunts:

Class I:

- Atrial septal defects and patent foramen ovale should be closed at the time of MCS implantation.

Level of evidence: C.

Class III:

- An LVAD alone in the setting of an unreparable ventricular septal defect or free wall rupture is not recommended.

Level of evidence: C.

Recommendations for intracardiac thrombus:

Class IIa:

- Echocardiography or CT, with contrast when necessary, should be used pre-operatively to screen for intracardiac thrombus.

Level of evidence: C.

Recommendations for atrial arrhythmias:**Class I:**

1. Atrial flutter or fibrillation is not a contraindication to MCS.

Level of evidence: C.

Class IIa:

1. Patients with medically refractory atrial tachyarrhythmias may benefit from ablation of the arrhythmia or atrioventricular node (with subsequent ICD/pacemaker placement) prior to LVAD implantation.

Level of evidence: C.

Recommendations for arrhythmia therapy:**Class IIa:**

1. Patients with treatment-refractory recurrent sustained ventricular tachycardia (VT) or ventricular fibrillation (VF) in the presence of untreatable arrhythmogenic pathologic substrate (eg, giant cell myocarditis, scar, sarcoidosis), should not be considered for LV support alone, but rather biventricular support or a total artificial heart.

Level of evidence: C.

Recommendations for peripheral vascular disease:^{33–35}**Class IIa:**

1. All patients with known atherosclerotic vascular disease or significant risk factors for its development should be screened for peripheral vascular disease prior to MCS.

Level of evidence: C.

Class IIb:

1. Peripheral vascular disease may be a relative contraindication to MCS based on its extent and severity.

Level of evidence: C.

Recommendations for life-limiting comorbidities and multiorgan failure:⁴**Class III:**

1. Consideration of MCS in the setting of irreversible multiorgan failure is not recommended.

Level of evidence: C.

Recommendations for pulmonary hypertension^{36–38}**Class I:**

1. All patients being considered for MCS should have an invasive hemodynamic assessment of pulmonary vascular resistance.

Level of evidence: C.

Recommendations for neurologic function:³⁹**Class I:**

1. A thorough neurologic examination should be performed on every patient being considered for MCS. Neurologic consultation should be obtained for patients with significant neurologic disease or dementia, or significant atherosclerotic vascular disease of their carotid or vertebral systems.

Level of evidence: C.

2. All patients being considered for MCS should have a carotid and vertebral Doppler examination as a screen for occult vascular disease.

Level of evidence: C.

3. CT scan or magnetic resonance imaging is warranted in patients with previous stroke to establish a pre-operative baseline study.

Level of evidence: C.

Class III:

1. MCS is not recommended in patients with neuromuscular disease that severely compromises their ability to use and care for external system components or to ambulate and exercise.

Level of evidence: C.

Recommendations for coagulation and hematologic disorders:^{40–44}**Class I:**

1. All patients evaluated for MCS therapy should have a prothrombin time/international normalized ratio (INR), partial thromboplastin time, and platelet assessed pre-operatively.

Level of evidence: C.

2. Baseline abnormalities in coagulation parameters not due to pharmacologic therapy should prompt an evaluation to determine the etiology prior to implant.

Level of evidence: C.

3. Patients with a history of thrombophilia prior to MCS should have a hypercoagulable assessment before implant.

Level of evidence: C.

Class IIa:

1. Patients with a clinical syndrome of heparin-induced thrombocytopenia should have confirmatory testing performed.

Level of evidence: C.

2. Thienopyridine anti-platelet agents should be stopped at least 5 days prior to surgery unless there is a compelling indication for continued use.

Level of evidence: C.

Recommendations for malignancy:**Class I:**

1. Patients with a history of a treated cancer who are in long-term remission or who are considered free of

disease may be candidates for MCS as BTT, with the involvement of an oncologist to determine risk of recurrence or progression.

Level of evidence: C.

Class IIa:

1. Patients with a history of recently treated or active cancer who have a reasonable life-expectancy (>2 years) may be candidates for DT if evaluated in conjunction with an oncologist to determine risk.

Level of evidence: C.

Class III:

1. MCS as BTT or DT is not recommended for patients with an active malignancy and a life expectancy of <2 years.

Level of evidence: C.

Recommendations for diabetes:⁴⁵⁻⁴⁷

Class I:

1. All patients should be screened for diabetes with a fasting glucose prior to MCS.

Level of evidence: C.

2. All patients with an abnormal fasting glucose or established diabetes should have a hemoglobin A_{1c} assessed and be evaluated for the degree of end-organ damage (retinopathy, neuropathy, nephropathy, and vascular disease).

Level of evidence: C.

3. Patients with poorly controlled diabetes should have a consultation with an endocrinologist prior to implantation.

Level of evidence: C.

Class IIb:

1. MCS is relatively contraindicated in the setting of diabetes-related proliferative retinopathy, very poor glycemic control, or severe nephropathy, vasculopathy, or peripheral neuropathy.

Level of evidence: C.

Recommendations for pregnancy:⁴⁸⁻⁵¹

Class I:

1. Use of contraception in women of childbearing age after MCS is recommended.

Level of evidence: C.

Class III:

1. MCS in the setting of active pregnancy is not recommended.

Level of evidence: C.

Recommendations for age:^{52,53}

Class IIb:

1. Patients aged > 60 years should undergo thorough evaluation for the presence of other clinical risk factors that may decrease survival or quality of life after MCS.

Level of evidence: C.

Recommendations for psychologic and psychiatric evaluation:⁵⁴⁻⁶¹

Class I:

1. All patients should have a screen for psychosocial risk factors prior to MCS.

Level of evidence: C.

2. All patients should have a screen for cognitive dysfunction prior to MCS.

Level of evidence: C.

3. Family, social, and emotional support must be assessed prior to MCS.

Level of evidence: C.

4. Patients with a history of a significant psychiatric illness who are considered for MCS should undergo a thorough psychiatric and psychologic evaluation to identify potential risk factors.

Level of evidence: C.

Class III:

1. MCS should not be performed in patients who are unable to physically operate their pump or respond to device alarms. In addition, an inability to report signs and symptoms of device malfunction or other health care needs to the MCS team, or patients who live in an unsafe environment are all contraindications to implantation.

Level of evidence: C.

2. MCS is not recommended in patients with active psychiatric illness that requires long-term institutionalization or who have the inability to care for or maintain their device.

Level of evidence: C.

Recommendations for adherence to medical therapy and social network:⁵⁹⁻⁶³

Class I:

1. Assessment of medical compliance, social support, and coping skills should be performed in all candidates for MCS device implantation.

Level of evidence: C.

Class IIa:

1. Lack of sufficient social support and limited coping skills are relative contraindications to MCS in patients with a history of non-adherent behavior.

Level of evidence: C.

Class III:

1. Poor compliance with medical regimens is a risk factor for poor outcomes related to MCS and death after heart

transplantation. Patients who demonstrate an inability to comply with medical recommendations on multiple occasions should not receive MCS.

Level of evidence: C.

Recommendations for tobacco use:

Class I:

1. Patients considered for MCS implantation should receive education on the importance of tobacco cessation and reduction in environmental and second-hand exposure before device implantation and throughout the duration of device support.

Level of evidence: C.

Class IIa:

1. Previous tobacco use should not preclude emergent pump implantation as a potential BTT. However, patients should not be made active on the transplant waiting list until 6 months of nicotine abstinence has been proven.

Level of evidence: C.

Recommendations for alcohol and substance abuse:⁶⁴

Class IIb:

1. The patient should be abstinent for a period of time as determined a priori by the program in order to be considered for MCS therapy.

Level of evidence: C.

Class III:

1. Active substance abusers (including alcohol) should not receive MCS therapy.

Level of evidence: C.

Recommendations for caregiver burden:^{65–68}

Class I:

1. Caregiver burden should be assessed prior to MCS implantation to assure that support will be available. Agreement on behalf of the patient is not sufficient.

Level of evidence: C.

Class IIb:

1. Significant caregiver burden or lack of any caregiver is a relative contraindication to the patient's MCS implantation.

Level of evidence: C.

Recommendation for the evaluation of patient's financial situation and insurance coverage:

Class IIa:

1. A mechanism must be in place to provide financial aid or support for post-operative care for those who have limitations to medical coverage. Depending on the

country, this may be provided by the government, an insurance agent, or an individual's family.

Level of evidence: C.

Task Force 2: Patient optimization, consent, and appropriate timing for MCS: Modifiable risk management prior to implantation

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Recommendations for obesity:^{2,69–73}

Class I:

1. Obesity (body mass index 30–35 kg/m²), in and of itself, is not a contraindication to MCS, but surgical risk and attendant comorbidities must be carefully considered prior to MCS in the morbidly obese patient (body mass index ≥ 35 kg/m²).

Level of evidence: B.

Recommendations for managing patient expectations:^{2,74,75}

Class I:

1. A detailed informed consent should discuss the salient aspects of the MCS placement, common expectations, and possible complications in the peri-operative and post-operative period.

Level of evidence: C.

Class IIb:

1. Quality of life should be assessed before and after MCS implantation to help guide patient decisions. Assessment tools, including Minnesota Living with Heart Failure questionnaire, Sickness Impact Profile, EuroQol, and others should be considered to help guide patient care.

Level of evidence: C.

Recommendations for palliative care:^{76,77}

Class IIa:

1. Palliative care consultation should be a component of the treatment of end-stage heart failure during the evaluation phase for MCS. In addition to symptom management, goals and preferences for end of life should be discussed with patients receiving MCS as DT.

Level of evidence: C.

Recommendations for managing renal function:^{78–88}

Class I:

1. All patients should have their renal function monitored closely prior to MCS implantation.

Level of evidence: C.

2. Patients with volume overload and/or poor output in the setting of renal dysfunction should have a period of hemodynamic optimization (with inotropic support if clinically indicated) combined with aggressive diuresis or mechanical volume removal.

Level of evidence: C.

3. Assessment of serum creatinine, blood urea nitrogen, and a 24-hour urine collection for creatinine clearance and proteinuria after patients are hemodynamically optimized should be performed in all patients being considered for MCS.

Level of evidence: C.

Class III:

1. Permanent dialysis should be a contraindication for destination therapy.

Level of evidence: C.

Recommendations for nutrition assessment:^{89,90}

Class I:

1. All patients should have assessment of their nutritional status prior to MCS implantation with at least a measurement of albumin and pre-albumin.

Level of evidence: B.

2. Patients who have indices of malnutrition prior to MCS implantation should have an evaluation by a nutritional consultation service.

Level of evidence: C.

Class IIa:

1. Patients who have evidence of malnutrition prior to MCS implantation should be considered for nutritional interventions prior to implantation if the patient's clinical status allows.

Level of evidence: C.

Class IIb:

1. Patients who have evidence of severe malnutrition prior to MCS implantation should consider having implantation delayed to maximize their nutritional status, if the patient's clinical status allows.

Level of evidence: C.

Recommendations for managing infection risk:⁹¹⁻⁹⁴

Class I:

1. All patients should have all unnecessary lines and catheters removed prior to MCS implantation.

Level of evidence: C.

2. All patients should have a dental assessment and any remedial treatment, if time and clinical status permits, prior to MCS implantation.

Level of evidence: C.

Recommendations for managing active infection:

Class I:

1. Patients with active infections should receive an appropriate course of antibiotic therapy, as directed by an infectious disease specialist, prior to MCS implantation.

Level of evidence: C.

Recommendations for antibiotic prophylaxis:⁹⁵⁻⁹⁷

Class I:

1. Patients should receive pre-operative antibiotics with broad-spectrum gram-positive and gram-negative coverage, as appropriate, prior to MCS implantation.

Level of evidence: C.

2. Routine antibiotic prophylaxis should include at least 1 dose prior to surgery administered within 60 minutes of the first incision, remain in the therapeutic range throughout the duration of their use, and not extend beyond 24 to 48 hours.

Level of evidence: C.

3. Patients should have a nasal swab to screen for methicillin-resistant *Staphylococcus aureus* and receive topical treatment if positive prior to MCS implantation.

Level of evidence: C.

Recommendations for hepatic dysfunction:^{3,40,85,86,98-102}

Class I:

1. Patients with a history of liver disease, abnormalities of liver function tests, chronic right heart failure, or Fontan physiology should have an ultrasound assessment of their liver to screen for cirrhosis prior to MCS implantation.

Level of evidence: C.

2. Patients who have suspected cirrhosis should receive further radiologic and tissue confirmation in conjunction with a hepatology consultation.

Level of evidence: C.

3. Patients with abnormal liver function and decompensated hemodynamics should receive aggressive therapy aimed at the restoration of hepatic blood flow and reduction of hepatic congestion.

Level of evidence: C.

Class II:

1. Patients with an elevated INR not due to warfarin therapy should be considered for treatment prior to MCS implantation, and efforts should be made to optimize nutrition and right-sided intracardiac filling pressures.

Level of evidence: C.

Class III:

1. Patients with confirmed cirrhosis or an increased Model for End Stage Liver Disease (MELD) score are poor candidates for MCS therapy.

Level of evidence: B.

Recommendations for pulmonary and thoracic assessment:^{103–117}

Class I:

1. Patients should have a chest X-ray and an arterial blood gas assessment prior to MCS implantation.

Level of evidence: C.

2. Patients should have some assessment of thoracic anatomy prior to MCS implantation or in the setting of prior surgery or suspected thoracic abnormalities. These may include a radiologic examination with CT or magnetic resonance imaging.

Level of evidence: C.

3. Positive airway pressure, early ambulation, induced cough, incentive spirometry, and effective pain control subsequent to surgery may all decrease post-operative complications.

Level of evidence: C.

Recommendations for management of patients with decompensated heart failure:^{1,118–120}

Class I:

1. Short-term mechanical support, including extracorporeal membrane oxygenation, should be used in acutely decompensated patients who are failing maximal medical therapy.

Level of evidence: C.

Recommendations for temporary mechanical support:^{119,121–129}

Class I:

1. The use of temporary mechanical support should be strongly considered in patients with multiorgan failure, sepsis, or on mechanical ventilation to allow successful optimization of clinical status and neurologic assessment prior to placement of a long-term MCS.

Level of evidence: C.

Recommendations for assessing RV function:^{102,130–139}

Class I:

1. All patients should have an echocardiographic assessment of RV function prior to MCS implantation.

Level of evidence: C.

2. All patients should have invasive assessment of intracardiac filling pressures prior to MCS implantation, with a particular emphasis on RV hemodynamics.

Level of evidence: C.

Recommendations for management of RV dysfunction:^{3,4,31,79,134,135,139–142}

Class I:

1. Pre-operatively, patients with evidence of RV dysfunction should be admitted to the hospital for aggressive management, which may include diuresis, ultrafiltration, inotropes,

intra-aortic balloon pump, or other short-term mechanical support. Once optimized, RV function should be reassessed.

Level of evidence: C.

2. RV dysfunction post-MCS should be managed with diuresis, inotropes, and pulmonary vasodilators, including nitric oxide or inhaled prostacyclin. RV dysfunction refractory to medical management may require placement of a short-term or long-term mechanical RV support device.

Level of evidence: C.

Class IIb:

1. Phosphodiesterase 5 inhibitors may be considered for management of RV dysfunction in the setting of pulmonary hypertension after MCS.

Level of evidence: C.

Task Force 3: Intraoperative and immediate post-operative management

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Topic 1: Anesthesia-related issues

Recommendations for managing anesthesia issues:^{143–157}

Class I:

1. Patients undergoing MCS placement should have insertion of a large-bore intravenous line, arterial line, and pulmonary artery catheter to allow for continuous monitoring and intravascular access.

Level of evidence: B

2. Cardiac anesthesia should be performed by those familiar with the clinical issues associated with MCS placement, including considerations at the time of induction, during surgery, during separation from cardiopulmonary bypass, and at the time the MCS is actuated.

Level of evidence: B

3. Intraoperative transesophageal echocardiography should be performed by physicians with advanced training in the intraoperative assessment of cardiac structure and function.

Level of evidence: B

Topic 2: Implantation techniques

Implant techniques vary with pump type; readers are referred to the on-line document for a full discussion of these issues (available on the JHLTonline.org Web site).

Topic 3: Special considerations for VAD implantation

These considerations may vary with pump type; readers are referred to the on-line document for a full discussion of these issues (available on the JHLTonline.org Web site).

Topic 4: Explantation techniques: Explantation of LVADs for heart transplantation

Explant techniques vary with pump type; readers are referred to the on-line document for a full discussion of these issues (available on the JHLTonline.org Web site).

Topic 5: Early post-operative management: Hemodynamic management

Recommendations for early post-operative hemodynamic management are presented in Table 1.^{88,158,159} Figure 1 provides recommendations for low pump output treatment. Early post-operative anti-coagulation management recommendations are presented in Tables 2, 3, and 4.^{43,87,160-167} Table 5 provides guidelines for removal of invasive lines and drains in a stable post-operative MCS patient. Ventilation parameters for the early post-operative period are outlined in Table 6.^{159,168-170} Table 7 outlines suggested guidelines for feeding, mobility issues, and discharge preparation.

Task Force 4: Inpatient management of patients with MCSDs

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Recommendations for the treatment of right heart dysfunction in the non-ICU post-operative period:^{172,173}

Class I:

1. Inotropic support may need to be continued into the remote post-operative period (> 2 weeks) when there is evidence for right heart dysfunction such as elevated jugular venous pressure, signs of venous congestion, decreased VAD flows (or low pulsatility in continuous-flow MCS), or end-organ dysfunction. Once euvolemic, inotrope wean should be done cautiously, with ongoing examination for recurrent signs and symptoms of RV dysfunction.

Level of evidence: C.

2. Diuretics and renal replacement therapy, such as continuous venovenous hemofiltration, should be used early and continued as needed to maintain optimal volume status.

Level of evidence: C.

Class IIb

1. Cardiac glycosides may be used to support RV function.

Level of evidence: C.

2. For patients with persistent pulmonary hypertension who exhibit signs of RV dysfunction, pulmonary hypertension-specific therapies, such as phosphodiesterase-5 inhibitors, should be considered.

Level of evidence: C.

3. Pacemaker therapy can be used if the heart rate is not optimal to support hemodynamics.

Level of evidence: C.

Table 1 Treatment Recommendations for Early Post-operative Hemodynamic Management

Cardiac index (liters/min/m ²)	MAP (mm Hg)	LV ejection	Primary recommendation	Alternative
< 2.2	< 65	No	Epinephrine Vasopressin Norepinephrine	Dopamine
		Yes	Increase pump speed	Volume for low CVP
	> 65	No	Dobutamine	Milrinone
		Yes	Increase pump speed	
	> 90	No	Milrinone	Sodium nitroprusside
		Yes	Sodium nitroprusside	Milrinone
> 2.2	< 65	No	Nitroglycerin	Nicardipine
		Yes	Nitroglycerin	
	> 65 and < 90	No	Hydralazine	
		Yes	No intervention	
	> 90	No	No intervention	
		Yes	Sodium nitroprusside	Milrinone
			Nitroglycerin	Nicardipine
			Hydralazine	
	Yes	Sodium nitroprusside	Nicardipine	

CVP, central venous pressure; LV, left ventricular; MAP, mean arterial pressure.

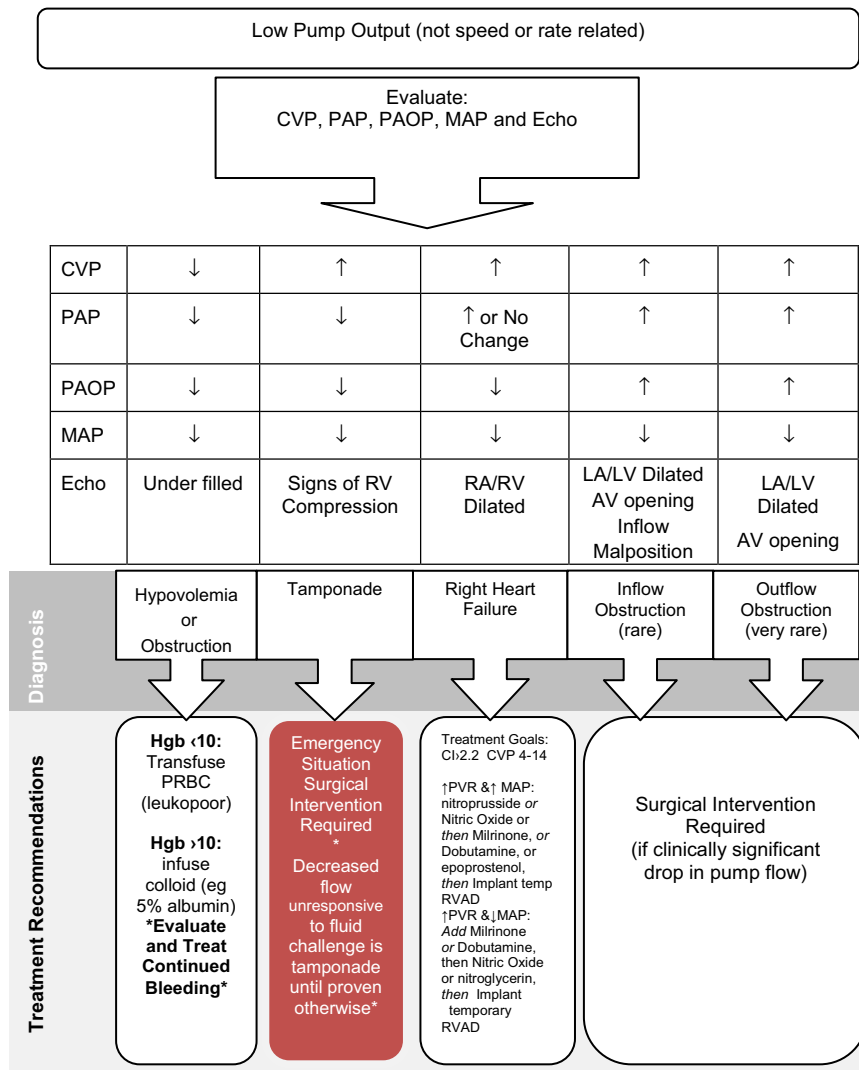


Figure 1 Treatment algorithm for low pump output. AV, arteriovenous; CI, cardiac index; CVP, central venous pressure; Hgb, hemoglobin; LA, left atrium; LV, left ventricle; MAP, mean arterial pressure; PAOP, pulmonary artery occlusion pressure; PAP, pulmonary artery pressure; PRBC, packed red blood cells; PVR, peripheral vascular resistance; RA, right atrium; RV, right ventricular; RVAD, right ventricular assist device.

Recommendations for managing hypotension in the non-ICU post-operative period:

Class I:

1. A systematic approach to hypotension should be used, as shown in Figure 2.
Level of evidence: C.

Recommendations for neurohormonal blockade and the treatment of hypertension post-MCS implant:

Class I:

1. Pharmacotherapy with heart failure medications (angiotensin-converting enzyme inhibitor, angiotensin receptor blocker, β-blocker, hydralazine, nitrates) is preferred for blood pressure management.
Level of evidence: C

Recommendations for echocardiography in the non-ICU post-operative period:¹⁷⁴⁻¹⁷⁶

Class I:

1. Echocardiography is an integral part of determining the revolutions per minute of continuous-flow pumps. Common goals include adequate LV unloading while maintaining the LV septum in the midline and minimizing mitral regurgitation.
Level of evidence: C.

Class IIb:

1. Post-operatively, the revolutions per minute of continuous-flow pumps should be set low enough to allow for intermittent aortic valve opening.
Level of evidence: B.

Table 2 Early Post-operative Anti-coagulation Management of HeartMate II^a Patients Using Heparin

Timing	Action	Target
After CBP—leaving operating room	Complete reversal of heparin	Not applicable
ICU admission—24 hours	No action required, consider acetylsalicylic acid	Not applicable
Post-operative Day 1–2	IV heparin or alternative anti-coagulation, if no evidence of bleeding	PTT (40–60 seconds)
Post-operative Day 2–3	Continue heparin Start warfarin and aspirin (81–325 mg daily) after removal of chest tubes	PTT (60–80 seconds) INR (2.0–3.0)

CPB, cardiopulmonary bypass; ICU, intensive care unit; INR, international normalized ratio; IV, intravenous; PTT, partial thromboplastin time.

^aThoratec, Pleasanton, California.

Table 3 Post-operative Anti-coagulation Management for Implantable Centrifugal Pumps

Timing	Action	Target
After CBP—leaving operating room	Complete reversal of heparin	Not applicable
ICU admission—24 hours	No action required, consider acetylsalicylic acid	Not applicable
Post-operative Day 1–2	IV heparin or alternative anti-coagulation, if no evidence of bleeding	PTT (40–60 seconds)
Post-operative Day 2–3	Continue heparin Start warfarin and aspirin (81–325 mg daily) after removal of chest tubes	PTT (60–80 seconds) INR (2.0–3.0)

CPB, cardiopulmonary bypass; ICU, intensive care unit; INR, international normalized ratio; IV, intravenous; PTT, partial thromboplastin time.

Table 4 Post-operative Anti-coagulation Management for Pulsatile Mechanical Circulatory Support Devices

Timing	Action	Target
After CBP—leaving operating room	Complete reversal of heparin	Not applicable
ICU admission—24 hours	No action	Not applicable
Post-operative Day 2	Start IV heparin if no evidence bleeding	PTT (40–60 seconds)
Post-operative Day 3	Continue heparin Start warfarin and aspirin (81–325 mg daily) after removal of chest tubes	PTT (60–80 seconds) INR (2.5–3.5)

CPB, cardiopulmonary bypass; ICU, intensive care unit; INR, international normalized ratio; IV, intravenous; PTT, partial thromboplastin time.

Table 5 Guidelines for Removal of Invasive Lines and Drains in the Non-complicated Post-operative Mechanical Circulatory Support Patient

Type of line/drain	Time to discontinuation	Notes
PA catheter	24–48 hours	Must remain in place for severe right heart failure requiring high doses of inotropes
Arterial line	48–72 hours	Must remain in place until all vasoactive medications are weaned
Central venous line	Until no longer needed	Must remain in place until all vasoactive medications are weaned
Chest tubes	48 hours or when drainage is < 100 ml in the previous 6 hours	Preferably after patient has sat up to assure that drainage is not positional
Pocket drain	72 hours or when drainage is < 100 ml for the previous 8 hours	May be removed sooner if pocket communicates with left pleural space and if the left sided chest tube remains in place

PA, pulmonary artery.

Table 6 Parameters for Post-operative Mechanical Circulatory Support Patient Ventilation¹⁷¹

Mode	Assist/Control
Rate	10–12 breaths/min
Tidal volume	6–8 ml/kg
Positive end expiratory pressure	5 cm H ₂ O

2. Long-term, maintaining intermittent aortic valve opening may reduce the risk of aortic valve fusion and the risk of late aortic valve insufficiency.

Level of evidence: B.

Recommendations for anti-coagulation and anti-platelet therapy post-MCS:¹⁶³

Class I:

1. Anti-coagulation and anti-platelet therapy initiated post-operatively in the ICU setting should be continued with the aim of achieving device-specific recommended INR for warfarin and desired anti-platelet effects.

Level of evidence: B.

2. Bleeding in the early post-operative period during the index hospitalization should be urgently evaluated with lowering, discontinuation, and/or reversal of anti-coagulation and anti-platelet medications.

Level of evidence: C.

Recommendations for infection prevention post-MCS therapy:^{96,177–203}

Class I:

1. The driveline should be stabilized immediately after the device is placed and throughout the duration of support.

Level of evidence: C.

2. A dressing change protocol should be immediately initiated post-operatively.

Level of evidence: C.

3. Secondary antibiotic prophylaxis for prevention of endocarditis has not been studied in the MCS population but would be considered reasonable due to the risk of bacteremia in this group.

Level of evidence: C.

Table 7 Mobility and Feeding Guidelines

Activity	Goal
Out of bed to chair	Post-op Day 1
Feeding	Post-op Day 1
Discharge from intensive care unit	Post-op Day 3–5

Recommendations for optimization of nutritional status:^{89,204–208}

Class I:

1. Consultation with nutritional services should be obtained at the time of implantation with ongoing follow-up post-operatively to ensure nutrition goals are being met.

Level of evidence: C.

2. Post-operatively for those unable to meet nutritional goals orally, feeding should be started early and preferably through an enteral feeding tube. Parenteral nutrition should only be started if enteral nutrition is not possible and under the guidance of nutritional consultation.

Level of evidence: C.

3. Pre-albumin and C-reactive protein levels can be monitored weekly to track the nutritional status of the post-operative patient. As nutrition improves, pre-albumin should rise and C-reactive protein should decrease.

Level of evidence: C.

Recommendations for health care provider and patient education:^{209–217}

Class I:

1. Health care providers should be trained in MCS therapy with opportunity to attend refresher classes and ongoing assessment of competency.

Level of evidence: C.

2. Patient and caregiver education should be initiated shortly after surgery and reinforced by the nursing staff. Educational strategies should use written, verbal, and practical methods.

Level of evidence: C.

Recommendations for documentation of device parameters:

Class I:

1. MCS parameters should be recorded in the medical record at regular intervals with established criteria for parameters which require physician notification.

Level of evidence: C.

Recommendations for device monitoring:

Class I:

1. Normal values for device parameters should be established and recorded in the medical record with triggers for physician notification.

Level of evidence: C.

2. The patient and family members should be taught to track their device parameters and alert staff when changes are observed.

Level of evidence: C.

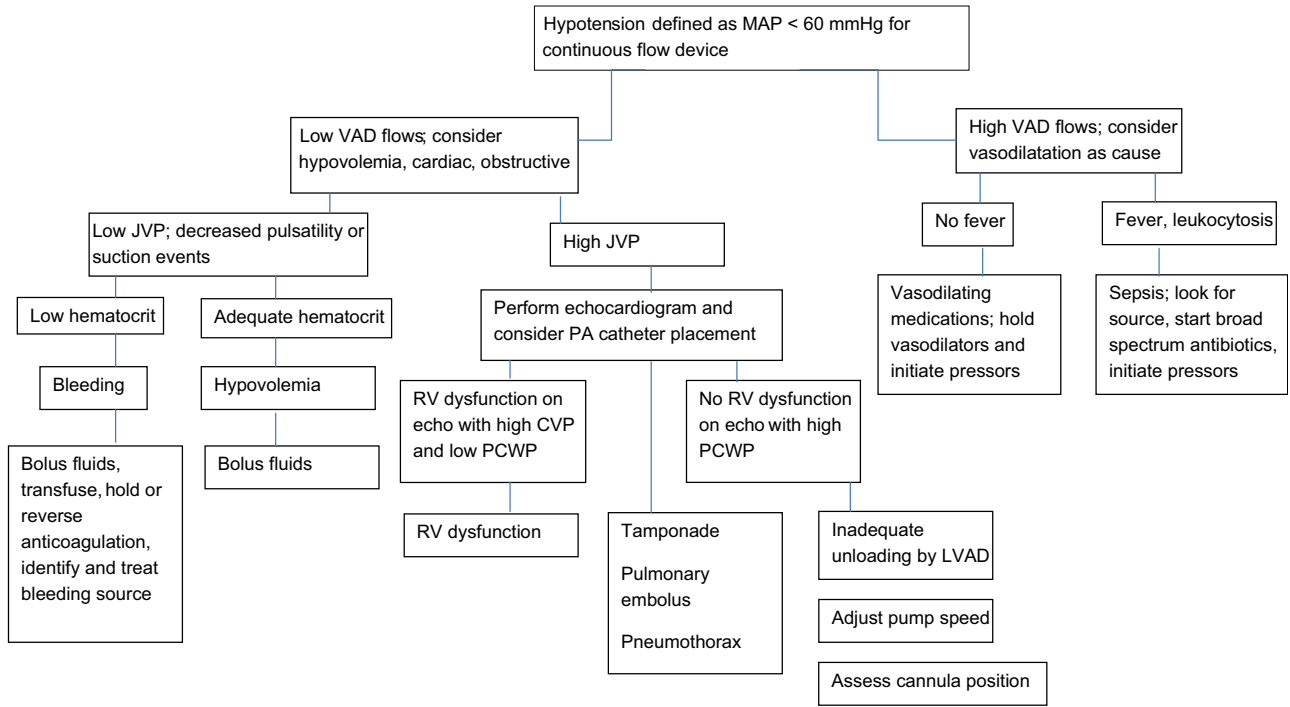


Figure 2 Algorithm for assessment of hypotension after implant. CVP, central venous pressure; JVP, jugular venous pressure; LVAD, left ventricular assist device; MAP, mean arterial pressure; PA, pulmonary artery; PCWP, pulmonary capillary wedge pressure; RV, right ventricular; VAD, left ventricular assist device.

3. Changes in parameters outside of normal ranges should be thoroughly evaluated and treated appropriately.
Level of evidence: C.

Recommendations for psychosocial support while hospitalized post-MCSD implantation:^{55,218-221}

Class I:

1. Routine support should be available from social workers, psychologists, or psychiatrists as patients and families adjust to life changes after MCS.
Level of evidence: B
2. Routine surveillance for psychiatric symptoms should be performed. If symptoms develop, consultation with specialists (including social work, psychology, and/or psychiatry) for diagnosis, treatment, and follow-up is recommended.
Level of evidence: B.

Recommendations for inpatient MCS care by a multidisciplinary team:^{76,222-231}

Class I:

1. A multidisciplinary team led cooperatively by cardiac surgeons and cardiologists and composed of subspecialists (ie, palliative care, psychiatry, and others as needed), MCS coordinators, and other ancillary specialties (ie, social worker, psychologist, pharmacist, dietitian, physical therapist, occupational therapist, and rehabilita-

tion services) is indicated for the in-hospital management of MCS patients.
Level of evidence: C.

Recommendations for routine assessment of health-related quality of life while hospitalized post-MCSD implantation:^{219-221,232}

Class IIb:

1. Routine assessment of health-related quality of life (HRQOL) while hospitalized after MCS implantation may be reasonable. Hospitalized patients are beginning to adjust to living with MCS and thus require MCS team support as they recover from surgery and rehabilitate. Assessment of specific problems that are related to domains of HRQOL (eg, depression, anxiety, or pain) based on symptoms should help guide an action plan for these patients.
Level of evidence: B.

Recommendations for successfully discharging a MCS patient:^{214,233}

Class I:

1. Caregiver and community provider education with written discharge instructions and preemptive home preparation regarding the safe management of the device and the MCS patient is recommended.
Level of evidence: C.

Recommendations for management of anti-coagulation and anti-platelet therapy for patients who present with gastrointestinal bleeding: ²³³⁻²⁴⁰

Class I:

1. Anti-coagulation and anti-platelet therapy should be held in the setting of clinically significant bleeding.
Level of evidence: C.
2. Anti-coagulation should be reversed in the setting of an elevated INR and clinically significant bleeding.
Level of evidence: C.
3. Anti-coagulation and anti-platelet therapy should continue to be held until clinically significant bleeding resolves in the absence of evidence of pump dysfunction.
Level of evidence: C.
4. The patient, device parameters, and the pump housing (if applicable) should be carefully monitored while anti-coagulation and anti-platelet therapy is being withheld or the dose reduced.
Level of evidence: C.

Recommendations for the evaluation and management of patients who present with a first episode of gastrointestinal bleeding:

Class I:

1. Patients should be managed in consultation with gastroenterology.
Level of evidence: C.
2. Patients should at least have a colonoscopy and/or upper endoscopic evaluation.
Level of evidence: C.
3. If the result of the colonoscopy and/or upper endoscopic evaluation is negative, evaluation of the small bowel, particularly in those with continuous-flow devices, should be considered.
Level of evidence: C.
4. In the setting of persistent bleeding and a negative endoscopic evaluation, a tagged red blood scan or angiography should be considered.
Level of evidence: C.
5. Once the gastrointestinal bleeding has resolved, anti-coagulation and anti-platelet therapy can be reintroduced with careful monitoring.
Level of evidence: C.

Recommendations for the evaluation and management of patients who present with recurrent episodes of gastrointestinal bleeding:

Class I:

1. Repeated endoscopic evaluation should take place in conjunction with gastroenterology consultation.
Level of evidence: C.
2. In the setting of recurrent gastrointestinal bleeding with no source or a source that is not amenable to therapy, the type and intensity or even the use of anti-platelet therapy

should be reevaluated in the context of the bleeding severity and pump type.

Level of evidence: C.

3. In the setting of recurrent gastrointestinal bleeding with no source or a source that is not amenable to therapy, the goal INR or even the continued use of warfarin should be reevaluated in the context of the bleeding severity and pump type.
Level of evidence: C.
4. The patient and device parameters should be carefully monitored when anti-coagulation and anti-platelet therapy have been reduced or discontinued due to recurrent gastrointestinal bleeding.
Level of evidence: C.

Class IIb:

1. Reducing the pump speed for continuous-flow pumps in the setting of recurrent gastrointestinal bleeding due to arteriovenous malformations may be considered.
Level of evidence: C.

Recommendations for the acute management of patients who present with a new neurologic deficit: ^{4,31,39,52,195,241-243}

Class I:

1. Assessment of current INR and review of recent INR is recommended.
Level of evidence: B.
2. Prompt consultation with neurology is recommended.
Level of evidence: B.
3. CT and angiography of the head and neck is recommended.
Level of evidence: B.
4. Review of pump parameters for signs of device thrombosis or malfunction is recommended.
Level of evidence: C.
5. Inspection of pump housing for clots in extracorporeal pumps is recommended.
Level of evidence: C.
6. Discontinuation or reversal of anti-coagulation in the setting of hemorrhagic stroke is recommended.
Level of evidence: B.

Class IIa:

1. Assessing for the source of thrombus in the setting of an embolic stroke should be considered.
Level of evidence: B.

Class IIb:

1. Selective use of an interventional radiologic approach to thrombotic strokes may be considered.
Level of evidence: C.
2. Selective use of thrombolytic agents in the setting of thrombotic stroke without CT scan evidence of hemorrhage may be considered.
Level of evidence: C.

Class III:

1. Routine use of an interventional radiologic approach to thrombotic strokes is not recommended.
Level of evidence: C.
2. Routine use of thrombolytics in the setting of thrombotic stroke without head CT scan evidence of hemorrhage is not recommended.
Level of evidence: C.

Recommendations for the chronic management of patients after presentation with a new neurologic deficit:**Class I:**

1. Formal stroke rehabilitation in consultation with neurology is recommended.
Level of evidence: B.
2. Close monitoring of anti-coagulation in the setting of an embolic event to assure adequate levels of anti-coagulation is recommended.
Level of evidence: C.
3. Long-term control of blood pressure is recommended.
Level of evidence: B.
4. Administration of National Institutes of Health (NIH) stroke scale at 30 and 60 days after a neurologic event is recommended.
Level of evidence: C.
5. Resumption of anti-coagulation in consultation with neurology or neurosurgery in the setting of hemorrhagic stroke is recommended.
Level of evidence: C.

Recommendations for assessment of neurocognitive deficits:^{32,244-246}**Class I:**

1. Routine neurocognitive assessment at 3, 6, 12, and 18 months after implant is recommended.
Level of evidence: C.

Recommendations for evaluation of MCS patients with a suspected infection:²⁴⁷**Class I:**

1. In all patients, a complete blood count, chest radiographic imaging, and blood cultures is recommended.
Level of evidence: A.
2. At least 3 sets of blood cultures over 24 hours should be drawn, with at least 1 culture from any indwelling central venous catheters.
Level of evidence: A.
3. For those with a suspected cannula or driveline infection, obtaining a sample for Gram stain, KOH, and routine bacterial and fungal cultures is recommended.
Level of evidence: A.

4. When clinically indicated, aspirate from other potential sources, as dictated by presenting symptoms and examination, is recommended.

Level of evidence: A.

5. Directed radiographic studies based on presenting symptoms and examination are recommended.

Level of evidence: A.**Class IIa:**

1. Erythrocyte sedimentation rate or serial C-reactive protein should be considered.

Level of evidence: C.**Class III:**

1. Routine CT of the chest, abdomen, and pelvis is not recommended.

Level of evidence: C.**Recommendations for determination of an MCS-specific infection (Table 8):²⁴⁷****Class I:**

1. A proven MCS-specific infection is defined as definitive microbiologic, histologic confirmation at MCS explant or 2 major clinical criteria.
Level of evidence: B.
2. A probable MCS-specific infection is defined as 1 major and 3 minor criteria or 4 minor criteria.
Level of evidence: B.
3. A possible MCS-specific infection is defined as 1 major and 1 minor or 3 minor criteria.
Level of evidence: B.

Recommendations for determination of an MCS pocket infection:**Class I:**

1. A proven MCS pocket infection is defined as organisms cultured from fluid, abscess, or other infection seen during surgical exploration, or 2 major criteria.
Level of evidence: B.
2. A probable MCS pocket infection is defined as 1 major and 3 minor or 4 minor criteria.
Level of evidence: B.
3. A possible MCS pocket infection is defined as 1 major and 1 minor or 3 minor criteria.
Level of evidence: B.

Recommendations for inpatient treatment of ventricular arrhythmias:²⁴⁸⁻²⁵²**Class I:**

1. MCS patients with incessant ventricular arrhythmias require prompt admission for further management because hemodynamic compromise may occur.
Level of evidence: C.

Table 8 Determination of Mechanical Circulatory Support Device Infections

Infection	Determined by
MCS-specific	
Proven	Definitive microbiology, or Histologic confirmation at explants, or 2 major clinical criteria
Probable	1 major and 3 minor criteria, or 4 minor criteria
Possible	1 major and 1 minor criteria, or 3 minor criteria
Unlikely	Presence of an alternative diagnosis, or Resolution after ≤ 4 days of antibiotics, or No pathologic evidence at surgery with antibiotics ≤ 4 days, or Not meeting established definitions
Pocket infections	
Proven	Organisms cultured from fluid, or Abscess, or Other infection seen during surgical exploration, or 2 major criteria
Probable	1 major and 3 minor criteria, or 4 minor criteria
Possible	1 major and 1 minor criteria, or 3 minor criteria
Unlikely	Definitive alternative diagnosis, or Resolution with ≤ 4 days of antibiotics, or No pathologic evidence at surgery after ≤ 4 days of antibiotics, or Negative cultures from fluid during surgery or aspiration

MCS, mechanical circulatory support device.

2. Patients with ongoing VT refractory to medical therapy may require catheter ablation, which should be performed by an electrophysiologist with the requisite knowledge and expertise in treating patients with MCS.

Level of evidence: C.

Recommendations for RV function:

Class I:

1. RV dysfunction after LVAD placement may occur as a late manifestation with symptoms and signs of right heart failure and changes in LVAD parameters, including a decrease in flows and pulsatility. Further evaluation should include an echocardiogram and right heart catheterization.

Level of evidence: C.

2. When evidence of RV dysfunction exists, MCS patients may need to be admitted to the hospital for optimization, which may include initiation of inotropic support.

Level of evidence: C.

Recommendations for device failure and malfunction:^{3,31,195,253–257}

Class I:

1. Pump stoppage of a continuous-flow MCSD constitutes a medical emergency, and the patient should be rapidly transported back to the implanting center or another expert MCSD center for treatment.

Level of evidence: C.

2. Definitive therapy for pump stoppage is surgical pump exchange if the patient is stable enough to undergo reoperation.

Level of evidence: C.

3. Patients with a functioning pump, but with alarms or changes in parameters that cannot be resolved as an outpatient, may need to be admitted to the hospital for observation and close monitoring.

Level of evidence: C.

Class IIb:

1. For patients who are unable to undergo surgery, the outflow cannula may be occluded percutaneously to halt the backflow of blood through the valveless outflow cannula as a stabilizing maneuver.

Level of evidence: B.

Recommendations for management of the MCS patient during non-cardiac procedures:^{258–265}

Class I:

1. The MCS team should be made aware when an MCS patient is undergoing a non-cardiac procedure so that collaboration between the MCS and surgical teams can take place.

Level of evidence: C.

2. For non-emergency procedures, warfarin and anti-platelet therapy may be continued if the risk of bleeding associated with the procedure is low. If therapy needs to be stopped, warfarin and anti-platelet therapy should be held for an appropriate period of time as determined by the type of procedure being undertaken and risk of bleeding. Bridging with heparin or a heparin alternative while a patient is off warfarin may be considered.

Level of evidence: C.

3. For emergency procedures, warfarin may need to be rapidly reversed with fresh frozen plasma or prothrombin protein concentrate. Vitamin K can be administered with caution, but has slower onset of action.

Level of evidence: B.

4. Post-procedure, warfarin and anti-platelet therapy may be resumed when risk of surgical bleeding is deemed acceptable. Patients may be bridged with heparin or a heparin alternative while waiting for the INR to reach the target range.

Level of evidence: B.

5. During minor procedures, blood pressure monitoring with Doppler is appropriate.

Level of evidence: C.

6. During procedures with risk of hemodynamic instability, an arterial catheter should be placed for blood pressure monitoring.

Level of evidence: C.

7. A central venous catheter may be placed for monitoring of central venous pressure and to administer drugs in the case of hemodynamic instability during surgical procedures of moderate or high risk.

Level of evidence: B.

8. During non-cardiac procedures, MCS parameters should be continuously monitored by expert personnel such as MCS nurses or perfusionists.

Level of evidence: C.

9. A cardiovascular surgeon should be in the operating room or immediately available, especially in situations when the non-cardiac procedure is occurring close to the MCS.

Level of evidence: C.

Class II:

1. Whenever possible, the surgeon performing the non-cardiac procedure should have experience in operating on patients with MCS.

Level of evidence: C.

Task Force 5: Outpatient management of the MCS recipient

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Topic 1: Transitioning the MCS patient to the home or community environment

Recommendations for evaluation of safety of the home environment:^{87,216,266,267}

Class I:

1. An uninterrupted supply of electricity to continuously power the MCS must be ensured. Outlets must be grounded, and the use of electrical extension cords or outlets with a switch should be avoided. The local electrical company must be notified of the customer's need for electricity to power life-sustaining equipment in the home. Patients are advised to develop an emergency plan in the event electricity becomes unavailable in the home.

Level of evidence: C.

2. Patients should have a working telephone to allow outgoing calls in the event of an emergency and to allow the implanting center to contact the patient. The patient should familiarize himself or herself with paging the MCS team should an actual emergency arise.

Level of evidence: C.

Class IIa:

1. Equipment at home should be placed in a configuration that minimizes the risk of falls, allows easy access to living and sleeping areas, and allows family members to hear alarms. Lighting should be adequate. The bathroom should be safe for showering with a shower chair, and have the appropriate toilet seat or any other necessary physical aids.

Level of evidence: C.

2. A discharge checklist may be developed to facilitate communication regarding the specific necessary home modifications and to document progress in meeting these requirements prior to discharge.

Level of evidence: C.

Recommendations for community outreach by the MCS team:^{216,233,263-268}

Class I:

1. Community outreach should be performed by the implanting center's MCS team to inform the local health care providers, including emergency medical services personnel, emergency department staff, and referring physicians, of the reintegration of the MCS patient to his or her local environment. Education should be delivered so providers have knowledge of the concepts involving MCS and the associated physiologic changes.

Level of evidence: C.

Class IIa:

1. Appropriate emergency maneuvers should be reviewed with local health care providers. Consideration may be given to developing a field guide for emergency medical services personnel to aid in emergency responses.

Level of evidence: C.

Recommendations for assessment of the social network:^{267,269}

Class I:

1. The primary designated caregiver should demonstrate competency in functioning of the MCS and the appropriate response to alarms.

Level of evidence: C.

2. The MCS team designee must interview patients and family members regarding the strength and depth of their social support. The social worker or other MCS staff member may need to develop a formal "social contract" with the patient's social network and/or caregiver(s) that outlines their commitment and responsibilities to ensure they are prepared to assist patients with device and/or driving needs until the patient is able.

Level of evidence: C.

Class IIb:

1. A survey tool should be developed that allows patients to provide feedback to the MCS program on their preparedness for the transition to the home environment.

The multidisciplinary MCS team should review survey results at regular intervals to help facilitate programmatic improvements.

Level of evidence: C.

Recommendations for driving a motor vehicle:²⁶⁷

Class IIb:

1. Clearance to drive a motor vehicle is a center-specific decision and should be guided by local laws.

Level of evidence: C.

Topic 2: Follow-up care

Recommendations for the multidisciplinary approach to follow-up care:

Class I:

1. Management of the patient with an MCS D should be performed by a multidisciplinary team that includes cardiovascular surgeons, advanced heart failure cardiologists, and specialized MCS coordinators. Other health care providers may collaborate with the primary MCS team when additional expertise is required.

Level of evidence: C.

Recommendations for frequency of visits:²⁷⁰

Class I:

1. MCS patients should be seen in clinic regularly, the frequency of which is dictated by their clinical stability.
2. MCS patients should have a routine schedule of testing to survey for patient-related or device-related issues that may adversely affect outcomes.

Level of evidence: B.

Class IIa:

1. Between routinely scheduled visits, monitoring phone calls from the MCS coordinator to the patient or caregiver may help proactively identify issues that may adversely affect patient outcomes.

Level of evidence: B.

Recommendations for the use of echocardiography:^{176,271–282}

Class I:

1. Echocardiography should be performed as part of the pre-operative assessment and routinely at regular intervals post-operatively to evaluate for signs of myocardial recovery and optimal MCS D function. Echocardiography can be used for setting optimal pump parameters.

Level of evidence: B.

2. In addition to routine studies, echocardiography should be performed as part of the evaluation of sub-optimal

MCS D function or in the presence of clinical signs of circulatory dysfunction, including congestive or low output symptoms.

Level of evidence B.

Recommendations for the use of right heart catheterization:

Class I:

1. Right heart catheterization is useful in the assessment of persistent or recurrent heart failure symptoms after MCS D placement and to evaluate for evidence of RV failure or device malfunction.

Level of evidence: B.

2. Right heart catheterization should be performed at regular intervals in patients being evaluated for or listed for heart transplant to document pulmonary artery pressures because irreversible pulmonary hypertension is associated with early allograft dysfunction/failure after heart transplantation.

Level of evidence: A.

Class IIa:

1. Right heart catheterization should be performed to help corroborate evidence of myocardial recovery. The pulmonary artery catheter may be left in place with serial lowering of the pump speed to confirm acceptable hemodynamics with decreasing VAD support prior to pump explanation.

Level of evidence: C.

Recommendations for use of CT angiography:^{283–285}

Class I:

1. CT angiography allows visualization of the native heart and MCS D components and may be valuable when other imaging modalities have not been revealing.

Level of evidence: B

Recommendations for functional capacity testing:^{286–294}

Class I:

1. Measurement of exercise capacity should be undertaken after MCS D placement to allow for appropriate exercise prescription, which may be part of a formal cardiac rehabilitation program.

Level of evidence: B.

Class IIa:

1. Cardiopulmonary stress testing and/or 6-minute walk testing performed at regular intervals may be helpful in objectively assessing functional capacity in patients with MCS D. Suggested intervals are 3 months, 6 months, at

6-month intervals through 2 years after implant, and then yearly thereafter.

Level of evidence: C.

Recommendations for HRQOL:²⁹⁵

Class IIa:

1. HRQOL should be measured before MCS D implantation and at regular intervals longitudinally for the duration of MCS D support. Generic measures and those specific to heart failure can both be used. Suggested intervals are 3 months, 6 months, at 6-month intervals through 2 years after implant, then yearly thereafter.

Level of evidence: B.

Recommendations for laboratory studies:

Class I:

1. Laboratory studies should be obtained at regular intervals to assess end-organ function, monitor device-specific issues, and diagnose or monitor the status of comorbid conditions.

Level of evidence: C.

Recommendations for assessment of the MCS D:

Class I:

1. The driveline, exit site, and MCS D components should be examined at each clinic visit to ensure their integrity. Alarm history and downloads should be obtained at regular intervals. Pump parameters should be reviewed regularly and adjusted accordingly to optimize pump functioning for the duration of time the patient is on support.

Level of evidence: C.

2. The driveline should be assessed for proper position and use of binder or driveline immobilization at each clinic visit.

Level of evidence: C.

3. The patient should be trained in proper self-care, including showering technique and dressing changes, prior to hospital discharge. These skills may need reinforcement over the patient's lifetime, depending on the clinical course.

Level of evidence: C.

Recommendations for health maintenance:

Class I:

1. Patients with MCS D therapy should continue to follow a general health maintenance schedule, including gender-related and age-specific recommendations, routine vaccinations, and dental care.

Level of evidence: A.

Topic 3: Cardiac rehabilitation and exercise guidelines

Recommendations for exercise and cardiac rehabilitation:^{296–308}

Class I:

1. All patients who are able should be enrolled in cardiac rehabilitation after surgical placement of an MCS D.

Level of evidence: C.

Topic 4: Medical management of the MCS D patient

Recommendations for anti-coagulation:^{86,160,309}

Class I:

1. Patients with MCS D should receive anti-coagulation with warfarin to maintain an INR within a range as specified by each device manufacturer (Table 9).

Level of evidence: B.

Recommendations for anti-platelet therapy:^{237,238,310–320}

Class I:

1. Chronic anti-platelet therapy with aspirin (81–325 mg daily) may be used in addition to warfarin in patients with MCS D.

Level of evidence: C.

2. Anti-platelet therapy beyond aspirin may be added to warfarin according to the recommendations of specific device manufacturers.

Level of evidence: C.

Table 9 Anti-coagulation and Anti-platelet Therapy for Approved Mechanical Circulatory Support Devices

Device	INR range
AbioCor TAH ^a	2.5–3.5
HeartMate II ^{b,c}	2.0–3.0
HeartWare HVAD ^d	2.0–3.0
MicroMed DeBakey ^e	2.5–3.5
Syncardia TAH ^f	2.5–3.5
Thoratec IVAD ^c	2.5–3.5
Thoratec PVAD ^c	2.5–3.5

INR, international normalized ratio; IVAD, implantable ventricular assist device; PVAD, percutaneous ventricular assist device; TAH, total artificial heart.

^aAbiomed, Danvers, Massachusetts.

^bGoal from the clinical trials.

^cThoratec, Pleasanton, California.

^dHeartWare International, Inc, Framingham, Massachusetts.

^eMicroMed Technology, Houston, Texas.

^fCardioWest SynCardia, Tucson, Arizona.

Class IIb:

1. Assessment of platelet function may be used to direct the dosing and number of anti-platelet drugs.
Level of evidence: C.

Recommendations for heart failure therapy:^{31,321–323}**Class I:**

1. Diuretic agents are useful for the management of volume overload during MCS.
Level of evidence: C.
2. An angiotensin-converting enzyme inhibitor or an angiotensin receptor blocker may be used for hypertension or for risk reduction in patients with vascular disease and diabetes.
Level of evidence: C.
3. β -Blockers may be used for hypertension or for rate control in patients with tachyarrhythmias.
Level of evidence: C.
4. Mineralocorticoid receptor antagonists may be used to limit the need for potassium repletion in patients with adequate renal function and for potential beneficial anti-fibrotic effects on the myocardium.
Level of evidence: C.

Class II

1. Digoxin may be useful in the setting of atrial fibrillation with rapid ventricular response.
Level of evidence: C.

Recommendations for hypertension management:**Class IIb:**

1. Patients with pulsatile MCSDs should have a blood pressure goal of systolic blood pressure of < 130 mm Hg and a diastolic blood pressure of < 85 mm Hg.
Level of evidence: C.
2. Patients with nonpulsatile MCSDs should have a mean blood pressure goal of ≤ 80 mm Hg
Level of evidence: C.

Recommendations for diabetes management:⁴⁷**Class IIa:**

1. Patients with diabetes should have continued therapy and close follow-up for their diabetes while receiving MCS.
Level of evidence: C.

Recommendations for treatment of renal disease:^{78,79,323}**Class IIb:**

1. Renal function should be monitored on an ongoing basis after MCSD placement.
Level of evidence: C.

2. Persistent renal insufficiency after MCS should prompt further evaluation and management in collaboration with nephrology.
Level of evidence: C.

Recommendations for evaluation and management of hemolysis:^{86,263,324–327}**Class I:**

1. Screening for hemolysis should occur in the setting of an unexpected drop in the hemoglobin or hematocrit level or with other clinical signs of hemolysis (eg, hemoglobinuria).
Level of evidence: C.
2. Hemolysis in the presence of altered pump function should prompt admission for optimization of anti-coagulation and anti-platelet management and possible pump exchange
Level of evidence: B.

Class IIa:

1. Routine screening for hemolysis with lactate dehydrogenase and plasma-free hemoglobin assessment in addition to hemoglobin or hematocrit should occur periodically throughout the duration of MCS.
Level of evidence: C.

Recommendations for dietary management:^{328,329}**Class IIa:**

1. Weight loss should be encouraged for all patients with a body mass index > 30 kg/m².
Level of evidence: C.

Recommendations for smoking and substance abuse:**Class I:**

1. Smoking cessation should be encouraged in all patients on MCS who continue to use tobacco.
Level of evidence: C.

Class IIa:

1. Alcohol and drug treatment programs should be required for patients with a history of substance abuse.
Level of evidence: C.

Topic 5: ICD and arrhythmia issues**Recommendations for ICD placement:**^{3,31,330}**Class I:**

1. For patients who have an ICD prior to MCS, the ICD should be reactivated in the post-operative setting.
Level of evidence: A.

Class IIa:

1. Routine placement of an ICD should be considered for patients who did not have an ICD prior to MCS.

Level of evidence: B.

2. Inactivation of the ICD should be considered in patients with biventricular assist devices who are in persistent VT/VF or who have frequent sustained runs of VT despite optimal anti-arrhythmic therapy.

Level of evidence: C.

Recommendations for management of atrial fibrillation and flutter:³³¹

Class I:

1. Cardioversion of atrial fibrillation is recommended in patients with rapid ventricular rates that compromise device performance.

Level of evidence: C.

Class IIa:

1. When atrial fibrillation is present and does not interfere with device functioning, management following the most recent American College of Cardiology/American Heart Association atrial fibrillation guidelines (2011)³³² is recommended.

Level of evidence: C.

Recommendations for management of ventricular arrhythmias:^{86,333}

Class I:

1. Cardioversion is recommended for VT that results in poor device flows and/or hemodynamic compromise.

Level of evidence: C.

2. The occurrence of VT on MCS should prompt a search for reversible causes such as electrolyte abnormalities or drug toxicities.

Level of evidence: C.

Class IIa:

1. Amiodarone is a reasonable chronic outpatient treatment to prevent recurrence of VT in patients with MCS.

Level of evidence: C.

2. Therapy with β -blockade may be a useful in the setting of recurrent VT.

Level of evidence: C.

3. Recurrent VT in the setting of a continuous-flow pump should prompt consideration of a suction event.

Level of evidence: C.

Class IIb:

1. In patients with biventricular support with VF who are refractory to therapy, but have stable flows, the patient may be left in VF with the defibrillator function of the ICD turned off.

Level of evidence: C.

Topic 6: Psychologic and psychiatric issues

Recommendations for psychologic and psychiatric issues:^{55,65,67,68,228,334-346}

Class I:

1. Patients being considered for MCS should have a detailed psychosocial evaluation.

Level of evidence: C.

2. A formal consultation with a psychiatrist should be obtained for those with concerns for psychiatric illness. Appropriate pharmacologic and psychologic therapy should be initiated as needed. Counseling may need to be extended to include family members as well.

Level of evidence: C.

Topic 7: Emergency procedures for device malfunction or failure

Recommendations for emergency procedures with device malfunction or failures:

Class I:

1. The patient and their caregivers should be trained to recognize MCS alarms and troubleshoot emergencies prior to hospital discharge. This training should be delivered using both written materials and visual demonstrations, and emergency response skills should be tested before the patient and caregiver leave the hospital.

Level of evidence: C.

2. Ongoing refreshers should be provided to patients and caregivers at outpatient visits to ensure they remain competent in emergency procedures.

Level of evidence: C.

3. An emergency on-call algorithm should be established that patients and caregivers are familiar with so they may quickly contact the implanting center in the event of emergencies.

Level of evidence: C.

4. An emergency transport system should be established to expedite transfer to the implanting center in the case of emergency.

Level of evidence: C.

Topic 8: End of life issues

Recommendations for end of life issues:^{4,58,347-350}

Class I:

1. Consultation with palliative medicine should be considered prior to MCS implantation to facilitate discussion of end of life issues and establish an advance directive or living will, particularly when implanted as DT.

Level of evidence: C.

2. In situations when there is no consensus about discontinuing MCS support, consideration may be given to consulting with the hospital ethicist or ethics board.

Level of evidence: C.

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Daniel J. Goldstein	Thoratec	Advisory Board
	Terumo	Chair, adverse events committee
Martin Strueber	Heartware	Speaker, consultant
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Supplementary data

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The 2013 International Society of Heart and Lung Transplantation Guidelines for Mechanical Circulatory Support

Task Force 1: Selection of Candidates for Mechanical Circulatory Support and Risk Management Prior to Implantation for Fixed Comorbidities

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Topic 1: Patient Selection

Introduction

Over the last three decades, the field of mechanical circulatory support (MCS) has made tremendous progress with over 30,000 patients receiving durable MCS devices (MCSDs) worldwide. Candidate selection is one of the most important determinants of successful operative and long-term outcomes for patients receiving MCS.

The ISHLT set forth an initiative to address the urgent need for uniform guidelines for MCS candidate selection and management, for use by MCS programs worldwide. These guidelines are intended to help clinicians and programs appropriately evaluate, implant, and manage patients with advanced heart failure who receive MCS. The primary focus of this document is the evaluation and management of patients with surgically implanted durable MCSDs. The management of patients with total artificial hearts (TAH) is not discussed in detail in these guidelines.

Types of MCS Devices

The 2 main types of implantable MCSDs are pulsatile and continuous flow. Currently available MCSDs share the same basic configuration regardless of the manufacturer and include the following components:

- a. A blood pump which is implanted in the intracorporeal position
- b. A motor housed within the pump
- c. Cannulas that connect the pump to the heart and aorta

- d. A percutaneous drive line that connects to the pump and exits the patient to allow for communication between the pump and external components
- e. A controller which monitors pump parameters and has audible and visual alarms
- f. A portable power source to allow unencumbered patient ambulation
- g. A system monitor to power the device when the patient is sedentary and to allow for pump adjustment and monitoring

Pulsatile, or positive displacement devices, are commonly referred to as first generation devices. They mimic the beating native heart with filling and emptying phases. Blood is entrained into the pump and forced out into the aorta. The pump consists of a housing divided by a flexible diaphragm, with one half housing the blood chamber and the other half containing the motor or air chamber. For those devices driven by a motor, the rotation of the motor leads to displacement of the diaphragm and ejection of blood. Other devices are driven by compressed air that is used to displace the diaphragm. Cannulas to and from the blood pump contain valves to assure unidirectional blood flow. The pump housing can be inside the body, referred to as an intracorporeal or implantable pump, or outside of the body, referred to as a paracorporeal pump. For many years, these devices provided support for patients awaiting transplantation, or alternatively, as permanent therapy for end-stage heart failure. However, a major limitation of this technology was device malfunction or failure, in large part due to wear of internal bearings.

More recently, continuous flow devices have superseded the positive displacement design. Continuous flow devices have either an axial or centrifugal configured blood pump. In contrast to pulsatile pumps, blood constantly moves through the blood pump, which may be placed next to or within the ventricle itself. Cannulas in these systems are valveless. Axial devices have a torpedo shaped impeller that lies in the same plane as the pump housing, which is connected to ball-and-cup bearings that accelerate blood along its axis. Axial pumps may also incorporate magnetic levitation of the rotor to achieve a design that does not require the use of bearings. Centrifugal devices accelerate blood circumferentially with a rotor that may be suspended within in the blood pool by electromagnetic or hydrodynamic forces.

Although patients with paracorporeal devices can be discharged and supported for long periods of time, they are less suitable than an implantable MCS for long-term use because of the large external peripherals that do not allow for mobility or ease of use and larger and more numerous percutaneous cannulae.

Devices may be configured to support the left ventricle, the right ventricle, or both. The vast majority of implants are left ventricular assist devices (LVAD), with a minority of patients requiring biventricular (BiVAD) support, TAH, or isolated right ventricular (RVAD) support. The most recent report from the Interagency Registry for Mechanically Assisted Support (INTERMACS) demonstrates that from January 2010 to June 2010, LVADs accounted for 87% of all MCS implantations in the United States, followed by BiVADs in 10%, and TAH in 3%.¹

Indication for MCS Device Implantation

As of 2012 in the United States, two major indications for MCS are accepted by regulatory bodies and payors: bridge to cardiac transplantation (BTT) or permanent therapy for end-stage systolic heart failure, referred to as destination therapy (DT).^{2,3} INTERMACS is a national registry of approved devices in the United States, as such devices under investigation are not entered into the INTERMACS database. All implanting centers in the United States are mandated to enter their data into INTERMACS in order to receive approval to implant patients as DT. As of June of 2012, there were 126 sites entering patient data and over 7000 patients in the database. The database consists of preimplantation demographics, hemodynamics and laboratory parameters. Post-implant, INTERMACS tracks patient outcomes and major adverse events as well as periodic follow-up data at prespecified intervals. Prior to the approval of continuous flow devices, approximately 200 implants per year were

entered into the INTERMACS database. Only a small fraction of these implants were for DT. After approval of continuous flow devices for BTT, pulsatile technology was quickly supplanted by continuous flow pumps, and the volume of implants recorded in INTERMACS tripled.⁴ The volume of implants again grew dramatically after the approval of a continuous flow device for DT, and the DT indication accounted for roughly one-third of all new implants.⁵ Despite the majority of patients being implanted as BTT, only about half of these patients are actually listed for transplantation at the time of MCS. While transplantation may be the ultimate intention for those not listed, these patients are often not initially eligible for transplantation for a variety of reasons. Implants under these circumstances are often colloquially referred to as “bridge to candidacy” (BTC), as in the United States the FDA does not recognize BTC as an approved indication. In some patients contraindications to transplant such as pulmonary hypertension, renal impairment, or obesity may improve after a period of MCS such that transplant candidacy may be reconsidered. Conversely, these same contraindications may persist or the patient may experience an adverse event during support that makes them ineligible for transplant. To illustrate this point, as many as 17% of DT recipients eventually undergo heart transplant, whereas many BTT patients, particularly those implanted as BTC, are deemed DT after a period of support.⁶

Bridge to recovery may also be a goal of MCS therapy in some patients. However, patients who experience recovery of their ventricles to the point where a device can be explanted account for only about 1-2% of all implants.⁴ Although BTT and DT are formally recognized as different indications in the US, many regulatory bodies do not make a distinction between BTT and DT.

Evaluation of Candidates for MCS Device Implantation

Identification and Treatment of Reversible Causes of Cardiac Disease

The initial evaluation for MCS or heart transplantation begins with the identification of potentially reversible factors that could contribute to worsening heart failure. The presence and degree of coronary ischemia, valvular heart disease, arrhythmias, or cardiotoxic agents should be determined, and appropriate therapeutic measures taken as indicated. Evidence-based heart failure therapy should be optimized, including consideration of cardiac resynchronization therapy (CRT) in appropriate patients. Temporary partial circulatory support systems (e.g. intraaortic balloon pump [IABP] or extracorporeal membrane oxygenation [ECMO]) can be

utilized for patients presenting in cardiogenic shock to stabilize hemodynamics and allow for ventricular as well as end-organ recovery. Patients presenting in shock after an acute myocardial infarction may require percutaneous or surgical revascularization in combination with temporary support.

Assessment of Potential Transplant Candidacy

Since heart transplantation currently provides superior long-term outcomes in comparison to MCS, patients who are being considered for MCS typically are also assessed for cardiac transplantation. DT is considered for patients deemed ineligible for transplant. Despite their suitability for transplant, many patients may eventually require MCS as BTT given the shortage of donor organs.

Goals of Evaluation for MCS Device Implantation

A number of factors must be considered during the patient assessment for MCS, beyond the presence of advanced heart failure. Comorbidities, surgical risk, expectation of benefit, psychological and social support, and the type of device must also be determined prior to implant. Many patients also require a period of aggressive pre-operative medical therapy to optimize their condition prior to MCS (see Section 2).

Recommendations for the Evaluation Process of MCS Candidates:

Class I:

1. All patients should have any reversible causes of heart failure addressed prior to consideration for MCS.

Level of Evidence: A.

2. All patients referred for MCS should have their transplant candidacy assessed prior to implant.

Level of Evidence: A.

Evaluation of Heart Failure Severity and Timing of MCS Implantation

Clinical Classification of Advanced Heart Failure Severity

New York Heart Association classification. The New York Heart Association (NYHA) system was introduced in

1928, and it continues to be a useful tool in the assessment of heart failure severity. Patients who have dyspnea with mild activity are considered NYHA Class III. Often, this class is informally divided into Class IIIa and IIIb, with the latter having dyspnea with very mild activity such as bathing or changing clothes. Patients who have persistent dyspnea at rest or who are inotrope dependent, regardless of their functional capacity, are considered NYHA Class IV.

INTERMACS classification. Limitations of the NYHA classification system with regard to categorization of advanced heart failure lead to the development of INTERMACS profiles. Seven profiles range in heart failure severity from patients who are NYHA Class IIIb (profile 7) to those in refractory cardiogenic shock (profile 1) (Table 1).⁷ These profiles correlate to some extent with post-implant patient outcomes, with patients in the lowest INTERMACS profile having the worst outcomes.⁸ However, large studies in patients with profiles 4 through 7 are not available, and the post-implant outcomes of these patients in comparison to those in profile 3 have not been assessed. Although not prospectively validated, the INTERMACS classification is a very useful tool to characterize the severity of illness for patients with advanced heart failure. Of note, patients with refractory arrhythmias, regardless of INTERMACS profile, constitute a high risk population.

Recommendations for the Clinical Classification of MCS Candidates:

Class I:

1. All patients being considered for MCS should have their NYHA class assessed.

Level of Evidence: C.

2. All patients being assessed for MCS should have their INTERMACS profile determined.

Level of Evidence: C.

Table 1 INTERMACS Classification

INTERMACS profile	Description	Time frame for intervention
Profile 1 Critical cardiogenic shock	Patients with life-threatening hypotension despite rapidly escalating inotropic support, critical organ hypoperfusion, often confirmed by worsening acidosis and/or lactate levels.	Definitive intervention needed within hours.
Profile 2 Progressive decline	Patient with declining function despite intravenous inotropic support, may be manifest by worsening renal function, nutritional depletion, inability to restore volume balance. Also describes declining status in patients unable to tolerate inotropic therapy.	Definitive intervention needed within few days.
Profile 3 Stable but inotrope dependent	Patient with stable blood pressure, organ function, nutrition, and symptoms on continuous intravenous inotropic support (or a temporary circulatory support device or both), but of weeks to few months. N Demonstrating repeated failure to wean from support due to recurrent symptomatic hypotension or renal dysfunction.	Definitive intervention elective over a period of weeks to few months.
Profile 4 Resting symptoms	Patient can be stabilized close to normal volume status but experiences daily symptoms of congestion at rest or during ADL. Doses of diuretics generally fluctuate at very high levels. More intensive management and surveillance strategies should be considered, which may in some cases reveal poor compliance that would compromise outcomes with any therapy. Some patients may alternate between 4 and 5.	Definitive intervention elective over period of weeks to few months.
Profile 5 Exertion intolerant	Comfortable at rest and with ADL but unable to engage in any other activity, living predominantly within the house. Patients are comfortable at rest without congestive nutrition, organ function, and activity. Symptoms, but may have underlying refractory elevated volume status, often with renal dysfunction. If underlying nutritional status and organ function are marginal, patient may be more at risk than INTERMACS 4, and require definitive intervention.	Variable urgency, depends upon maintenance of nutrition, organ function, and activity.
Profile 6 Exertion limited	Patient without evidence of fluid overload is comfortable at rest, and with activities of daily living and minor activities outside the home but fatigues after the first few minutes of any meaningful activity. Attribution to cardiac limitation requires careful measurement of peak oxygen consumption, in some cases with hemodynamic monitoring to confirm severity of cardiac impairment.	Variable, depends upon maintenance of nutrition, organ function, and activity level.
Profile 7 Advanced NYHA III	A placeholder for more precise specification in future, this level includes patients who are without current or recent episodes of unstable fluid balance, living comfortably with meaningful activity limited to mild physical exertion.	Transplantation or circulatory support may not currently be indicated.

Table 1 (continued).

Modifiers for Profiles	
TCS Temporary Circulatory Support	Can modify only patients in hospital (other devices ^{1,2,3} in hospital). Includes IABP, ECMO, TandemHeart, Levitronix, BVS5000 or AB5000, or Impella.
A Arrhythmia	Can modify any profile. Recurrent ventricular tachyarrhythmias that have any profile. Recently contributed substantially to clinical compromise. This includes frequent ICD shock or requirement for external defibrillator, usually more than twice weekly.
FF Frequent Flyer	Can modify only outpatients, designating a patient requiring frequent visits to the emergency visits or hospitalizations for diuretics, ultrafiltration, or temporary intravenous vasoactive therapy. Can modify profile 3 if at home, 4,5,6, and rarely profile 7

From: Lynne Warner Stevenson, Francis D. Pagani, James B. Young, Mariell Jessup, Leslie Miller, Robert L. Kormos, David C. Naftel, Karen Ullisney, Patrice Desvigne-Nickens, James K. Kirklin [INTERMACS Profiles of Advanced Heart Failure: The Current Picture](#) The Journal of Heart and Lung Transplantation, Volume 28, Issue 6, June 2009, Pages 535-541

Risk Stratification to Determine Timing of MCS Therapy

MCS should be considered in patients whose ventricular function is unlikely to recover or who are too ill to maintain normal hemodynamics and vital organ function without MCS. Ambulatory patients with advanced heart failure who are not inotrope dependent (INTERMACS profile 4-7), constitute one of the most challenging groups with regard to determining the optimal timing for MCS. Clinicians following these patients over time should remain vigilant to factors known to be associated with worsening prognosis. Clinical indicators of decline include worsening functional capacity, inability to tolerate neurohormonal antagonism, problematic volume management, recurrent hospitalizations, the cardiorenal syndrome, and recurrent implantable cardioverter defibrillator (ICD) shocks. Traditionally, physicians have focused on cardiac and hemodynamic indices when assessing prognosis in heart failure patients. However, it has recently been appreciated that in addition to indices of cardiac performance, measures of end-organ function also need to be assimilated into the decision making algorithm. Several risk scores incorporating cardiac and non-cardiac indices exist, and these may aid in determining prognosis by allowing clinicians to calculate expected survival for their heart failure patients with ongoing medical management at a given point in time. Several examples are described below.

Seattle Heart Failure Model. The Seattle Heart Failure Model (SHFM) was originally derived and validated in a cohort of ambulatory heart failure outpatients from four clinical trials and two observational registries. It is comprised of 20 readily available clinical, laboratory and therapeutic variables. These include age, gender, weight, ischemic etiology, NYHA class, left ventricular ejection fraction (LVEF), systolic blood pressure, medications (ACE-I, angiotensin receptor blocker [ARB], beta blocker, mineralocorticoid receptor antagonist, statin, allopurinol, and diuretics with dosage), hemoglobin, lymphocyte percent, uric acid, sodium, total cholesterol, presence of QRS \geq 120 ms, and use of CRT, ICD or both.⁹ Decreasing event-free survival has been associated with low-, medium- and high- risk scores as calculated by the model in a cohort referred for transplantation.¹⁰ When additional variables of IABP, ventilator and inotrope use were added to the model and validated against the REMATCH cohort, there was good correlation between observed outcomes and those predicted by the model in the medically treated and LVAD treated groups.¹¹ However, some studies have found the model to underestimate risk, for example in African Americans, patients listed UNOS status 2 for cardiac transplantation, and those with INTERMACS level 1. cardiogenic shock, including patients who subsequently require biventricular support.¹²⁻¹⁴ Since the model has not been validated in hospitalized patients, it should be used cautiously in this population.

Heart Failure Survival Score (HFSS). The HFSS includes 7 parameters: resting heart rate, mean blood pressure, LVEF, serum sodium, presence of ischemic heart disease, presence of QRS ≥ 120 ms, and peak VO_2 on metabolic treadmill testing. Scores are stratified into low, medium and high risk categories.¹⁵ The HFSS provides better discriminative value than peak VO_2 alone among patients of different ages, genders, ethnic groups, in those receiving beta blockers, and in the era of CRT-D.¹⁶⁻¹⁹ The need to perform metabolic treadmill testing with its inherent challenges is a limitation of this score. A comparison of the HFSS to the SHFM showed similar discriminative ability to predict outcome in patients referred for heart transplantation.¹⁰

Role of cardiopulmonary stress testing. Cardiopulmonary testing described by Mancini et al in the early 1990's has been one of the best tools in predicting long-term outcomes of non-inotrope dependent patients with advanced heart failure. It has been routinely used for many years in the determination of transplant candidacy in ambulatory patients.²⁰ The accepted thresholds for listing candidates for heart transplantation include peak $\text{VO}_2 \leq 14$ mL/kg/min in patients intolerant of a β -blocker and peak $\text{VO}_2 \leq 12$ mL/kg/min in patients who receive β -blockers. In addition, for young patients (<50 years) and women, it is reasonable to consider using alternate parameters in conjunction with peak VO_2 , such as <50% predicted peak VO_2 and VE/VCO_2 slope with adjustment of peak VO_2 to lean body mass in obese patients.²¹ It is important to note that in the current era of medical and device therapy, interpretation of the cardiopulmonary test in isolation from other predictors of survival may not be sufficient.

Need for inotropes. Inotrope dependence is an important threshold to consider for MCS. Several studies have demonstrated that patients who are inotrope dependent have extremely poor outcomes on medical therapy. Subgroup analysis from the REMATCH trial showed that randomization to VAD conferred a survival benefit in comparison to medical therapy alone in patients who were on inotropes at baseline. No survival benefit of VAD therapy was detected in the subgroup of patients who were not receiving inotropes at baseline.²² Single center and multicenter trials have demonstrated very high mortality in patients on chronic inotropic therapy.^{23,24} Heart transplantation and MCS have been shown to provide a significant survival benefit at this stage of heart failure and, in the current era, these therapeutic options should be routinely considered for patients demonstrating inotrope dependency.

Prediction of Survival Post MCS

Several risk scores have been developed to predict outcomes *after* MCS, which may be helpful in decision making. Proceeding with a futile implant places the patient and their family through undue anguish and also drains limited health care resources. Patients proceeding to MCS should have a reasonable chance of survival and improvement in quality of life.

Risk scores, including the Columbia risk score,²⁵ Lietz-Miller score,²⁶ the APACHE II score,²⁷ INTERMACS level and SHFM⁹ were retrospectively applied to a cohort of continuous flow LVAD patients, and the scores' correlation with 30 day, 90 day and 1 year mortality were evaluated. This study found that the Columbia and Lietz-Miller scores, originally developed in patients with pulsatile MCSs, were not predictive of mortality at any time point in this group of continuous flow patients. The APACHE II and INTERMACS scores correlated with 90 day and 1 year outcomes, and the SHFM correlated with outcomes at all three time points with a superior ability to stratify continuous-flow LVAD patients into low- and high-risk groups and in its prediction of post-implantation mortality.²⁸ In other studies, the Lietz-Miller score was only modestly discriminative in continuous flow patients who were classified into the high-risk group, with increased observed in-hospital mortality.²⁹ The INTERMACS score was useful in risk-stratifying patients in an analysis of implants across three large-volume centers.⁸ More recently, the HeartMate II risk score (HMRS), derived and validated using data from the HeartMate II BTT and DT trials, showed incremental improvement in survival stratified by high, medium and low risk scores.³⁰ The multivariate predictors of mortality were age, albumin, international normalized ratio (INR), implantation after May 2007, and if the implant center had performed at least 15 implants. Not only was this risk prediction model based entirely on continuous flow devices, but the score was also validated in a separate cohort of patients with continuous flow devices.

Decision Making for Advanced Therapy: MCS versus Transplantation

Once the decision to proceed with advanced therapy has been made, it can be challenging to determine whether to proceed with MCS or await a donor organ. In patients whose hemodynamics are marginal despite medical therapy, MCS should be considered early because post-transplant outcomes may be adversely affected by the development of irreversible end-organ dysfunction and secondary pulmonary hypertension. This decision has to be weighed against local donor availability, the recipient's blood group, and body size.

A general approach to the decision making for MCS (BTT and DT) is presented in Figure 1.

Recommendations for Risk Stratification for Consideration of MCS:

Class IIa:

1. Long-term MCS for patients who are in acute cardiogenic shock should be reserved for the following:
 - a. Patients whose ventricular function is either deemed unrecoverable or unlikely to recover without long-term device support.
 - b. Patients who are deemed too ill to maintain normal hemodynamics and vital organ function with temporary MCSs or who cannot be weaned from temporary MCSs or inotropic support.
 - c. Patients with the capacity for meaningful recovery of end-organ function and quality of life.
 - d. Patients without irreversible end-organ damage.

Level of Evidence: C.

2. Patients who are inotrope dependent should be considered for MCS, as they represent a group with high mortality with ongoing medical management.

Level of Evidence: B.

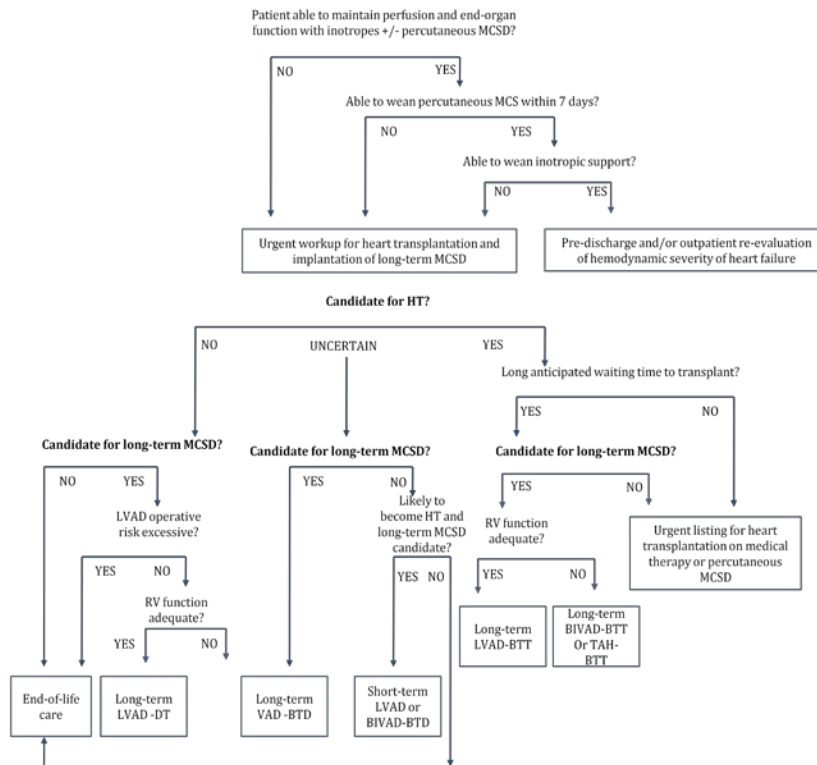
3. Patients with end-stage systolic heart failure who do not fall into recommendations 1 and 2 above should undergo routine risk stratification at regular intervals to determine the need for and optimal timing of MCS. This determination may be aided by risk assessment calculators and cardiopulmonary stress testing.

Level of Evidence: C.

4. Heart failure patients who are at high-risk for one year mortality using prognostic models should be referred to advanced therapy including heart transplant, or MCS (BTT or DT) as appropriate.

Level of Evidence: C.

Figure 1 Approach to MCSD implantation: BTT and DT



* MCS - mechanical circulatory support device, HT - heart transplant, RV - right ventricle, LVAD - left-ventricular assist device, BIVAD - biventricular assist device, TAH - total artificial heart, DT - destination therapy, BTD - bridge to decision, BTT - bridge to transplantation

Topic 2: Risk Management of Comorbidities

Cardiovascular Considerations for MCS Device Implantation

Coronary Artery Disease

Ischemic heart disease is the most common indication for device implantation, accounting for nearly half of all MCSD implants.^{31,32} Surgical revascularization may take place with a predetermined plan for temporary MCS if the patient cannot be weaned from bypass. However, this practice is not an approved indication for an intracorporeal device. For those with prior bypass surgery, the number of prior sternotomies affects surgical risk and the location of bypass grafts should be identified by computed tomography (CT) scanning to allow proper surgical planning.

Recommendations for Patients with Coronary Artery Disease:

Class IIa:

1. Patients being considered for MCS who have a history of coronary artery bypass grafting should have a chest CT scan to provide the location and course of the bypass grafts to guide the surgical approach.

Level of Evidence: C.

Acute myocardial infarction. Acute myocardial infarction with cardiogenic shock presents several challenges. Use of anticoagulation and antiplatelet therapy during the percutaneous intervention can substantially increase the bleeding risk at the time of device placement. For those who were not revascularized prior to their hemodynamic deterioration, temporary MCS may allow for stabilization and subsequent percutaneous or surgical revascularization. Permanent MCS in the first several days after ischemia of the LV apex can be complicated as the ischemic tissue can be friable and compromise the placement of the inflow cannula. Patients presenting with an acute infarction may not have sufficient remodeling of the LV cavity to allow the proper functioning of a continuous flow device, pulsatile devices may need to be considered in such a setting (see restrictive myopathy below).

Recommendations for Patients with Acute Myocardial Infarction:

Class IIb:

1. If possible, permanent MCS should be delayed in the setting of an acute infarct involving the LV apex.

Level of Evidence: C.

Non-Ischemic Cardiomyopathy

Non-ischemic cardiomyopathy is the second most common indication for MCSD implantation. Potentially reversible causes of myopathy such as myocarditis, peripartum myopathy, or environmental or self-induced toxins should be considered prior to implantation.

Restrictive and Hypertrophic Cardiomyopathies

LV support for patients with advanced heart failure due to restrictive or constrictive physiology, such as constrictive pericarditis, hypertrophic cardiomyopathy, cardiac amyloidosis or other infiltrative heart disease should be considered with caution as the literature describing the outcomes of such patients is sparse. Many of these processes affect both the left and right ventricles. Therefore, left ventricular (LV) support alone may be inadequate, and biventricular support or a TAH may be required. These myopathies may also present in their end-stages with little to no dilation of the LV chamber, which may compromise the function of a continuous flow device due to frequent suction events. For patients who require MCS but who do not have a dilated left ventricle, a pulsatile device(s) or a TAH may need to be considered.

Congenital Heart Disease

While many patients with congenital heart disease may be candidates for MCS, a careful assessment of prior surgeries, shunts, and the anatomy of the heart, great vessels, and venous system are essential. Single ventricle physiology, multiple shunts or atypical situs may be prohibitive for proper pump function or placement.

Recommendations for the Evaluation of MCS Candidates with Congenital Heart Disease:

Class I:

1. All patients with congenital heart disease should have recent imaging to fully document cardiac morphology, assess for the presence of shunts or collateral vessels, and the location and course of their great vessels.

Level of Evidence: C.

Class IIa:

1. Patients with complex congenital heart disease, atypical situs, or residual intraventricular shunts who are not candidates for LV support should be considered for a TAH.

Level of Evidence: C.

Valvular Disease

The specific operative approaches to valvular disease are addressed in Task Force 3.

Aortic

Pre-existing aortic mechanical valves. The presence of a mechanical aortic prosthesis presents a risk with MCS because the valve opens infrequently, if at all, and places the valve at risk for thrombus formation and subsequent embolic events. As such, patients who are considered for MCS typically have the mechanical valve replaced by a bioprosthetic valve at time of implant. Another option is to oversew the aortic root. However, if the patient experiences a device failure, then the ability to maintain even marginal cardiac output through the aortic valve is lost, although some cardiac output may be ejected through the pump. Notably, a functioning bioprosthetic valve does not require replacement.

Recommendations for Aortic Valve Disease:

Class I:

1. Functioning bioprosthetic prostheses do not require removal or replacement at the time of implant.

Level of Evidence: C.

2. Replacement of a pre-existing aortic mechanical valve with a bioprosthetic valve or oversewing the aortic valve at the time of implantation is recommended.

Level of Evidence: C.

Aortic regurgitation. One of the most important anatomic requirements for MCS implantation is a competent aortic valve. In the setting of aortic insufficiency, the flow from the outflow cannula regurgitates through the aortic valve back into the left ventricle and then back into the pump, creating a closed loop of flow that does not contribute to perfusion.

Recommendations for Aortic Regurgitation:

Class I:

1. More than mild aortic insufficiency should prompt consideration for surgical intervention during device implantation (see section 3).

Level of Evidence: C

Aortic stenosis. Aortic stenosis usually does not require correction before implanting an MCSD. However, significant stenosis often coexists with aortic insufficiency and may need to be surgically addressed as discussed in section 3.

Recommendations for Aortic Stenosis:

Class I:

1. Patients with aortic stenosis of any degree that is accompanied by more than mild aortic insufficiency should prompt consideration for a bioprosthetic aortic valve replacement during MCS implant (see section 3).

Level of Evidence: C.

Class IIb:

1. Patients with severe aortic stenosis may be considered for aortic valve replacement, regardless of the degree of concomitant aortic insufficiency.

Level of Evidence: C.

Aortic root disease. The presence of severe aortic root dilation may be a causal or contributing factor to aortic insufficiency and should be a consideration when approaching patients with aortic insufficiency. There are few data on lone aortic root aneurysms at the time of MCS, but the need for extensive root repair clearly adds to the risks of MCS. Lastly, aortic root calcification should be considered as it is the location of the anastomosis of the outflow graft. Extensive atheromatous disease of the ascending aorta may increase the risk of thromboembolic events at the time of implantation, and a careful pre-operative approach should include such considerations (see Section 3).

Recommendations for Aortic Root Disease:

Class IIa:

1. Patients with a history of vascular disease and/or coronary artery disease should have a pre-operative assessment of their ascending aorta for aneurysmal dilation and atherosclerotic burden with a CT scan prior to implant.

Level of Evidence: C.

Mitral Valve Considerations

Mitral valve regurgitation. A significant proportion of mitral regurgitation (MR) in end-stage heart failure is from annular enlargement secondary to LV dilation. Once the LV is decompressed with MCS, the MR frequently resolves or is only trace to mild in severity and can often be managed through adjustment in pump speeds and optimizing medical therapy. If a patient is deemed likely to recover, then the valvular surgery may be considered at the time of implant or explant (see section 3).

Recommendations for Mitral Valve:**Class IIb:**

1. Severe mitral insufficiency is not a contraindication to MCS and does not routinely require surgical repair or valve replacement, unless there is expectation of ventricular recovery.

Level of Evidence: C.

Class III:

1. Routine mitral valve repair or replacement for severe MR is not recommended.

Level of Evidence: C.

Mitral valve stenosis. Unlike aortic valve stenosis, mitral stenosis will limit LV filling and thus pump inflow, therefore limiting proper decompression of the left atrium and pulmonary circulation. Thus, significant mitral stenosis needs to be addressed at the time of implant to allow for proper decompression of the left atrium and functioning of the device.

Recommendations for Mitral Valve Stenosis:**Class I:**

1. Valve replacement with a tissue valve should be considered if there is moderate or worse mitral valve stenosis at the time of LVAD implantation.

Level of Evidence: C.

Mechanical mitral valves. The high transvalvular flow associated with an apical inflow LVAD allows for proper functioning of the valve. Therefore, the presence of a mechanical valve in this position is not felt to increase chance of embolization. However, higher maintenance INRs may be warranted.

Recommendations for Mechanical Mitral Valves:**Class III:**

1. Routine replacement of properly functioning mechanical mitral valve is not recommended.

Level of Evidence: C.

Tricuspid valve (TV). Mild to moderate tricuspid regurgitation (TR) generally is tolerated during LVAD support and frequently improves after MCS implant due to the reduction in RV afterload. However, the resolution of TR is multifactorial and depends on TV annular anatomy, leaflet anatomy (e.g., leaflet scarring secondary to pacing leads), degree of RV afterload reduction, and resolution and reversibility of high pulmonary vascular resistance. Thus, an

analysis of these factors may prompt consideration for TV repair. Generally, severe TR may compromise right ventricular (RV) function, thereby exacerbating post-operative RV function and should be addressed at the time of MCS implant (see section 3). However, there are numerous factors which contribute to the decision to repair the tricuspid valve such as the leaflet morphology, the presence and number of pacing wires, or the presence of pulmonary hypertension.

Recommendations for Tricuspid Valve**Regurgitation:****Class IIa:**

1. Moderate or greater tricuspid regurgitation should prompt consideration of surgical repair at the time of implant.

Level of Evidence: C.

Infective Endocarditis

In the presence of active endocarditis, there is a high risk of seeding the implanted device. These patients are considered ill-advised for MCS.

Recommendations for Infective Endocarditis:**Class I:**

1. Device implantation in patients who had been bacteremic should have documented clearance of the bacteremia for at least 5 days on appropriate antimicrobial therapy. This antimicrobial therapy should include a total duration of at least 7 total days prior to MCS implantation.

Level of Evidence: C.

Class III:

1. Acute valvular infectious endocarditis with active bacteremia is an absolute contraindication to MCS implantation.

Level of Evidence: C.

2. Active infection of an ICD or pacemaker with bacteremia is an absolute contraindication to MCS implantation.

Level of Evidence: C.

Intracardiac Shunts

Atrial septal defects, ventricular septal defects, or other congenital shunts may severely impact pump function and systemic oxygenation (cardio-pulmonary function) and should be addressed at the time of implantation.

Recommendations for Intracardiac Shunts:*Class I:*

1. Atrial septal defects and patent foramen ovale should be closed at the time of MCS implantation.

Level of Evidence: C.

Class III:

1. An LVAD alone in the setting of an unreparable ventricular septal defect or free wall rupture is not recommended.

Level of Evidence: C.

Intracardiac Thrombus

The presence of intracardiac thrombus is relatively common in the setting of LV dysfunction and dilation. If not recognized at the time of implantation, such thrombi may embolize distally or be ingested into a continuous flow VAD and result in pump dysfunction, hemolysis, pump thrombosis, stroke, or peripheral embolus. Right ventricular thrombi are less common, but they should be considered prior to implanting a RVAD.

Recommendations for Intracardiac Thrombus:*Class IIa:*

1. Echocardiography or CT, with contrast when necessary, should be used pre-operatively to screen for intracardiac thrombus.

Level of Evidence: C.

Arrhythmias

Atrial. Atrial tachycardia or fibrillation is usually tolerated in LVAD recipients. Such atrial arrhythmias, particularly if acute in onset, may be exacerbated by poor preimplant hemodynamics. As such these arrhythmias can resolve after a period of MCS due to decompression of the left ventricle and therefore the left atrium. For patients with an LVAD, refractory tachyarrhythmias may precipitate or induce RV dysfunction.

Recommendations for Atrial Arrhythmias:*Class I:*

1. Atrial flutter or fibrillation is not a contraindication to MCS.

Level of Evidence: C.

Class IIa:

1. Patients with medically refractory atrial tachyarrhythmias may benefit from ablation of the arrhythmia or AV node

(with subsequent ICD/pacemaker placement) prior to LVAD implantation.

Level of Evidence: C.

Ventricular. Ventricular tachycardia (VT) or fibrillation (VF) often induces or worsens RV dysfunction and thus affects proper filling of an LVAD. VT/VF associated with decompensated hemodynamics prior to implant may resolve with resolution of the heart failure state. However, VT/VF that is not associated with decompensated hemodynamics, such as in the setting of scar or myocarditis, is less likely to resolve after MCS and may require surgical ablation or warrant consideration of biventricular support. Patients who present with VT storm and require urgent MCS should be considered for a BiVAD or a TAH.

Recommendations for Arrhythmia Therapy:*Class IIa:*

1. Patients with treatment refractory recurrent sustained ventricular tachycardia or ventricular fibrillation in the presence of untreatable arrhythmogenic pathologic substrate (e.g., giant cell myocarditis, scar, sarcoidosis), should not be considered for LV support alone, but rather biventricular support or a TAH.

Level of Evidence: C.

Peripheral Vascular Disease

Peripheral vascular disease itself is not a contraindication to MCS. However, patients undergoing MCS evaluation should be assessed for the presence and severity of peripheral vascular disease. There may be concern for perioperative cerebral complications in patients with severe (>70%) carotid stenosis, especially if bilateral. In asymptomatic patients, however, carotid revascularization may not be necessary prior to MCS, as successful neurologic outcomes have been shown in patients undergoing cardiopulmonary bypass (for coronary bypass surgery) who have severe carotid disease.^{33,34} In patients who are symptomatic with transient ischemic attack (TIA) or stroke, it may be preferable to proceed with carotid revascularization prior to consideration of MCS.³⁵ With regards to femoral artery stenosis, there is a risk of compromising limb perfusion if urgent cannulation is necessary at that site for cardiopulmonary bypass.

Recommendations for Peripheral Vascular Disease:*Class IIa:*

1. All patients with known atherosclerotic vascular disease or significant risk factors for its development should be screened for peripheral vascular disease prior to MCS.

Level of Evidence: C.

Class IIb:

1. Peripheral vascular disease may be a relative contraindication to MCS based on its extent and severity.

Level of Evidence: C.

Life-Limiting Comorbidities and Multi-Organ Failure

Any severe noncardiac disease that significantly adversely affects two-year survival should be considered a relative-contraindication to device implantation, while systemic disease that limits one year survival is an absolute contraindication. Such diseases include, but are not limited to, advanced or irreversible pulmonary disease, advanced hepatic disease (cirrhosis and portal hypertension), severe peripheral vascular disease, metastatic cancer, and irreversible neurologic or neuromuscular disorders. Multi-organ failure, defined as multiple, progressive, end-organ dysfunction not responsive to medical therapy is almost invariably associated with poor post-implant outcome after MCS.⁴

Recommendations for Life-Limiting Comorbidities and Multiorgan Failure:*Class III:*

1. Consideration of MCS in the setting of irreversible multi-organ failure is not recommended.

Level of Evidence: C.

Pulmonary Hypertension

Increased pulmonary vascular resistance has traditionally been associated with increased risk of early cardiac allograft dysfunction.^{36,37} Pulmonary vascular resistance must be assessed with invasive hemodynamics. A transpulmonary gradient >15 mmHg or a fixed pulmonary vascular resistance >5 Wood units has been associated with an increased 30 day mortality rate.³⁷ Patients with elevated pulmonary vascular resistance refractory to sequential aggressive heart failure medical therapy, continuous inotropy, and/or an oral phosphodiesterase inhibitor for 4 to 8 weeks as determined with serial right heart catheterization should be considered for MCS device implantation. Chronic LVAD support can effectively reduce elevated pulmonary arterial pressures even in those deemed refractory to aggressive medical therapy.³⁸

Recommendations for Pulmonary Hypertension:*Class I:*

1. All patients being considered for MCS should have an invasive hemodynamic assessment of pulmonary vascular resistance.

Level of Evidence: C.

Neurologic Function

Knowledge about the neurologic and neurocognitive status and history of patients referred for MCS is critical, particularly for those referred emergently. A thorough neurologic examination should be performed to determine potential neurologic risk factors and contraindications for device implantation.³⁹ Specifically, post-stroke deficits should be assessed to determine the cognitive ability of the patient to understand device limitations, alarms, and troubleshooting, and their physical ability to care for the device, such as changing batteries or controllers. All patients should be screened for dementia and those that screen positively should have more formal neuropsychological testing. In emergency cases with uncertain neurologic recovery, a short-term MCS may be considered to allow for proper assessment of the neurologic status of the patient. A recent or evolving stroke is considered at least a temporary contraindication.

Recommendations for Neurologic Function:*Class I:*

1. A thorough neurologic examination should be performed on every patient being considered for MCS. Neurologic consultation should be obtained for patients with significant neurologic disease or dementia, or significant atherosclerotic vascular disease of their carotid or vertebral systems.

Level of Evidence: C.

2. All patients being considered for MCS should have carotid and vertebral Doppler examination as a screen for occult vascular disease.

Level of Evidence: C.

3. CT scan or magnetic resonance imaging (MRI) is warranted in patients with previous stroke to establish a pre-operative baseline study.

Level of Evidence: C.

Class III:

1. MCS is not recommended in patients with neuromuscular disease that severely compromises their ability to use and care for external system components, or to ambulate and exercise.

Level of Evidence: C.

Coagulation and Hematologic Disorders

Attempts should be made to correct or improve clotting abnormalities, similar to the assessment of a patient undergoing any major surgical procedure. All patients should have their PT/PTT, INR, and platelet count assessed. Pre-operative coagulopathies are common in heart failure patients due to hepatic dysfunction and the use of anti-coagulant or anti-platelet medications.⁴⁰ When possible, these medications should be stopped prior to implant. There is controversy about continuing the use of thienopyridine anti-platelets (e.g. clopidogrel) during the peri-operative period in patients who have recently received a drug-eluting stent. Few data are available to guide this decision; thus, the risks and benefits for each patient must be weighed individually. Heparin-induced thrombocytopenia (HIT) is a clotting abnormality that warrants consideration for patients who have a platelet count <150,000 or in those who have had a >20% decrease in their baseline platelet count.⁴¹ The serotonin release assay is the most reliable test for establishing the diagnosis of HIT.⁴² The presence of HIT may require the use of alternative anti-coagulants (e.g. argatroban and bivalirudin). However, if the patient is stable, HIT can be reassessed over time and if negative, heparin can then be re-considered.^{43,44}

Recommendations for Coagulation and Hematologic Disorders:**Class I:**

1. All patients evaluated for MCS therapy should have a PT/INR, PTT, and platelet count assessed pre-operatively.

Level of Evidence: C.

2. Baseline abnormalities in coagulation parameters not due to pharmacologic therapy should prompt an evaluation to determine the etiology prior to implant.

Level of Evidence: C.

3. Patients with a history of thrombophilia prior to MCS should have a hypercoagulable assessment prior to implant.

Level of Evidence: C.

Class IIa:

1. Patients with a clinical syndrome of HIT should have confirmatory testing performed.

Level of Evidence: C.

2. Thienopyridine anti-platelet agents should be stopped at least 5 days prior to surgery unless there is a compelling indication for continued use.

Level of Evidence: C.

Malignancies

Recent hematologic or solid organ malignancies, with the exception of many non-invasive basal and squamous cell skin cancers, are an absolute contraindication to heart transplantation. However, in selected cases, MCS can be used to allow for proper oncologic follow up. Patients who have maintained disease free status may be candidates for transplantation. Collaboration with oncology should occur to assess the risk of tumor recurrence in patients being evaluated for BTT who have a history of a treated malignancy. Alternatively, patients who have a reasonable cancer recurrence-free life expectancy (>2 years) may be candidates for MCS as DT.

Recommendations for Malignancy:**Class I:**

1. Patients with a history of a treated cancer who are in long-term remission or who are considered free of disease may be candidates for MCS as BTT, with the involvement of an oncologist to determine risk of recurrence or progression.

Level of Evidence: C.

Class IIa:

1. Patients with a history of recently treated or active cancer who have a reasonable life-expectancy (>2 years) may be candidates for DT if evaluated in conjunction with an oncologist to determine risk.

Level of Evidence: C.

Class III:

1. MCS as BTT or DT is not recommended for patients with an active malignancy and a life expectancy of <2 years.

Level of Evidence: C.

Diabetes

Diabetes in and of itself is not a contraindication to MCS. Rather the burden of end-organ disease determines the risk for patients with diabetes. As many as 10% of patients who undergo device implantation have diabetes.⁴⁵ Single center

studies have reported that carefully selected patients with diabetes on insulin or oral therapy can undergo successful pump placement without increased one year mortality.⁴⁵⁻⁴⁷ However, poorly controlled diabetes with end-organ damage, such as peripheral neuropathy, may lessen a patient's quality of life.

Recommendations for Diabetes:

Class I:

1. All patients should be screened for diabetes prior to MCS with a fasting glucose.

Level of Evidence: C.

2. All patients with an abnormal fasting glucose or established diabetes should have a hemoglobin A1c drawn and be assessed for the degree of end-organ damage (retinopathy, neuropathy, nephropathy, and vascular disease).

Level of Evidence: C.

3. Patients with poorly controlled diabetes should have consultation with an endocrinologist prior to implantation.

Level of Evidence: C.

Class IIb:

1. MCS is relatively contraindicated in the setting of diabetes related proliferative retinopathy, very poor glycemic control, or severe nephropathy, vasculopathy, or peripheral neuropathy.

Level of Evidence: C.

Pregnancy

Although successful pregnancy has been reported in LVAD recipients, pregnancy remains a relative contraindication to MCS.⁴⁸⁻⁵¹ Women who are of child bearing potential who have MCS should be counseled to use contraception. The use of hormonal-based contraception has known thrombotic risks and these risks must be considered in the setting of MCS. However, evidence is lacking to quantify this risk.

Recommendations for Pregnancy:

Class I:

1. Use of contraception in women of child bearing age after MCS is recommended.

Level of Evidence: C.

Class III:

1. MCS in the setting of active pregnancy is not recommended.

Level of Evidence: C.

Advanced Age

Although the risk of operative complications with LVAD implantation increases with patient age,⁵² encouraging survival outcomes with device implantation have been observed in patients >70 years old.⁵³ While advanced age in and of itself does not constitute a contraindication to MCS implantation, older patients may be more vulnerable to complications due to their many coexisting co-morbidities. Moreover, daily living with the device may present much greater physical, psychological, and emotional challenges than those experienced by younger patients.

Recommendations for Age:

Class IIb:

1. Patients >60 years old should undergo thorough evaluation for the presence of other clinical risk factors that may decrease survival or quality of life after MCS.

Level of Evidence: C.

Psychosocial Evaluation of MCS Candidates

Potential candidates considered for MCS implantation should undergo comprehensive psychosocial evaluation.⁵⁴ The goals of the evaluation process are to (1) identify and appraise any potential psychosocial risks for poor outcome after MCS including risks related to the individual's psychiatric history or social stability; (2) ensure that the prospective MCS recipient comprehends the risks, benefits and implications of device implantation to the patients and caregiver; (3) determine the patient's and caregiver's ability to cope with major surgery and the requirements of life on MCS and review lifestyle circumstances (e.g. employment, family relationships) that might be impacted by MCS; (4) determine that support systems are in place and ensure a realistic plan for recovery and living with the device.

Psychosocial evaluation of MCS candidates should be conducted by a clinical social worker, psychologist, or other similarly qualified health-care professional. The evaluation should be done as soon as device therapy is considered, so that pump implantation can be avoided if major psychosocial contraindications are apparent. The complete psychosocial evaluation should cover the following elements: (1) assessment of the general demographic information; (2) physical functioning; (3) psychological and psychiatric status; (4) behavior and coping; (5) family and support network and (6) financial situation, as shown in Table 2. Patients in cardiogenic shock may require a brief psychosocial evaluation to exclude the major contraindications.

Table 2 Suggested Components of the Psychosocial Evaluation Interview

Component	Details
Demographics	Age, gender, educational level, living situation, cultural background, religious beliefs and practices, significant relationships, employment, lifestyle, community activities, legal offense history and citizenship
Physical functioning	Ability to safely operate and care for the device (e.g. degree of sensory or physical impairment). In the case of patient disability, the caregiver's ability to safely operate and care for the device.
Psychological and psychiatric status	<ul style="list-style-type: none"> • Presence of current and prior psychiatric disorders, including but not limited to mood, anxiety, substance use and personality disorders. • Current or prior therapeutic interventions (counseling, medications). • Psychological stressors.
Cognitive ability and capacity to comprehend	Formal neurocognitive evaluation
Behavior and coping	Coping skills used to manage previous life or health-related stressors
Adherence	Determine history of adherence to medical therapy, keeping clinical appointments and following diet and exercise recommendations
Substance abuse	Current and prior use of cigarettes, alcohol and illicit drugs
Family and support network	<ul style="list-style-type: none"> • Social support networks available during recovery from surgery. • Ability of support network to provide care on an ongoing basis if needed.
Caregiver burden and support systems	Caregiver age, physical function and general health
Financial support	<ul style="list-style-type: none"> • Financial stability. • Ability to handle financial obligations. • Disability assistance available • Health insurance (if relevant)

Assessment of Psychosocial Risk Factors

Physical functioning. Patients should be assessed for their physical and cognitive ability to safely operate the device in their home situation. In situations where deficits exist, an individualized plan of assessing competency and safety should be devised. Patients and/or caregivers should be pre-assessed to determine competency to safely assume responsibility for the following: changing power sources, charging batteries, managing alarms and emergencies, stabilizing the driveline and changing the driveline dressing, monitoring and reporting signs and symptoms to the device coordinator.

Home environment. The patient's physical surroundings should be safe. There should be grounded electricity outlets available, access to telephone, free of clutter or unsafe surroundings and accessible by patient, support network and emergency services.

Psychological and psychiatric risk factors. All MCS candidates who are of high psychosocial risk should undergo a thorough psychiatric evaluation to determine potential risk factors and contraindications for MCS implantation.⁵⁵⁻⁵⁸ Patients who suffer from active psychiatric illness, and in particular major depression, schizophrenia, or anxiety are at high risk for non-adherence to therapy which may jeopardize

device outcomes.^{55,56} Patients with lower levels of social support are at particularly high risk of developing significant psychiatric difficulties post-heart transplant or implant. In addition, morbidity and mortality after transplantation is increased in the setting of serious psychiatric illness.^{55,59,60} Patients with a significant psychiatric history should be referred to a psychiatrist or therapist as early as possible to ensure that proper treatment is initiated or optimized.

Recommendations for Psychological and Psychiatric Evaluation:

Class I:

1. All patients should have a screen for psychosocial risk factors prior to MCS.

Level of Evidence: C.

2. All patients should have a screen for cognitive dysfunction prior to MCS.

Level of Evidence: C.

3. Family, social, and emotional support must be assessed prior to MCS.

Level of Evidence: C.

4. Patients with a history of a significant psychiatric illness who are considered for MCS should undergo a thorough psychiatric and psychological evaluation to identify potential risk factors.

Level of Evidence: C.

Class III:

1. MCS should not be performed in patients who are unable to physically operate their pump or respond to device alarms. In addition, an inability to report signs and symptoms of device malfunction or other healthcare needs to the MCS team, or patients who live in an unsafe environment are all contraindications to implantation.

Level of Evidence: C.

2. MCS is not recommended in patients with active psychiatric illness that requires long-term institutionalization or who have the inability to care for or maintain their device.

Level of Evidence: C.

Adherence to medical therapy and coping skills. Compliance with medical recommendations, drug therapy, lifestyle changes and regular follow-up are crucial to the long-term success of MCS.

Medical non-compliance is associated with inferior MCS outcomes. Patients who have displayed non-adherent behaviors prior to pump implantation are at significant risk of displaying the same behaviors after surgery.⁶¹⁻⁶³ Higher levels of social support seems to be an important factor in mitigating non-adherence behaviors.^{64,65} Therefore, in patients being actively considered for MCS with a history of non-adherent behavior, a strong social support system should be available. Assessment of coping strategies should include standardized testing where possible, as this may provide more objective information regarding coping strategies of patients and their caregivers and the ability to provide structured intervention where necessary.

Family and social network. Due to the similarities related to ongoing medications, attendance at medical appointments, and the stresses experienced by MCS patients, the social support requirements should be similar to those expected for heart transplantation recipients. The patient's social support network becomes more important when complications post implant occur. In the case of high risk patients such as those who have been previously non-adherent or those with psychiatric illness, lack of social support has been shown to significantly predict poor outcomes.^{64,65} Although not demonstrated specifically in VAD patients, lack of a social partner is a significant predictor of graft loss after heart transplantation.⁶⁶

Recommendations for Adherence to Medical Therapy and Social Network:

Class I:

1. Assessment of medical compliance, social support and coping skills should be performed in all candidates for MCS device implantation.

Level of Evidence: C.

Class IIa:

1. Lack of sufficient social support and limited coping skills are relative contraindications to MCS in patients with a history of non-adherent behavior.

Level of Evidence: C.

Class III:

1. Poor compliance with medical regimens is a risk factor for poor outcomes related to MCS and mortality after heart transplantation. Patients who demonstrate an inability to comply with medical recommendations on multiple occasions should not receive MCS.

Level of Evidence: C.

Tobacco use. Tobacco exposure has been correlated with the development of cardiovascular disease, chronic obstructive pulmonary disease, and lung cancer. Life sustaining therapy with MCS should not be offered to patients who continue unhealthy habits. The patient and family members should understand that continuing to use tobacco while supported on MCS may jeopardize heart transplant candidacy and has unknown effects on platelet function and risk of pump thrombosis. Centers should provide the recommended smoking cessation support for patients and family members if necessary.

Recommendations for Tobacco Use:

Class I:

1. Patients considered for MCS implantation should receive education on the importance of tobacco cessation and reduction in environmental and second-hand exposure before device implantation and throughout the duration of device support.

Level of Evidence: C.

Class IIa:

1. Previous tobacco use should not preclude emergent pump implantation as a potential BTT. However, patients should not be made active on the transplant waiting list until 6 months of nicotine abstinence has been proven.

Level of Evidence: C.

Alcohol and substance abuse. Patients who abuse alcohol and other substances experience higher non-adherence and mortality rates.⁶⁷ Excessive alcohol or illegal drug use should be a contraindication to elective device implantation. If a patient is already involved in a recovery program, the continuation of this form of treatment should be mandatory. Referral to a substance abuse expert should be made as an adjunct to therapy.

Recommendations for Alcohol and Substance Abuse:

Class IIb:

1. The patient should be abstinent for a period of time as determined *a priori* by the program in order to be considered for MCS therapy.

Level of Evidence: C.

Class III:

1. Active substance abusers (including alcohol) should not receive MCS therapy.

Level of Evidence: C.

Caregiver Burden

It must be kept in mind that caregiver burden is significant in many cases of MCS support. Informed consent from the caregiver designated to assist the LVAD recipient is just as important as acquiring consent from the patient, as caregivers are informally “recruited” to provide continuous care after patients are discharged home. Caregivers undergo vigilant device education and are expected to respond to device emergencies 24 hours a day. This imposes significant physical, psychological, and financial strain on caregivers.^{68,69} Fear of device emergencies, depression, anxiety and posttraumatic stress disorders have all been described among caregivers.^{70,71} For this reason, a substantial caregiver burden may occasionally become the reason to forgo LVAD surgery for the patient. This is not uncommon in elderly patients who would have to rely on their spouses for help, who often have their own medical problems. MCS programs should therefore have support mechanisms in place for caregivers of MCS patients.

Recommendations for Caregiver Burden:

Class I:

1. Caregiver burden should be assessed prior to MCS implantation to assure that support will be available. Agreement on behalf of the patient is not sufficient.

Level of Evidence: C.

Class IIb:

1. Significant caregiver burden or lack of any caregiver is a relative contraindication to patient’s MCS implantation.

Level of Evidence: C.

Financial situation and insurance coverage. In countries where socialized medicine is unavailable, a complete assessment of the patient’s financial situation should be performed. Insurance and prescription coverage, or a charity care initiative must be thoroughly established to determine whether the patient has adequate financial support to undergo VAD therapy or heart transplantation.

Class IIa:

1. A mechanism must be in place to provide financial aid or support for post-operative care for those who have limitations to medical coverage. Depending on the country, this may be provided by the government, insurance agent or an individual’s family.

Level of Evidence: C.

ABBREVIATIONS

ACE-I = angiotensin converting enzyme inhibitor
 ARB = angiotensin receptor blocker
 BiVAD = biventricular assist device
 BTC = bridge to candidacy
 BTT = bridge to transplant
 CRT = cardiac resynchronization therapy
 CT = computed tomography
 DT = destination therapy
 ECMO = extracorporeal membrane oxygenation
 HFSS = Heart Failure Survival Score
 HIT = heparin induced thrombocytopenia
 HMRS = HeartMate II risk score
 IABP = intraaortic balloon pump
 ICD = implantable cardioverter defibrillator
 INR = international normalized ratio
 INTERMACS = Interagency Registry for Mechanically Assisted Support
 LV = left ventricular
 LVAD = left ventricular assist device
 LVEF = left ventricular ejection fraction
 MCS = mechanical circulatory support
 MCSD = mechanical circulatory support device
 MR = mitral regurgitation
 MRI = magnetic resonance imaging
 NYHA = New York Heart Association
 PT/PTT = prothrombin time/partial thromboplastin time
 REMATCH = Randomized Evaluation of Mechanical Assistance for the Treatment of Congestive Heart Failure
 RV = right ventricular
 RVAD = right ventricular assist device
 SHFM = Seattle Heart Failure Model
 TAH = total artificial heart
 TIA = transient ischemic attack
 TR = tricuspid regurgitation
 TV = tricuspid valve
 UNOS = United Network for Organ Sharing
 VF = ventricular fibrillation
 VT = ventricular tachycardia

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The 2013 International Society of Heart and Lung Transplantation Guidelines for Mechanical Circulatory Support

Task Force 2: Patient Optimization, Consent, and Appropriate Timing for Mechanical Circulatory Support: Modifiable Risk Management Prior to Implantation

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Introduction

Evaluation of a patient for long-term mechanical support parallels the evaluation for cardiac transplantation. Salvage situations certainly exist, precluding the ability to perform a thorough evaluation. Nevertheless, a comprehensive assessment of the patient and preoperative optimization using a multi-systems approach prepares the patient for the best chance of a successful outcome. Preoperative risk scoring systems use markers of physiologic perturbations to estimate outcomes. They provide guidance in preoperative organ optimization, which has been shown to influence outcomes, but they cannot circumvent experienced clinical judgment. The final portion of this section includes a template of a suggested patient consent form (Appendix 1). This template is provided in an effort to develop a standard for which clinicians and health care systems can adapt to meet the needs of their individual institution.

Preoperative Management

Obesity

Although obesity has been shown to increase the perioperative risk for infections, the overall risk for infection after mechanical circulatory support device (MCS) placement for durable implants is likely to be driven by multiple factors. One study has shown an increased risk for driveline infections¹ while another demonstrated an increase in the cumulative incidence of driveline infections, sepsis and reoperations for infection,² most studies have shown that the body mass index (BMI), including the level of morbid obesity, does not have a detrimental effect on infection, or overall outcomes, with careful patient selection.³⁻⁶ However wait

times may be longer for the obese who are implanted as bridge to transplant (BTT).

To date, published data are limited on the morbidly obese and the utilization of mechanical circulatory support (MCS) as a “bridge to weight loss” (in BTT patients). MCS resulted in significant weight loss over medically managed patients in one small study.⁴ In another retrospective analysis, patients with the HeartMate XVE device lost weight while those with the HeartMate II device did not⁶, while in another study there was no significant weight loss for the obese compared to the nonobese while on support.²

Recommendations for Obesity:

Class I:

1. Obesity (BMI 30-35 kg/m²), in and of itself, is not a contraindication to MCS, but surgical risk and attendant comorbidities must be carefully considered prior to MCS in the morbidly obese (BMI ≥ 35 kg/m²).

Level of Evidence: B.

Patient Expectations

Mechanical support has demonstrated improved survival, particularly when used as destination therapy (DT). It also results in substantial improvements in quality of life.^{7,8} Nevertheless, this therapy is associated with several risks including infection, bleeding complications, device malfunction, arrhythmias, and stroke. These adverse events and their frequency should be discussed with the patient to facilitate shared decision-making (Universal Consent form, Appendix 1).⁹

Recommendations for Managing Patient

Expectations:

Class I:

1. A detailed informed consent should discuss the salient aspects of the MCS placement, common expectations, and possible complications in the peri- and post-operative period.

Level of Evidence: C.

Class IIb:

1. Quality of life should be assessed prior to and following MCS implantation to help guide patient decisions. Assessment tools including Minnesota Living with Heart Failure (MLWHF), Sickness Impact Profile, Euroqol and others should be considered to help guide patient care.

Level of Evidence: C.

Palliative Care

According to American College of Cardiology/American Heart Association (ACC/AHA) guidelines, palliative care should be part of the management of stage D patients with heart failure.¹⁰ Palliative care consultation can help frame expectations, address end of life issues and needs, support families, and facilitate physician patient communication. Palliative care issues are discussed in Section 5 of these guidelines.

Recommendations for Palliative Care:¹¹

Class IIa:

1. Palliative care consultation should be a component of the treatment of end-stage heart failure, and it should be addressed during the evaluation phase for MCS. In addition to symptom management, goals and preferences for end of life should be discussed with patients receiving MCS as DT.

Level of Evidence: C.

Renal Function

Renal dysfunction at the time of MCS implantation is common, and it results from a combination of factors including renal hypoperfusion, elevated right atrial pressures, intensive diuretic therapy, pre-existing intrinsic renal disease, and the adverse neurohormonal milieu of heart failure. Preoperative management focuses on addressing these etiologies and avoiding nephrotoxic drugs and intravenous contrast. Renal perfusion pressure is determined by the mean arterial blood pressure minus the central venous pressure. Thus, in order to improve renal perfusion pressure, both forward flow and venous congestion must be addressed. The use of inotropes or vasopressors and even an intraaortic balloon pump (IABP) can improve renal blood flow.

Aggressive attempts at diuresis are important, but progressive cardio-renal dysfunction may require the use of mechanical volume removal. Improving renal function is particularly important to optimize patient outcomes. Severe class IV renal insufficiency and end stage renal failure requiring chronic dialysis after MCS is associated with high levels of morbidity and mortality, particularly in the DT population.¹²⁻¹⁴

Although there is some evidence from animal studies that continuous flow results in periarteritis in the kidney,¹⁵ several small studies have shown there are no notable differences in renal recovery with continuous flow versus pulsatile flow devices.¹⁶⁻¹⁸ In a study of 309 patients from the HeartMate II BTT trial, renal function improved over 6 months of follow-up. However, the mean creatinine at study entry was 1.4 +/- 0.5 mg/dL.¹⁹ The effects of MCS on patients with more advanced renal dysfunction are not well established, since patients with a creatinine ≥ 3.5 mg/dL or on chronic dialysis were excluded from both the HeartMate II BTT and DT trials.^{20,21} A single center study of both pulsatile and continuous flow devices demonstrated that patients undergoing MCS with a preimplant creatinine clearance (CrCl) <45 mL/min had a substantial overall improvement in renal function at six months as compared to baseline, 34.1 vs. 62.3 mL/min respectively, $p=0.0001$.²² Despite this overall improvement, only 53% of this population was able to achieve a CrCl >60 mL/min.

Recommendations for Managing Renal Function:

Class I:

1. All patients should have their renal function monitored closely prior to MCS implantation.

Level of Evidence: C.

2. Patients with volume overload and/or poor output in the setting of renal dysfunction should have a period of hemodynamic optimization (with inotropic support if clinically indicated) combined with aggressive diuresis or mechanical volume removal.

Level of Evidence: C.

3. Assessment of serum creatinine (SCr), blood urea nitrogen (BUN), and a 24 hour urine collection for creatinine clearance and proteinuria after patients are hemodynamically optimized should be performed in all patients being considered for MCS.

Level of Evidence: C.

Class III:

1. Permanent dialysis should be a contraindication for destination therapy.

Level of evidence: C.

Nutrition

Poor nutrition is associated with more severe heart failure. There is little prospective evidence that even intensive nutritional interventions are efficacious in patients with advanced heart failure awaiting MCS. Furthermore, the risk of patient deterioration, which is associated with worse outcomes after MCS implantation, must be weighed against the time needed to make a meaningful impact on the patient's nutritional status preimplantation. Studies of early aggressive nutritional interventions in intensive care unit (ICU) patients demonstrated that patients achieved caloric goals more often with aggressive intervention, but these interventions did not result in changes in length of stay or hospital mortality.²³ Thus, nutritional assessment may be most useful to risk stratify patients preoperatively and ensure timely intervention postoperatively. However patients should be evaluated by an interdisciplinary team which not only focuses on assessment, but also determines and administers a comprehensive nutritional support plan either pre-operatively or post-operatively.²⁴

Studies of both pulsatile and continuous flow devices have shown improvement in albumin over time with MCS, but the impact of nutritional interventions before MCS on outcomes after MCS has not been evaluated. Data from the Interagency Registry for Mechanically Assisted Support (INTERMACS) have also demonstrated that patients who are less ill at implantation have a significantly higher prealbumin (12.5 vs. 15 vs. 21 vs. 21 mg/dL, INTERMACS profiles 1-4, respectively, $p < 0.0001$) and albumin (2.95 vs. 3.2 vs. 3.6 vs. 3.5 mg/dL, INTERMACS profiles 1-4 respectively, $p < 0.0001$).²⁵

Recommendations for Nutrition Assessment:*Class I:*

1. All patients should have assessment of their nutritional status prior to MCS implantation with at least a measurement of albumin and prealbumin.

Level of Evidence: B.

2. Patients who have indices of malnutrition prior to MCS implantation should have an evaluation by a nutritional consultation service.

Level of Evidence: C.

Class IIa:

1. Patients who have evidence of malnutrition prior to MCS implantation should be considered for nutritional interventions prior to implantation if the patient's clinical status allows.

Level of Evidence: C.

Class IIb:

1. Patients who have evidence of severe malnutrition prior to MCS implantation should consider having their implantation delayed to maximize their nutritional status, if the patient's clinical status allows.

Level of Evidence: C.

Infection Risk

Chronic heart failure results in a state of both chronic inflammation and immunosuppression, with a linear correlation between the severity of heart failure and the degree of immunosuppression.^{26,27} In addition to heart failure, other chronic conditions such as malnutrition and renal failure can exacerbate the risk for infection.^{28,29} Many patients with heart failure who are being considered for MCS therapy have had long hospitalizations resulting in an increased risk for colonization with and infection from antibiotic resistant organisms. Furthermore, peripherally inserted central catheter (PICC) lines, central venous catheters, indwelling urinary bladder catheters, IABP, and endotracheal tubes represent ongoing infectious risks to the patient. Care must be taken to remove all unnecessary lines prior to implant. Indwelling lines that are required for the patient's clinical stability or safety should be inspected and changed with cultures drawn, if suspicious. If time and clinical status permits, a preoperative dental assessment for all patients is warranted.

Recommendations for Managing Infection Risk:*Class I:*

1. All patients should have all unnecessary lines and catheters removed prior to MCS implantation.

Level of Evidence: C.

2. All patients should have a dental assessment and any remedial treatment, if time and clinical status permits, prior to MCS implantation.

Level of Evidence: C.

Active Infection

Patients must be assessed for signs of infection. Any infection identified prior to implant should be aggressively treated and eradicated, if the patient's clinical status permits. Active infection at the time of implantation can be highly morbid, resulting in seeding of the device that is rarely abated, even with prolonged and aggressive antibiotic therapy. Once a device becomes infected in selected patients, the infection may or may not be chronically suppressed with selective antibiotics and surgical therapies; alternatively, sometimes the only recourse is to consider a higher-risk transplant for those patients who will not tolerate explant. For some patients, it may be appropriate in select situations to perform a device

exchange. While it is ideal to explant the older device and provide hemodynamic support and antibiotics for a period of treatment, this frequently is not the best clinical course, and it is not feasible for some patients. This strategy should be considered whenever possible because it is common to reseed the newly implanted device. With a pump exchange, treatment of an infection prior to MCS implantation must be balanced with the risk of recurrent infection and the risk of clinical deterioration. In such cases, consultation with an infectious disease team is critical.

Recommendations for Managing Active Infection:

Class I:

1. Patients with active infections should receive an appropriate course of antibiotic therapy as directed by an infectious disease specialist prior to implantation of a MCS.

Level of Evidence: C.

Antibiotic Prophylaxis

All patients should receive prophylactic antibiotic treatment. The regimen will vary from center to center, but a patient care pathway should be in place to ensure all patients receive their antibiotics dosed appropriately to the patient's renal function and timed to be most efficacious with the upcoming surgery. Preoperative antibiotics typically consist of gram-positive coverage, with Methicillin-resistant *Staphylococcus aureus* (MRSA) coverage (if at risk for MRSA infection, known to be colonized with MRSA, or if hospitalized >48 hours), and mupirocin ointment to the nares. The role of broad-spectrum Gram-negative coverage is of unclear value and should be used by centers based upon known epidemiological data, risk of infection with these pathogens, colonization rates, and individual optimization. Other considerations for antifungal coverage should be considered in select high-risk patients or in specific regions known to have potentially pathological organisms endogenous to a given region.³⁰⁻³²

Recommendations for Antibiotic Prophylaxis:

Class I:

1. Patients should receive preoperative antibiotics with broad spectrum gram-positive and gram-negative coverage as appropriate prior to MCS implantation.

Level of Evidence: C.

2. Routine antibiotic prophylaxis should include at least one dose prior to surgery administered within 60 minutes of the first incision, remain in the therapeutic range throughout their duration, and not extend beyond 24-48 hours.

Level of Evidence: C.

3. Patients should have a nasal swab to screen for MRSA and receive topical treatment if positive prior to MCS implantation.

Level of Evidence: C.

Hepatic Dysfunction

Hepatic dysfunction is occasionally a result of circulatory shock from acute decompensation. Conversely, chronic-occult hepatic dysfunction is not uncommon with chronic heart failure, especially in the setting of poor RV function, persistently high right atrial pressures, or Fontan circulation. Many such patients may have significant hepatic dysfunction with no or only modest abnormalities of alanine aminotransferase (ALT) or aspartate aminotransferase (AST) or total bilirubin. Providers should have a low threshold to screen such patients with ultrasonography or even CT scanning to assess hepatic architecture for signs of cirrhosis. If there is evidence of cirrhosis, a hepatologist should be involved early in the patient's management, and there should be consideration given to performing a transjugular hepatic biopsy to assess for the presence and degree of cirrhosis. Those with acute decompensation and elevations of transaminases or bilirubin should receive aggressive therapy with diuresis, inotropes, and IABP as necessary to improve hepatic function prior to implantation. Those patients that have confirmed cirrhosis or end stage liver disease are poor candidates for MCS except in very rare circumstances.^{33,34}

Centrilobular necrosis manifested by elevation of AST and ALT is a common phenomenon in acute cardiogenic shock. A low cardiac output and elevated central venous pressure in part mediates the etiologic basis for the necrosis. In fact, it has been hypothesized that chronic passive congestion may predispose the liver to injury from hypoperfusion.³⁵

The degree of liver disease may be assessed through both the Childs-Pugh class and the Model for End Stage Liver Disease (MELD) score. The Childs-Pugh class is determined by the presence or degree of ascites, bilirubin, and international normalized ratio (INR) (Table 1). Those with Child-Pugh class A are generally at increased, but acceptable, risk for acute perioperative hepatic decompensation, whereas those with class B and C are at much higher risk for this complication. The MELD score is a weighted calculation of creatinine, bilirubin, and INR levels. The MELD score is an

independent predictor of poor outcome in multivariate analyses of a single-center patient cohort and from the INTERMACS database. An increasing MELD score is associated with the need for more perioperative blood

products. An absolute score >13-17 is predictive of poorer surgical outcomes, and in those patient who do survive the peri-operative period, there is a decrease in long-term outcomes with increased morbidity.^{34,36,37}

Table 1 Assessment of Hepatic Function

Child-Pugh Score			
Measure	1 point	2 points	3 points
Bilirubin (mg/dL)	< 2.0	2.0-3.0	> 3.0
Albumin (mg/dL)	> 3.5	2.8-3.5	< 2.8
Ascites	Absent	Mild	Moderate
Encephalopathy	None	Suppressed with meds	Refractory to meds
INR	< 1.7	1.7-2.3	> 2.3
Scores	Class		
5-6	A		
7-9	B		
10-15	C		
MELD score			
= [(0.957*ln(Cr mg/dL)) + (0.378*ln(bilirubin (mg/dL)) + (1.120*ln(INR)))] * 10			
If patient was on HD at least twice in the past week then Cr = 4			
Score	30-day post-op mortality		
0-5	3.2%		
6-10	8.6%		
11-15	21.9%		
16-20	44.0%		
21-25	55.6%		
26+	87.5%		

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Even in the absence of hepatic failure, patients with hepatic dysfunction prior to MCS implantation are at increased risk of bleeding, and may have substantial transfusion requirements. Such patients are at greater risk for allosensitization, lung injury with exacerbation of right ventricular (RV) dysfunction, and infection. To minimize the risk of bleeding, coagulation abnormalities should be

corrected, and unnecessary antiplatelet agents should be discontinued prior to MCS implantation, ideally 3-7 days before surgery.

As with renal function, abnormal baseline hepatic function improves after MCS implantation and to a similar degree for both pulsatile and continuous flow devices.³⁸ Data from the Heart Mate II study showed that, in the majority of

patients, hepatic dysfunction normalized by one month and remained stable through 6 months. Bilirubin initially increased through day 7, but normalized by 2 months and remained stable through 6 months.¹⁹ There are few data on outcomes with MCS in patients with significant hepatic dysfunction at baseline. The HeartMate II BTT trial excluded patients with an INR >2.5 not due to warfarin therapy, a bilirubin >5 mg/dL, transaminase >2000 IU/mL, or biopsy proven cirrhosis.²⁰ The HeartMate II DT trial had similar exclusion criteria with the exception of a transaminase elevation >5 times the upper limit of normal.³⁹

Recommendations for Hepatic Dysfunction:

Class I:

1. Patients with a history of liver disease, abnormalities of liver function tests, chronic right heart failure, or Fontan physiology should have an ultrasound of their liver to screen for cirrhosis prior to MCS implantation.

Level of Evidence: C.

2. Patients who have suspected cirrhosis should receive further radiologic and tissue confirmation in conjunction with a hepatology consultation.

Level of Evidence: C.

3. Patients with abnormal liver function and decompensated hemodynamics should receive aggressive therapy aimed at the restoration of hepatic blood flow and reduction of hepatic congestion.

Level of Evidence: C.

Class II:

1. Patients with an elevated INR not due to warfarin therapy should be considered for treatment prior to MCS implantation, and efforts should be made to optimize nutrition and right-sided intracardiac filling pressures.

Level of Evidence: C.

Class III:

1. Patients with confirmed cirrhosis or an increased MELD score are poor candidates for MCS therapy.

Level of Evidence: B.

Pulmonary Function

Pre-operative evaluation of pulmonary function and thoracic anatomy is essential to optimize outcomes and prognosticate the potential post-operative morbidity and recovery after surgery. These guidelines do not specifically cover pulmonary hypertension or congenital considerations and serve only to provide some direction regarding the optimization or avoidable pitfalls prior to MCS surgery.

Characterization of cardiac and extra-cardiac structures is essential for identifying previous grafts, chest irregularities, aortic anatomy, or diaphragmatic abnormalities. A posteroanterior and lateral chest x-ray should be obtained and in many cases, consideration should be given to acquiring a chest computed tomography (CT) or magnetic resonance imaging (MRI) scan prior to surgery, particularly in those with pre-existing pulmonary disease. These additional imaging modalities may be essential in determining practical surgical feasibility and aid in the evaluation of a MCS candidate.^{41,42}

Pre-operative pulmonary risk factors can be divided into patient-related and procedurally related risk categories.⁴³ The patient-related risk factors include age, chronic disease [e.g. chronic obstructive pulmonary disease (COPD), asthma, sleep apnea, pulmonary hypertension], tobacco history, obesity, general health status, functional dependence and any current respiratory infection or unresolved metabolic issues. Operative risk factors include the surgical incision site, the duration of surgery, anesthetic technique, and if the surgery is on an emergent basis.⁴⁴

Subsequent to a chest radiography or CT scanning an evaluation of lung function utilizing pulmonary function test (PFTs) will help delineate most COPD, restrictive and lung diffusion pathology. Although many patients may have a restrictive pattern on their PFTs, frequently this is the result of heart failure and an anatomical consequence of the patient's cardiomyopathy.⁴⁵ Thus, treatment of the patient's anemia, heart failure, and reverse remodeling associated with MCS placement will frequently improve the patient's lung diffusion capacity and restrictive filling pattern. Less alterable restrictive filling related to obesity, spinal, or rib cage abnormalities may be less relevant after addressing all the other "reversible items". Conversely, patients with COPD have a 2.7-4.7-fold increased risk of post-surgical complications.^{46,47}

An assessment of COPD should begin with a social and occupational history including patients' social habits, previous history of asthma, systemic or familial diseases affecting pulmonary parenchyma or a history of intubation. Of those patients undergoing a cardiac surgery, COPD is by far the most common cause of pulmonary dysfunction. Failure to properly characterize the extent of lung disease prior to surgery can result in prolonged intubation after MCS in those with advanced lung disease.^{48,49} Pulmonary complications after surgery are common and lead to the longest length of stay.⁵⁰ Based on the 2006 American College of Physicians guideline, spirometry is helpful to determine the level of disease and establish a baseline for patients with known asthma or COPD. These studies may be used to identify patients who may benefit from more aggressive preoperative medical management. Spirometry may also be

used to evaluate exercise intolerance or shortness of breath not otherwise explained by the patient's cardiac disease. The results obtained prior to surgery may be confounded by the patient's overall preoperative constitution, and they should not be used as a single factor to exclude the patient from surgery.^{44,46,47,51}

A significant controversy persists with regard to the prognostic utility of PFTs. In combination with clinical judgment and other known factors, they may be helpful to identify very high risk patients and those who may benefit from preoperative medication optimization, as well as postoperative incentive spirometry and intermittent positive airway pressure.

Smoking cessation for 4-8 weeks or more prior to surgery (if electively scheduled) will attenuate post-operative complications. Further risk stratification may be achieved by using the multifactorial risk index for postoperative respiratory failure⁵² or the Canet Risk Index.⁵³ Although there is a significant degree of variability, most pulmonologists and thoracic surgeons will agree that an FEV1 <70% predicted (severe disease <50% of predicted⁵⁴), FVC <70%, or an FEV1/FVC <70% is consistent with significant pulmonary disease. However, the numbers in themselves are not highly sensitive/specific for all patients, and may under diagnose younger or taller patients and over diagnose older and shorter patients.^{55,56} Perhaps the most accurate of these measures is the FEV1/FVC ratio of 65-70% of predicted.⁵⁵

Recommendations for Pulmonary and Thoracic

Assessment:

Class I:

1. Patients should have a chest x-ray prior to MCS implantation.

Level of Evidence: C.

2. Patients should have some assessment of thoracic anatomy prior to MCS implantation, in the setting of prior cardiothoracic surgery or suspected thoracic abnormalities. These may include a radiologic examination with either CT or MRI.

Level of Evidence: C.

3. Positive airway pressure, early ambulation, induced cough, incentive spirometry, and effective pain control subsequent to surgery may all decrease postoperative complications.

Level of Evidence: C.

Management of Patients with Decompensated Heart Failure

Numerous retrospective studies and collective experience suggest that the mortality and morbidity associated with urgent MCS insertion or cardiac transplantation in patients with decompensated heart failure remains ill advised.^{57,58} Despite the desire to implant devices earlier before the onset of end-organ dysfunction, it remains inevitable that many patients will continue to present with acute decompensated heart failure, volume overload, and low cardiac output.

Most experienced centers now routinely optimize hemodynamics prior to MCS implantation. These steps include 1) central hemodynamic monitoring and concomitant addition of inotropes and/or inodilators; 2) optimization of volume status, either by increased dosage of intravenous diuretics administered as intermittent boluses or as a continuous infusion, or by institution of mechanical fluid removal; 3) use of an IABP; and 4) correction of metabolic and electrolyte abnormalities.

Routine monitoring of central venous and pulmonary pressures, serum electrolytes (particularly sodium levels), serum BUN, hemoglobin, platelets, serum creatinine, and markers for hepatic dysfunction (transaminases, bilirubin, and INR) are necessary to monitor the progress of continued aggressive medical management. Reduction of pulmonary vascular congestion and passive hepatopathy, will lead to decreased right ventricular failure and fewer perioperative bleeding complications. This approach can significantly improve the baseline clinical state (INTERMACS level) of the decompensated patient and transition an emergent MCS implantation into a planned surgical implant.

There is a general lack of consensus regarding the therapy of choice for patients presenting in acute cardiogenic shock with hemodynamic collapse. For patients with severe biventricular failure, the most recent data from INTERMACS on biventricular support suggests a 55% survival at 6 months.⁵⁹ In addition, total circulatory support with the total artificial heart has demonstrated favorable results with 79% surviving to transplantation in a very sick cohort of patients.⁶⁰ The morbidity associated with these complex operations in patients *in extremis* is high. Frequently under these circumstances, the suitability for transplantation, patient's neurologic status, or even the patient's desire to live with a MCS is unclear. These patients often have multi-organ failure and infection. Temporary MCS as a bridge to decision are being increasingly used by many centers to restore the circulation while the evaluation process is initiated.

Recommendations for Management of Patients with Decompensated Heart Failure:

Class I:

1. Short-term mechanical support including ECMO should be used in acutely decompensated patients who are failing maximal medical therapy.

Level of Evidence: C.

Temporary Mechanical Support

Currently, improved short-term devices have become more widely available. Use of these devices can help improve end organ dysfunction, provide hemodynamic support, and facilitate extubation in severely infirm patients. This hemodynamic support allows time for a more comprehensive neurologic, social, and psychological assessment. In experienced centers, results have been favorable with various short-term circulatory support systems as a bridge-to-decision in patients with refractory acute cardiogenic shock and multisystem organ failure.⁶¹ These same devices have also been used successfully for bi-ventricular support in a limited number of patients.⁶²⁻⁶⁴ In addition, several of the short term devices now allow the ability to splice an oxygenator into the circuit, thereby allowing for total cardiopulmonary support of patients in florid respiratory failure.⁵⁹ Although there are a variety of temporary devices, there is little evidence comparing these devices. Thus, the device choice is often made based upon the expertise available at each center rather than on data generated from large studies.

More recently, percutaneous options have also become available which may allow for more rapid establishment of effective circulation. Peripheral placement requires an assessment of peripheral vascular disease, and it may be limited by luminal diameter and center experience. These extra-corporeal pumps may utilize an inflow cannula inserted into the left atrium via a trans-septal cannula from the left femoral vein with an outflow cannula placed through the femoral artery into the iliac vessels.⁶⁵ This strategy can be very effective in unloading the left ventricle and alleviating pulmonary congestion.⁶⁶ Most reports suggest establishment of adequate flows and promising clinical results.⁶⁶ Many of these devices can be adapted for right ventricular support as well, with cannula placement in the right atrium and across the pulmonary valve into the pulmonary artery. Limitations include the technical challenge of a transeptal cannulation, and the size of the iliac vessels. Of note, an additional anterograde cannulation of the distal artery may be a good strategy to preemptively circumvent vascular complications in elderly, small, or peripheral vascular disease (PVD) patients.

An alternative technology places the device percutaneously from the femoral artery and across the aortic valve into the left ventricle. These devices come in two sizes

supporting flows of roughly 2.5 and 5 liters/min respectively.⁶⁷⁻⁶⁹ These ventricular placed devices are contraindicated in patients with left ventricular thrombus or significant arrhythmias. In addition, these devices are only approved at this juncture for left sided support; therefore, they are not useful in patients with biventricular failure. However, at the time these guidelines were published, a right-sided device was being evaluated in limited centers. While smaller individual series utilizing percutaneous support have shown promise, there is insufficient evidence to date on the optimal device, timing, or circumstances to apply these technologies. Therefore, these guidelines conclude at this juncture that there is not enough experience with any one or two devices to warrant recommendations regarding a specific device preference in acute decompensated heart failure.

Recommendations for Temporary Mechanical Support:

Class I:

1. The use of temporary mechanical support should be strongly considered in patients with multi-organ failure, sepsis, or on mechanical ventilation to allow successful optimization of clinical status and neurological assessment prior to placement of a long-term device.

Level of Evidence: C.

Right Ventricular Function

RV dysfunction is common in the setting of advanced heart failure as a consequence of pulmonary venous hypertension from chronically elevated left ventricular filling pressures, valvular pathology, or a combination of these processes.⁷⁰ Non-cardiac sources of elevated pulmonary artery pressures such as hypoxic lung disease, sleep apnea, or pulmonary thromboembolism may further exacerbate RV dysfunction. Adequate RV function is critical for a patient to do well with left ventricular (LV) support alone.

The impact of MCS on RV function can be both beneficial and detrimental. The beneficial effects are realized through unloading the left ventricle and decreasing filling pressures, thereby reducing RV afterload. The potential detrimental effects include an increase in RV preload from the normalized cardiac output, and the septal shift observed with unloading the left ventricle.^{71,72} With lower left ventricular filling pressures, the septum will tend to shift to the left and decrease the septal contribution to RV output. This septal shift phenomenon can be observed with continuous flow devices due to active, continuous unloading of the left ventricle. In contrast, pulsatile devices have mostly passive filling and tend to have a less dramatic effect on the position of the septum. Thus, based on a determination of the severity and reversibility of RV dysfunction; clinicians should make an

effort to determine if a given patient will need LV support alone, LV support with temporary RV support, or biventricular support.

RV dysfunction after MCS leads to high levels of morbidity and mortality, longer lengths of stay, and worse posttransplant outcomes.^{38,73-75} Biventricular support, although a reasonable option when necessary, requires a more extensive surgery, has a worse device patient interface than LV support alone, and is not approved for or desirable as DT.^{76,77}

Assessing Right Ventricular Function. Although two dimensional echocardiography is the most widely employed modality to assess RV function, there are challenges with this approach due to incomplete visualization of the right ventricle in one particular view, making application of formulas used to evaluate the left ventricle less accurate. RV size can be measured by transthoracic echocardiogram in the apical 4-chamber view at the end of diastole, as well as by the transesophageal method in the mid esophageal 4-chamber view. By qualitative assessment, RV area or mid cavity diameter should be smaller than that of the left ventricle.⁷⁸ Other echocardiographic parameters such as tricuspid annular plane systolic excursion (TAPSE) <1.5 cm, right-to-left ventricular end – diastolic diameter >0.72, and RV stroke volume index have been used and demonstrated in some studies to be helpful in predicting postoperative RV failure.⁷⁹ While MRI provides excellent assessments of RV ejection fraction and size, it cannot be applied in many heart failure patients due to the presence of an implantable cardioverter defibrillator (ICD) or clinical instability. Regardless of the non-invasive assessment of RV function, obtaining invasive hemodynamics are essential for a comprehensive evaluation.

An RV that appears severely dysfunctional by echocardiography may still be able to maintain low right atrial filling pressures and generate high pulmonary pressures. Conversely, a mildly dysfunctional RV by echocardiography may be severely compromised when hemodynamics are invasively assessed.⁸⁰ In addition, invasive hemodynamics also allow the calculation of RV stroke work index (RVSWI): $RVSWI = [\text{mean pulmonary artery pressure (PA)} - \text{mean right atrial pressure (RA)}] \times [\text{cardiac index (CI)/heart rate (HR)}]$. In one study a value <450 mmHg * ml/m² was predictive of RV failure⁸⁰, however 36% of those RV failure had a RVSWI > 450 and 57% with scores <450 did not have RV failure. The largest study of continuous flow devices for pre-operative risk factors of RV failure found a RVSWI of 300 was predictive of RV failure; however the RVSWI was not found to be a multivariate predictor of RV failure.⁸¹ In the setting of marginal RV function, hemodynamically guided therapy with a Swan-Ganz catheter in an ICU setting for several days may

be needed to determine if the patient can be managed with MCS alone or will need biventricular support.

Recommendations for Assessing Right Ventricular Function:

Class I:

1. All patients should have an echocardiographic assessment of RV function prior to MCS implantation.

Level of Evidence: C.

2. All patients should have invasive assessment of intracardiac filling pressures prior to MCS implantation, with a particular emphasis on RV hemodynamics.

Level of Evidence: C.

Incidence of Right Ventricular Failure. The incidence of RV failure varies in the literature not only by era and by device, but also by the definition of RV failure. While almost all definitions of RV failure include the need for an RVAD, many also include; a prolonged period of postoperative inotropic infusion, extended use of inhaled agents, ventilator support greater than a week, or the need to discharge a patient from the hospital on inotropic support. In the era of pulsatile pumps, the rate of RVAD use was 4-25%, and the rate of overall RV failure was 10-39%.⁸² In the current era of continuous flow pumps, there is a lower incidence of RV failure. INTERMACS data for devices implanted between June 2006 and March 2009 demonstrate that the rate of RV failure per 100 patient months was significantly lower with continuous flow pumps than with pulsatile pumps, 2.23 vs. 3.15 respectively.⁸³ Overall, in trials of both axial flow and centrifugal flow devices, there is a 4-6% incidence of RVAD use and a 13-20% incidence of the need for prolonged inotropes.^{39,83,84}

Risk of RV Failure after Mechanical Support. Risk scores may aid clinicians in quantifying the risk of RV failure, although these risk scores also have important limitations (Tables 2 and 3).^{74,75,82} An analysis from the University of Pennsylvania demonstrated that a cardiac index ≤ 2.2 L/min/m², RVSWI ≤ 250 mmHg * mL/m², the presence of severe RV dysfunction, serum creatinine ≥ 1.9 mg/dL, previous cardiac surgery, and systolic blood pressure ≤ 96 mmHg were independent predictors of the need for RVAD support. It should be noted that less than 4% of patients in this study had continuous flow devices (Table 2).⁸⁵ The University of Michigan risk score included 197 patients with LVADs, 35% of whom had RV failure defined as inotropes >14 days, use of inotropes for ≥ 48 hours, the need for ECMO or RVAD, or discharge from the hospital on an inotropic agent. Only 15% of the devices were continuous flow, and 94% of the

patients were implanted as BTT. The multivariate risk factors for RV failure included vasopressor requirement, AST ≥ 80 IU/L, bilirubin ≥ 2.0 mg/dL, and serum creatinine ≥ 2.3 mg/dL (Table 3).⁸⁰

The largest study to date of the risk of RV failure after a continuous flow device included 484 patients who had a HeartMate II implanted as part of the BTT trial.⁸¹ Overall, 6% of patients required an RVAD, 7% required prolonged inotropic support, and another 7% required late initiation of inotropic support. Multiple clinical, echocardiographic, and hemodynamic parameters were assessed, including RVSWI and the University of Michigan RV failure score. The only significant multivariate predictors were the need for ventilator support, a central venous pressure/wedge pressure ratio >0.63 , and a BUN of >39 mg/dL (Figure 1). While risk prediction models for RV failure are useful, they are not strongly predictive and are clearly limited by the significant impact of other peri-operative factors on post-operative RV function, such as bleeding (Table 4).¹³

Management of Right Ventricular Dysfunction Pre- and Post MCS Placement. RV dysfunction exacerbates venous congestion, which results in renal, hepatic, and intestinal congestion and subsequent organ impairment. In the

preoperative phase, potential MCS patients may require admission to the hospital for optimization of RV function. Intravenous loop diuretics, often administered as a continuous infusion and frequently accompanied by a thiazide diuretic, are the mainstay of therapy. In severe cases, mechanical volume removal with ultrafiltration or continuous renal replacement therapy (CRRT) may be required to overcome diuretic resistance. Left ventricular inotropic support with dobutamine and/or milrinone is often instituted before MCS. It is critical to maintain LV filling in the setting of RV dysfunction. IABP or other short-term MCS may also be utilized to help optimize hemodynamics with a view to unloading the RV. Once hemodynamics have been aggressively managed, RV function is re-evaluated.

In the post-operative period, diuretics and inotropes are used in conjunction with direct pulmonary vasodilators such as nitric oxide and inhaled prostacyclin to further reduce RV afterload. Phosphodiesterase 5 inhibitors such as sildenafil are receiving increased interest as adjunctive therapies, although they are not proven in this setting of post-operative RV failure. However, they may be more useful as chronic therapy. Refractory RV failure post MCS placement may require subsequent placement of a short or long-term right-sided mechanical support device.

Table 2 University of Pennsylvania RV Failure Risk Score

Parameter	Odds Ratio	Points
Cardiac index ≤ 2.2 L/min/m ²	5.7	18
RVSWI ≤ 0.25 mmHg*L/m ²	5.1	18
Severe RV dysfunction pre-op	5.0	17
Serum creatinine ≥ 1.9 mg/dL	4.8	17
Previous cardiac surgery	4.5	16
SBP ≤ 96 mmHg	2.9	13
Score Interpretation		
<50 vs. ≥ 50	Sensitivity 83%, specificity 80%	
LVAD alone (%)	Score <30 – 96%	
	Score ≥ 65 – 11%	

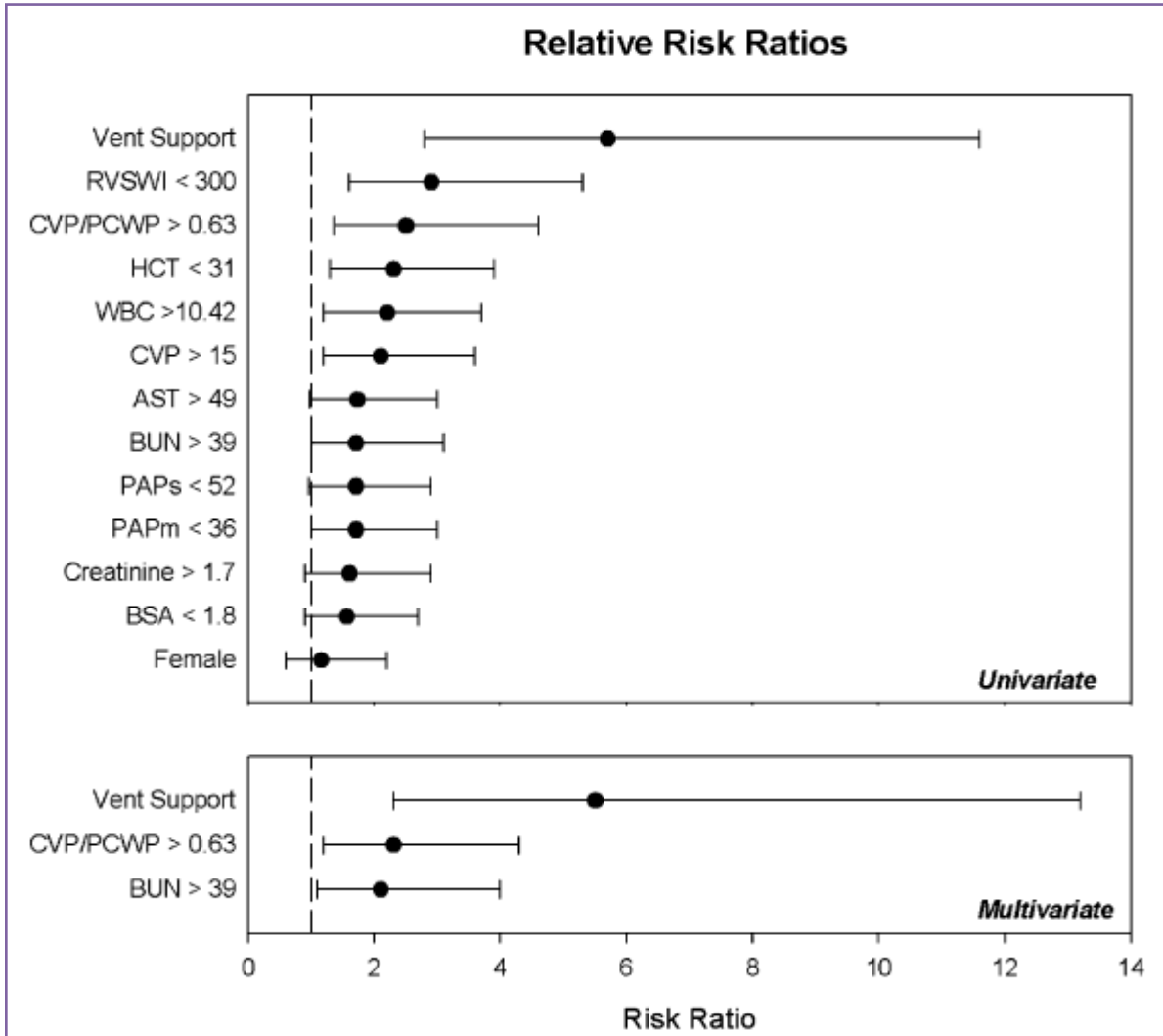
Reprinted with permission from Fitzpatrick JR et al. J Heart Lung Transplant 2008;27:1286-92.⁸⁵

Table 3 University of Michigan RV Failure Risk Score

Parameter	Odds Ratio	Points
Vasopressor requirement	3.9	4
AST ≥80 IU/L	2.1	2
Bilirubin ≥2mg/dL	2.4	2.5
Serum creatinine ≥2.3 mg/dL	2.9	3
Score Interpretation		
Likelihood Ratio of RV Failure		
≤3.0	0.49	
4.0-5.0	2.8	
≥5.5	7.6	

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Figure 1 Univariate and Multivariate Risk Factors for RV Failure in the HeartMate II BTT Population



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Table 4 Intra-Operative and Postoperative Characteristics of Patients who Required RV Support in a HeartMate II BTT Population

	RVF subgroups				P value§	Any early RVF (n=65)
	No RVF (n=386)	RVF-RVAD (n=30)	RVF-early inotropes (n=35)	RVF-late inotropes (n=33)		
Percentage of total patients (n=484)	80	6	7	7	---	13
Reoperation for bleeding*	72 (19%)	12 (40%)†	7 (20%)	9 (27%)	.03	19 (29%)*
Bleeding >2 units during implantation	269 (70%)	25 (83%)	21 (60%)	20 (61%)	.15	46 (71%)
Bleeding >6 units during implantation	102 (26%)	16 (53%)†	7 (20%)	8 (24%)	.01	13 (20%)
Bleeding >2 units <48 hours	207 (54%)	15 (52%)	15 (43%)	12 (38%)	.19	30 (46%)
Bleeding >6 units <48 hours	110 (29%)	9 (31%)	7 (20%)	6 (19%)	.44	16 (25%)
PRBC during <48 hours	5.5 ± 5.8	14.3 ± 18.9*	4.8 ± 4.8	5.1 ± 5.7	.04	8.8 ± 13.9
Cardiopulmonary bypass time (min)	106 ± 61	149 ± 76‡	101 ± 41	99 ± 40	.004	124 ± 64*

RVF, right ventricular failure; RVAD, right ventricular assist device; PRBC, packed red blood cells.

*P<.05; †P<.01; ‡P<.001 compared with the no-RVF group. §P value for differences between the 4 subgroups.

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Recommendations for Management of Right Ventricular Dysfunction:

Class I:

1. Preoperatively, patients with evidence of RV dysfunction should be admitted to the hospital for aggressive management, which may include diuresis, ultrafiltration, inotropes, IABP, or other short term mechanical support. Once optimized, RV function should be reassessed.

Level of Evidence: C.

2. RV dysfunction post MCS should be managed with diuresis, inotropes and pulmonary vasodilators including nitric oxide or inhaled prostacyclin. RV dysfunction refractory to medical management may require placement of a short or long term mechanical RV support device.

Level of Evidence: C.

Class IIb:

1. Phosphodiesterase 5 inhibitors may be considered for management of RV dysfunction post MCS.

Level of Evidence: C.

ABBREVIATIONS

ACC/AHA = American College of Cardiology/American Heart Association

ALT = alanine aminotransferase

AST = aspartate aminotransferase

BMI = body mass index

BTT = bridge to transplant

BUN = blood urea nitrogen

CI = cardiac index

CrCl = creatinine clearance

COPD = chronic obstructive pulmonary disease

CRRT = continuous renal replacement therapy

CT = computed tomography

DT = destination therapy

ECMO = extracorporeal membrane oxygenation

FEV1 = forced expiratory volume at 1 second

FVC = forced vital capacity

HR = heart rate

IABP = intraaortic balloon pump

ICD = implantable cardioverter defibrillator

ICU = intensive care unit

INR = international normalized ratio

INTERMACS = Interagency Registry for Mechanically Assisted Support

LV = left ventricular

MCS = mechanical circulatory support

MCS D = mechanical circulatory support device

MELD = Model for End Stage Liver Disease

MLWHF = Minnesota Living With Heart Failure

MRI = magnetic resonance imaging

MRSA = methicillin resistant staphylococcus aureas

PA = posteroanterior

PICC = peripherally inserted central catheter

PFTs = pulmonary function tests

PVD = peripheral vascular disease

RV = right ventricular

RVAD = right ventricular assist device

RVSWI = right ventricular stroke work index

SCr = serum creatinine

TAPSE = tricuspid annular plane systolic excursion

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APPENDIX 1 –Universal Consent Form**XXX HOSPITALS & HEALTH CENTERS****Request and Consent to Evaluation and Expectations for Mechanical Circulatory Support Device (MCSD)
Implantation Bridge to Transplantation-Destination Therapy (BTT or DT)**

Your heart failure is defined as a condition in which your heart is unable to pump enough blood to support the basic needs of your body. This can make you feel tired, have abnormal rhythms, and shortness of breathe, in addition to causing your other organs to fail (e.g. liver or kidneys). You are being offered this treatment option because you have a marked increase risk of irreversible end-organ damage or death over the (time period). For this reason, you are being considered for placement of a Mechanical Circulatory Support Device (MCSD) at (XXX Hospital & Health System). The heart pump is designed to take over the pumping action of your heart but before you undergo this procedure, it is important that you and your family understand the options, benefits, risks, and expectations associated with having a MCSD. It is required that you and your proposed caregiver(s) understand and agree with the treatment plan and are willing to participate in the guidelines outlined in the following pages.

At this time, you are being considered for a MCSD or more commonly called a Ventricular Assist Device (VAD) for Bridge to Transplantation. Bridge to transplant (BTT) is when a VAD is used to help extend the life of someone waiting for a heart transplant. This is subject to change pending the results from your evaluation and your Physician's decision. This consent pertains only to VAD therapy; you will receive information regarding heart transplantation allocation, procedures, and risks from the transplant program at a different time. Although you are being considered for MCSD implantation for Bridge to Transplantation, it is possible that you will not be a transplant candidate after you receive the MCSD if your medical condition worsens.

OR

At this time, you are being considered for a Ventricular Assist Device (VAD) for Destination Therapy. Destination therapy is when a VAD is used as a long-term treatment for patients who are not candidates for transplant, such as those with end-stage congestive heart failure. In these patients, the pumps are placed permanently to help the heart work better. This is subject to change pending the results from your evaluation and your Physician's decision.

Types Of Mechanical Circulatory Support Devices:

A MCSD is a pump that assists or replaces a weakened heart and carries blood to the rest of your body. There are several different types of mechanical circulatory support devices:

- Left ventricular assist devices (LVAD) help the left side of the heart pump blood to the largest artery of the body, the aorta.
- Right ventricular assist devices (RVAD) help the right side of the heart pump blood to the lungs. -Bi-ventricular assist devices (BVAD) help both sides of the heart pump.
- Total Artificial Heart (TAH) that replaces the heart and pumps blood to the body.

MCSDs can also be categorized into short and long-term therapies. Short-term devices are considered when patients are in cardiogenic shock and need help to pump blood for a few short hours to a few days/ weeks. Long-term devices are used for patients for months to years. Some patients may receive a short-term device prior to implantation of a long-term device.

When Is A VAD Used?

A VAD is used to assist the pumping action of a severely weakened heart. It works with your heart to improve and increase blood flow; it does not replace your own heart. When medications can no longer help, and other surgical options have been exhausted, a physician may recommend a VAD. VADs are most often used for patients experiencing New York Heart Association (NYHA) Class III-IV heart failure symptoms.

Other Medical Options:

If you are not found to be a candidate for VAD implantation or if you decide that a VAD is not the best option for you, you will continue to receive customary standard of care. You may also continue optimal medical management alone including

the use of inotrope therapy. An inotrope is an IV medication that helps the strength of the hearts contraction. However, the reason that you are being considered for VAD implantation is because optimal medical management has not been adequate and without a VAD, your condition is likely to deteriorate over time.

You May Not Be Eligible To Receive A MCSD If You Are Found To Have Any Of The Following:

- Uncorrected thyroid disease
- Obstructive or restrictive cardiomyopathy
- Amyloidosis
- Active pericardial disease
- Untreated aortic aneurysm
- Irreversible pulmonary disease or fixed pulmonary hypertension
- Irreversible renal disease
- Irreversible liver disease
- Unresolved stroke or uncorrected cerebral vascular disease
- Irreversible cognitive dysfunction
- History of psychiatric disease, uncontrolled affective disorder, or any cognitive dysfunction that may prevent you from managing self-care
- Diabetes with severe retinopathy or peripheral neuropathy
- Obesity
- Severe chronic malnutrition
- Uncorrected blood disorders
- Active uncontrolled infection
- Pregnancy (positive pregnancy test)
- Inadequate social support to be successful at home after surgery
- A history of chronic noncompliance
- Using illicit drugs or alcohol

Possible Benefits:

The overall goal is improved health and quality of life. In most cases, because circulation has been restored as a result of the MCSD, you can expect to have more energy and also experience less heart failure symptoms. Since MCSDs help deliver more oxygen rich blood, you may feel well enough to resume many of the usual activities and hobbies that you enjoy. The improved circulation may prolong life and may improve some organ damage caused by your heart failure. This is supported by some studies that have shown that LVAD patients have a longer survival than patients treated with medications alone. Although the VAD can improve your chances for survival, the type and severity of your heart disease may outweigh any benefits from the device and you may still die.

Possible Risks:

As with any surgery or procedure, there are risks and the possibility of complications. There are also risks related to the operation itself and undergoing anesthesia, and risks related to the device itself. You will discuss the risks in detail with the Cardiac Surgeon who intends to perform your surgery. Below is a list of risks related to the surgery and the MCSD.

Operative Procedure Risks:

There are many risks with this operation including but not limited to: death, heart attack, stroke, nerve injury, blood clots, bleeding and hemorrhage, hemolysis, infection, development of new antibodies in your blood, mediastinitis, arrhythmia, right heart failure, heart block, or the need for pacemaker or ICD implantation. In addition, the need for re-operation for any cause, renal, hepatic or pulmonary failure resulting in death or long-term need of ventilation or dialysis, and blood transfusion with its risk of HIV, and hepatitis. Studies have also shown that patients may have problems with memory, attention, and speed of processing thoughts after a cardiac surgical procedure. Any of these complications will be explained to you in more detail if you desire. In addition to these potential complications, there may be other risks that are currently unknown. The longer you are on the device, the greater the chances that complications will develop. It is also possible that you may reach a point where your quality of life is so impaired, that the decision to terminate your VAD-support will need to be addressed.

LVAD Therapy Risks (After The Surgery):

Include but not limited to: death, need for re-operation, device malfunction or device infection, blood clots, stroke, pain, or bleeding. Patients may also experience a potential decrease in their quality of life including limitations of their normal activities. In addition, 24-hour caregivers may experience increased stress in their day-to-day life as a result of caring for a loved one with a VAD.

Evaluation Process:

There will be many people involved in the evaluation process to assure that this is the best choice for you. You will receive a number of tests and consultations. Some of the people that may help evaluate you include Heart Failure Physicians, Cardiac Surgeons, Social Workers and VAD Coordinators. During this process, you will be given education about the MCS and the care that you would require. After the evaluation, the group will decide if you meet the criteria to have a MCS implanted. You may require or have already been implanted with a short-term VAD prior to surgery for a long-term VAD.

Device Choice:

MCSs are currently approved by the Food and Drug Administration (FDA) to be used as Bridge to Transplantation (BTT) or Destination Therapy (DT). A full list will be provided for you and your family to review if desired. This Health System also participates in clinical trials with devices that are considered investigational, and are not yet FDA approved for BTT/DT. Your Surgeon and Cardiologist will discuss with you which device is the best option for you. VADs have four main parts: the implantable heart pump, a tube that passes through the skin of your abdomen (driveline), a controller (small computer) that controls the pump operation, and an external power source (batteries or power device). In addition, there are other VADs that are used temporarily when patients are in cardiogenic shock.

What if I Change My Mind Prior to Surgery?

You have the right to refuse surgery at any time. This consent will help you to make an informed decision. If you choose that this is not the best option for you at this time, you may choose to be re-evaluated at a later time and you may choose to receive the implant at a later time if you are still a candidate.

Surgical Procedure:

The surgical procedure to implant the VAD will require open-heart surgery and can take on average between 6-12 hours. The surgeon will need to make an incision down the front of your chest to reach your heart. You will have a breathing tube (endotracheal or ET tube) and be under general anesthesia. The VAD is placed below the heart and the surgeon will connect the pump to your heart and secure it in place with sutures. Once the pump is in place, the LVAD along with your natural heart will resume pumping blood through your body. After the surgery is completed, you will return to the ICU.

Post-Operative Care Expectations:

Upon arrival to the ICU, you will receive close monitoring and support from the following medical mechanisms:

- Heart monitor (telemetry) to monitor heart rate and rhythm.
- A breathing tube (endotracheal tube) to assist with breathing and maintain and open airway.
- An oral-gastric tube will be utilized to keep the stomach empty when connected to suction, as well as to give the nursing staff the capability to administer oral medications directly into the stomach.
- A Foley catheter to measure urinary output.
- A Swan-Ganz Catheter to measure pressures within the heart and lungs.
- An arterial line catheter in order to measure arterial blood pressure.
- Chest tubes to collect and measure drainage from surgery.
- A VAD driveline that exits the skin in the abdominal area and is connected to the VAD power source.
- Temporary pacemaker wires which may aid in the event of an arrhythmia associated with heart surgery.

You will receive medications for sedation and to control your pain in order to achieve a tolerable level of comfort. You will also be on IV medications until your blood pressure and fluid status are stable. Your home medications will be resumed as soon as possible if still medically relevant. In addition to your previous taken medications, patients with VADs are commonly

prescribed medications for anticoagulation/anti-platelet, antibiotics, blood pressure, and vitamin/mineral supplements. Your length of stay in the ICU will depend on how fast you recover. Once you are more stable, breathing on your own with your lines and tubes out, you will be transferred to a general care unit where you can expect to stay for another 1-3 weeks. On average, your total length of stay will be about three weeks after your surgery. During this time, it is expected that you and your family will begin to learn to manage the device and learn how to manage your care at home. Most patients are able to return home after VAD implantation, but this cannot be guaranteed. Complications may require a prolonged period of hospitalization. If you are unattended and the device fails, you may not be able to perform the emergency procedures yourself, which could result in death and/or blood clots in the device.

Education:

Verbal, written, and visual educational materials are provided throughout your hospitalization and are available to anyone involved in your care at home. You and your caregiver(s) will be trained by a VAD Coordinator on how to manage your care and device. Other staff such as your bedside Nurse, the Occupational and Physical Therapists will also provide training to you. You and your caregiver(s) must show ability to manage the device, understand how it operates, troubleshoot problems, and care for your driveline exit site. It is expected that a caregiver(s) will be present and available while you are in the hospital to learn how to manage the device and how to care for you when you are at home. The education will be an ongoing process while you are here at the hospital. Near the time of your expected discharge, your family and/or caregivers will be required to show competency in the care and management of you and your VAD. Once it has been determined that you and your caregiver(s) are competent in your MCS care, you will participate in an outing away from the hospital with a trained hospital team member in attendance with you. Following the supervised outing, you and your caregiver(s) will perform an unsupervised outing away from the hospital. In addition, a VAD Coordinator will ensure that your local fire department, emergency personnel, and any other community members will be given education materials and training as necessary. Your home must have consistent electricity and phone services; the outlets must be three pronged and grounded. Any additional safety needs are arranged during this time.

Discharge Process:

Your daily progress will be followed by a team of people involved in your care including your Surgeon, Cardiologist, VAD Coordinators, Staff Nurses, Nurse Practitioners, Physician Assistants, Physical/Occupational Therapy, Social Workers, and a Discharge Planner. They will monitor your recovery and help you to adjust to life with a VAD. Soon after your surgery, it will be very important to begin preparing for your discharge. You will have to be both physically recovered and show competence in the management of your VAD to be discharged. Most patients return home after successful outings; however, some patients choose to live with a caregiver or need a rehabilitation facility for a short period before returning home. If resources allow, a Visiting Nurse may be recommended to come to your home and assist you in your care when you return home. The length of time that the Visiting Nurse will come to your home will depend on your overall recovery. It is recommended after you return home that you enroll in a Cardiac Rehab program to continue to improve your physical health.

Follow up care:

After you are discharged, you will follow up with your Surgeon, your Heart Failure Cardiologist and your VAD coordinator. They will collaboratively care for you and make decisions about your treatment. Typically, your first visit will be 1-2 weeks after discharge, then monthly thereafter while you have the VAD. Once you are considered a stable established patient, your Physicians may decide that you can follow-up every 2-3 months. Along with seeing your Cardiologist and Surgeon, you will have laboratory testing, and other physiological testing done on a regular basis in order to monitor and maintain your progress and health. The types of testing that you may need and the frequency will be decided by your Physicians but can include blood tests, EKG, Echocardiogram, Right Heart Catheterization, V02 Treadmill Stress Test, and Implantable Cardioverter Defibrillator (ICD) device check. If you have received an investigational VAD, you may have other testing that will be required for the research study. Many VADs require patients to take anticoagulation medications, also known as "blood thinning" medications. You will also be in frequent contact with a VAD Coordinator who will make phone calls to assess how you are doing at home and assist you with any problems that may arise. A VAD Coordinator, a Heart Failure Cardiologist and a Surgeon are also available 24 hours a day in the event that you have an emergency. On average, you can expect that within 12 weeks after surgery, you will be able to return to most activities, with the permission of your VAD Team.

Lifestyle Changes:

You will have few limitations and can resume most usual activities. Certain activities are hazardous or fatal after implant. Persons with implantable LVADs must not allow their controller/computer and electrical equipment to submerge in water. Showering is possible with proper protective equipment. You may only resume showering once your driveline has healed and your surgeon gives their permission. Swimming and baths are prohibited. Contact sports, repetitive jumping, or impact with an airbag are examples of activities that may cause trauma to the pump attachments and must be avoided. Medical care after implant includes lifetime follow up to monitor device function and health status. You may not have a magnetic resonance imaging (MRI) test because of the magnetic fields. You may not vacuum due to the static electricity. LVAD therapy requires significant self-care responsibility and a willingness to participate with you LVAD team. Driveline exit site dressings must be performed daily using sterile technique or as directed by the VAD team. Maintenance care of the device components, batteries, and driveline is necessary to prevent pump failure, infections, or other serious complications.

VAD Equipment:

Along with the device that is implanted inside your body, you will have a number of other external pieces of equipment that will require care and maintenance. You will have a driveline that exits your body through your abdomen that will power a controller, which is the "computer" component that tells the heart pump how to perform. The controller will also tell you about alarms, sounds, and words, on how your pump is operating and if there are any problems. In order to power the device and the controller, you will have batteries and a battery charger and/or power device. The batteries allow you to be mobile and move freely without being attached to outlet power. The charger or power device allows you to be connected to power for long periods of time such as when you are sleeping. Different MCSDs have similar pieces of equipment, but will vary depending on the device you receive. You will receive education and teaching before you leave the hospital to make sure you understand clearly how to operate the equipment and troubleshoot problems that may occur.

By signing this form, you understand and have reviewed the implant procedure as well as the potential benefits and risks involved with the getting a VAD. You also acknowledge and understand the care that will required to maintain this device and yourself, including changes in your lifestyle, and impact on your independence.

I HAVE READ AND UNDERSTAND THE INFORMATION ON THIS FORM AND ON THE PREVIOUS PAGES BEFORE I SIGN THIS CONSENT FORM.

Signature of Patient or Legally Authorized Representative (if patient is a minor or unable to sign)

Printed Name of Legally Authorized Representative (if patient is a minor or unable to sign)

Relationship: Spouse Parent Next-of-Kin

Consent Obtained, Explained and Witnessed by:

Legal Guardian DPOA

_____; ID#: _____

Signature of Surgeon

Date: ____/____/____ **Time:** _____ **A.M. / P.M.**

Questions

We encourage you to learn everything you can about the potential benefits and risks of having a VAD. If you or your family has any questions, you should feel free to contact your Transplant Coordinator, your Cardiologist or your Cardiac Surgeon @ xxx-xxx-xxxx.

The 2013 International Society of Heart and Lung Transplantation Guidelines for Mechanical Circulatory Support

Task Force 3: Intraoperative and Immediate Postoperative Management

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Topic 1: Anesthesia Related Issues

Introduction

The anesthetic management of the patient undergoing mechanical circulatory support device (MCS) insertion requires an understanding of the pathophysiology of decompensated heart failure, as well as an understanding of its impact on overall cardiovascular function. Many of the principles of caring for these patients are similar to those that apply to the anesthetic management of any patient with advanced cardiac disease. However, there are also a number of features of mechanical circulatory support (MCS) that pose unique challenges.

Induction and Maintenance of General Anesthesia

Patients with heart failure are prone to hypotension on induction of anesthesia for a number of reasons: use of angiotensin converting enzyme (ACE)-inhibitors, decreased myocardial reserve, and autonomic dysfunction. Positive pressure ventilation may exacerbate the hypotensive effects of induction as it leads to a decrease in venous return and an increase in right ventricular (RV) afterload. Moreover, the treatment of hypotension on induction is complicated by the fact that the blood circulation time is prolonged in patients with low RV and left ventricular (LV) ejection fractions, and the response to pharmacologic treatment of hypotension on induction is thereby delayed. A large-bore intravenous line and arterial line for continuous blood pressure monitoring should be placed prior to the induction of anesthesia. Typically, anesthesia is maintained with a combination of narcotics, benzodiazepines, muscle relaxants, and inhalational anesthetics. The use of pulmonary arterial catheters is important for diagnosis of pulmonary hypertension and monitoring of changes in pulmonary vascular resistance

(PVR), as well as monitoring central venous pressure and waveform (for emergence of new v-waves), thermodilution or continuous cardiac output assessment, and mixed-venous oxygen saturation (MVO₂). A pulmonary arterial occlusion pressure is indicated in patients with elevated pulmonary arterial pressures to determine the contribution from elevated PVR or left atrial pressure. Implantable defibrillators should be de-activated, and pacing functions should be reprogrammed to asynchronous mode at a rate that exceeds post-induction heart rate. A comprehensive transesophageal echocardiography (TEE) exam is considered standard of care and should be performed.¹

Transesophageal Echocardiography

TEE is essential for the diagnosis of anatomic and valvular abnormalities, to aid in patient management during initiation of MCS function, and to diagnose RV failure early in its course. In the pre-bypass period, key aspects of the exam include determination of aortic valve competency (will cause pump recirculation), identification of LV mural thrombi (will impact on cannulation technique), and the presence of a patent foramen ovale or any other right-to-left shunt (the shunt fraction will increase during MCS). It is also useful to determine baseline RV size, function, and the severity of tricuspid insufficiency to help determine the potential need for intervention on the tricuspid valve as well as for the sake of post-implantation comparison. The tricuspid regurgitation can also be characterized as originating from annular dilation, leaflet pathology, or secondary to implantable cardioverter defibrillator (ICD) or pacemaker leads. While initiating MCS flow, TEE is useful for intracardiac air surveillance, the proper position of the MCS inflow cannula, and assessing the degree of LV unloading. During the immediate post-bypass period, the TEE is useful for the assessment of

RV size and function, and early detection of septal dysfunction, LV over-decompression, and RV failure.

Right Ventricular Dysfunction

The ability of the RV to generate pressure during systole is significantly impacted by the function of the intraventricular septum.² The LV serves to buttress the septum during RV pressure generation. During LV systolic hypotension (as seen with ventricular assist), the septum moves towards the LV during RV systole and thus reduces overall RV contractility. The sensitivity of the RV to changes in LV systolic pressure is termed left-to-right systolic gain; this gain is in part dependent on septal thickness and septal contractile function.³ Thus, patients with a thin-walled septum or acute septal ischemia are particularly prone to RV failure during initiation of MCS. In order to minimize septal dysfunction, it is important to ensure that the LV is not overly decompressed.

RV hypoperfusion decreases RV contractility. Common reasons for RV hypoperfusion associated with MCS insertion include air emboli and systemic hypotension. Air detection by echocardiogram and de-airing maneuvers are used to reduce the incidence of emboli. Systemic hypotension may be due to a reduction in MCS flow or systemic vasodilation. Maintenance of systemic vascular resistance with a combination of epinephrine, norepinephrine, and vasopressin⁴ is important for preservation of RV systolic function.

In most series, 40-50% of patients undergoing MCS therapy have ischemic cardiomyopathy as an underlying etiology. Hence, occlusive disease of the native right coronary artery (RCA) and/or grafts supplying this distribution is commonly observed. Coronary angiography is an integral part of the patient evaluation for MCS implantation. A clinical challenge arises when hemodynamically significant stenoses are encountered, particularly in the presence of a dominant or co-dominant RCA system.

To determine the optimal approach in this situation, it is important to understand the effect that non-pulsatile flow has on coronary blood flow, since it has become the dominant mode of long-term MCS. The impact of non-pulsatile flow on coronary blood flow and myocardial oxygen consumption has been studied in animals⁵⁻⁷ and in small human studies.^{8,9} One consistent finding among these studies is that myocardial perfusion is reduced secondary to the drop in LV wall stress afforded by LV unloading. Some investigators have documented unchanged coronary blood flow in native coronaries or vein grafts,^{7,10} while others have demonstrated a reduction in flow (secondary to decreased demand) leading to premature graft closure.^{5,6,8,9} These limited and controversial data limit the ability to put forth a strong recommendation regarding the best strategy for managing significant stenosis of

the right coronary system. Several authors have suggested that grafting of a compromised right coronary system at the time of MCS implantation was beneficial, but these data were all from single case reports.^{11,12}

Separation from Cardiopulmonary Bypass

In order to provide the most favorable conditions for the right heart, pulmonary vasodilation therapy should be initiated in patients with reactive pulmonary vasculature prior to separation from bypass. Inhaled pulmonary vasodilators (such as nitric oxide and inhaled prostaglandins¹³) are associated with less systemic vasodilatory effects and improvement in V/Q matching,¹⁴ and they are indicated in the setting of systemic hypotension or significantly impaired lung function. Inotropic therapy such as milrinone or dobutamine should be initiated in all patients while on bypass. Careful attention to volume status is important to prevent right heart distention during the transition to MCS support. Typically, the patient is completely separated from cardiopulmonary bypass before initiating left ventricular assist device (LVAD) flow to carefully preserve septal orientation and thus RV function.

Early Post-Operative Period

Typically, patients remain sedated and mechanically ventilated for at least several hours post-operatively. As always, hemodynamic stability, normothermia, hemostasis, non-depressed respiratory drive, adequate oxygenation, and responsiveness are prerequisites for extubation. Patients with reactive pulmonary vasculature are at risk for an acute pulmonary hypertensive response and right heart failure. Dexmedetomidine is often used in this patient population to help facilitate smooth emergence.¹⁵ MCS flow rates may be increased as long as right heart function remains adequate. Significant reductions in pulsatility in the absence of pump speed changes are usually the result of changes in left ventricular preload from volume loss or right ventricular dysfunction. Inotropes and pulmonary vasodilators may be weaned as tolerated. Diuresis and continuous veno-venous hemofiltration (CVVH) should be initiated early to prevent significant elevations in filling pressures and consequent RV dilation and failure.

Recommendations for Managing Anesthesia Issues:

Class I:

1. Patients undergoing MCS placement should have insertion of a large bore intravenous line, arterial line, and pulmonary artery catheter to allow for continuous monitoring and intravascular access.

Level of Evidence: B

2. Cardiac anesthesia should be performed by those familiar with the clinical issues associated with MCS D placement, including considerations at the time of induction, during surgery, during separation from cardiopulmonary bypass (CPB), and at the time the MCS D is actuated.

Level of Evidence: B

3. Intra-operative TEE should be performed by physicians with advanced training in the intra-operative assessment of cardiac structure and function.

Level of Evidence: B

Topic 2: Implantation Techniques

Implantation Technique for MCS D

Although the technique for MCS D implantation varies depending on the institution and individual surgeon, there are certain common steps in the operation as follows:¹⁶⁻¹⁹

- a. Skin incision
- b. Creation of a pre-peritoneal pocket (note: some MCS Ds lie within the pericardial space and do not require a pre-peritoneal pocket)
- c. Tunneling of the driveline
- d. Mediastinal exposure
- e. Cannulation of the aorta and venous system
- f. Initiation of CPB
- g. Coring the LV, placing core sutures on LV, inserting inflow cannula into LV apex, connecting pump to the outflow graft.
- h. Fixing pump in place to prevent later migration
- i. Outflow graft anastomosis to ascending aorta
- j. Deairing the device
- k. Weaning off CPB, actuating MCS D
- l. Establishing hemostasis
- m. Closing sternotomy (and preperitoneal pocket if necessary)

The surgical team consists of the lead surgeon, an experienced assistant, a scrub nurse, a circulator, and a scrubbed person to assemble pump [physician's assistant, ventricular assist device (VAD) coordinator, or scrub nurse]. The pump team is in the room with the heart lung machine primed.

Incision

A vertical midline incision is made beginning just below the sternal notch with variable extension below the xyphoid depending on the type of device being implanted and the corresponding required pocket size, if any. The Bovie electrocautery is used for hemostasis. It is critical to remain in

the midline. A sternotomy is made. For pumps that are not intrapericardial in position, the left pleural space is often entered to allow for pump pocket drainage to avoid the need for long-term pocket drains. Otherwise, care is taken to avoid entering the pleural spaces unless there are pleural effusions that need to be drained. Likewise, the peritoneal cavity is not entered.

Development of MCS D Pocket for Devices Requiring Preperitoneal Positioning

The MCS D pocket is developed posterior to the posterior rectus sheath in the preperitoneal space. Alternatively, the MCS D pocket can be developed between the internal and external obliques to avoid entering the peritoneum. The pocket can also be created prior to the sternotomy. A portion of the left hemidiaphragm is transected to accommodate the MCS D. This can be best accomplished using a stapling device with seam guards. Careful attention is given to hemostasis during this process by using the Bovie electrocautery and by clipping larger sized vessels. A model of the device can be used to confirm appropriate sizing of the pocket. The pocket should extend as laterally as possible, usually to the level of the rib cage, to allow optimal positioning of the inflow cannula. If the pocket is too small, obtaining proper orientation of the pump and cannulae may be difficult. The device is then placed in the preperitoneal pocket.

Tunneling of the Driveline

The driveline is screwed onto the tunneler. The spear end of the tunneler is then brought into the incision, pierces through the fascia just to right of the midline in the pocket, and is tunneled to exit the skin through a previously placed circular incision in the right or left upper quadrant. The exit point is generally halfway between the umbilicus and the costal margin. The driveline is pulled through the exit site. All velour is kept in the subcutaneous space so that only silicone is in contact with skin at exit site. The LVAD is then positioned in the pocket. Consideration should be given to fixation of the device to the rib cage and/or abdominal wall to reduce chance of future device migration and secondary inflow cannula malposition.

Mediastinal Exposure

The retrosternal fat and perithymic tissue are divided in a hemostatic fashion using the Bovie and clips. The pericardium is opened along the right side of the heart, down to the diaphragm and then over to the left by the apex of the heart. Superiorly, the pericardium is opened up just above the aorta until the pericardial reflection. Retraction sutures are placed, creating a pericardial well for exposure of the heart.

Cannulation

The patient is fully heparinized. Two pursestrings are placed on the distal ascending aorta using 3-0 Prolene suture. A pursestring suture is then placed on the anterior portion of the right atrial appendage. When the activated clotting time (ACT) is 400 seconds or higher, the ascending aorta is cannulated at the level of the pericardial reflection. The cannula is deaired and secured, and the line is tested. The right atrium (RA) is then cannulated and connected to the bypass circuit. If a tricuspid valve repair or closure of an atrial septal defect (ASD) is planned, venous drainage is obtained with selective superior vena cava (SVC) and inferior vena cava (IVC) cannulation with vessel loops and snares placed around the SVC and IVC cannulas. CO₂ is also brought onto the field.

Initiating Cardiopulmonary Bypass

The patient is then placed on CPB and kept at normothermia or mild hypothermia. Hemofiltration is routinely used to remove excess intravascular volume and permit transfusion of blood products that are often necessary to address coagulopathy that routinely ensues. During the course of the operation, carbon dioxide is used to flood the surgical field. This maneuver has been shown in randomized trials to reduce microemboli.^{20,21} Moreover, the use of carbon dioxide field flooding has been shown to preserve neurocognitive function in one randomized trial,²² but not in a recent meta-analysis.^{23,24}

In most instances, MCS implantation can be easily completed without the need for aortic cross-clamping and cardioplegic arrest. The latter can worsen pre-existing right heart dysfunction, particularly in the presence of native RCA or graft disease. It is therefore recommended that MCS implantation occur under full CPB at normothermia or mild hypothermia with the heart fully decompressed. This allows easy elevation of the LV for apical coring, LV cavity inspection, and inflow cannula insertion. Creation of the outflow graft anastomosis can be easily achieved with use of a partial occluding clamp placed on the lateral aspect of the ascending aorta.

Additional procedures, such as closure of patent foramen ovale or tricuspid valve repair can be performed with bicaval cannulation, snaring, and right atriotomy without the need for cardioplegic arrest. As discussed previously, grafting of the right coronary system can be accomplished with the use of an off pump retractor to stabilize the right coronary target while the empty heart beats and a hand-held blower used by the assistant can aid in visualization of the anastomosis. Cardioplegic arrest of the heart is mandatory in the presence of significant aortic insufficiency (requiring valve repair, patch placement, or valve replacement) or in the presence of a

short ascending aorta with patent grafts that complicate placement of a partial occluding clamp for creation of the outflow graft anastomosis. As discussed earlier, mitral valve procedures are seldom necessary, but they do require cardioplegic arrest. Ligation of the left atrial appendage may be considered in patients with atrial fibrillation.

Most recently, it has been suggested that the entire implantation procedure can be performed without the aid of CPB.²⁵ This strategy could potentially reduce ischemic insult and perioperative bleeding, but it requires very close attention by the anesthesia team. Manipulation of the dilated LV for apical cannulation can be met with hemodynamic instability. Bleeding from the cored out apex may be difficult to control, and it is not possible to examine the entire LV cavity for thrombus. These restrictions have limited widespread adoption of this approach.

Maintenance of a low level of ventilation at low volumes at a rate of approximately 5 to 10 breaths a minute may enhance pulmonary perfusion. It is also advisable to avoid the use of a left atrio-ventricular vent during the case as this will make the de-airing process more complex if air is present in the left atrium during the case. In addition, mild hypothermia may avoid profound vasodilation in patients with inflammatory syndromes related to severe heart failure; alternatively, low levels of an alpha agonist such as vasopressin may be used. Alpha agonists may also be required during the case to maintain an aortic perfusion pressure of at least 55 mmHg and thus reducing the chance of air embolism. Finally, many will take advantage of the cardiopulmonary bypass ultra filtration membrane to remove excess volume in overloaded patients in order to provide room for blood products that are required for maintenance of coagulation.

Coring Procedures

After CPB is commenced, the LV apex is exposed by placing several surgical sponges in the posterior pericardial space, elevating the heart, and bringing the apex to the middle of the field. The LV is then incised at the apex, precisely where the dimpling of the heart occurs. This is generally 1 cm to the left of the left anterior descending artery. A Foley catheter is inserted into the LV, the balloon is inflated, and the Foley is lifted up, abutting the balloon against the coring site. Coring is performed using a 14 French coring knife, directing the knife to the LV cavity and not the septum. Alternatively, a coring site located slightly anterior to the left apical dimple of the LV is favored by a significant number of surgeons. The LV is then inspected for trabeculations. Prominent trabeculations are excised and any thrombus is removed. Full thickness 2-0 Tevdek pledget sutures are placed in a horizontal mattress fashion around the circumference of the ventriculotomy. The sutures are placed through the sewing

ring of the inflow cuff, the sewing ring is seated, and the sutures are tied and cut. The cannula is then inserted into the inflow housing and secured with a tie and 2-3 umbilical tapes. The lap pads are removed, the heart is placed back in its normal position, and the LVAD is placed back in the pocket. To assure maintenance of proper pump alignment, the device should be anchored to the diaphragm or chest wall.

Outflow Graft Anastomosis

The outflow graft is measured and cut at a bevel to be anastomosed to the proximal ascending aorta. This measurement should be such that the graft eventually lies lateral to the right atrium and right ventricle thus precluding undue pressure on these structures following sternal closure. Moreover, lateral placement protects the outflow from injury during sternal reentry. A partial occlusion side biting clamp is then applied to the proximal ascending aorta. An aortotomy is made with a 15 blade and the aortotomy is then extended with a Potz or Iris scissors. The graft is then anastomosed to the proximal ascending aorta using two 4-0 Prolene sutures in running or interrupted fashion, with or without buttressing Teflon pledgets or bovein pericardium. The graft is then deaired and clamped, and the anastomosis is inspected for bleeding.

Deairing

Procedures involving incisions into the left heart (left atrium, LV, or aorta) are associated with entrapment of air within the left-sided cardiac chambers. All available long-term implantable MCSs require coring of the LV apex for insertion of an inflow cannula. Hence, LVAD implantation is inevitably accompanied by some degree of entrained left-sided air. The RCA lies most anteriorly in the aortic root. Thus, it becomes a common destination for air ejected from the LV. Such air embolization can be electrically and mechanically silent, or it may lead to right coronary malperfusion, ischemia and dramatic right ventricular dysfunction.

Several maneuvers are indicated to reduce the chance of air entrapment and subsequent embolization. Of paramount importance is the use of continuous transesophageal guidance, as this remains the best method to diagnose the presence and successful evacuation of intracardiac air. One area that may be susceptible to microscopic air entrapment are scintered inflow cannulae. The use of transesophageal echocardiography in the intraoperative management of the LVAD recipient is discussed in Topic 1.

Following completion of the implant, the patient is slowly weaned from CPB. The inflow connection is submerged under water or wrapped with wet surgical sponges. The heart is allowed to fill with volume as the anesthesiologist gives large breaths to evacuate air that may be entrapped in the pulmonary

veins. A venting needle is placed in the outflow graft and/or the ascending aorta while the patient is placed in Trendelenburg position. Of note it is important to keep the outflow graft clamped during any deairing procedures with needles while the pump is turned off or is not running at a sufficient RPM to produce forward flow, otherwise microscopic air from the graft or ascending aorta will be blown back into the left ventricle and complicating the deairing process. This procedure limits air entering the cerebral circulation, and it encourages air bubbles to rise toward the aortic root and vented out the previously placed needle. Under transesophageal guidance, the LV and left atrial appendage are shaken by the surgeon to further encourage displacement of trapped bubbles. Dilated, poorly contracting LVs can harbor air bubbles within the trabeculae that can be difficult to clear and may require extensive shaking of the ventricle and patience to fully evacuate.

Once all air is evacuated as determined by transesophageal monitoring, the patient is separated from CPB. At times, this process can be accompanied by a sudden appearance of new air bubbles in the ascending aorta. Reinstitution of bypass and repeat deairing maneuvers may be necessary. Device support can be instituted after weaning from bypass.

Embolization of air into the RCA may be suspected by visualization of air within the small acute marginal branches coursing on the surface of the right ventricle or by the appearance of inferior wall ST segment elevations. Right ventricular dysfunction with chamber dilatation, elevation of central venous pressure, development of significant tricuspid regurgitation, and poor LVAD filling may occur and mandate reinstitution of full extracorporeal circulation, maintenance of high perfusion pressures to push the air through the right coronary system, and further deairing maneuvers. Even in the most dramatic instances, air-induced right heart failure can be fully reversed and RVAD support averted.

Inotrope support (e.g., dobutamine and / or milrinone) is started at this point to optimize right heart function. Additionally, pressors (norepinephrine and vasopressin) are started to maintain a mean arterial pressure (MAP) of 65-90 mmHg. Failure to maintain adequate systemic blood pressure can result in over decompression of the left ventricle and profound septal shift.

Weaning off CPB and Actuating MCS

CPB is weaned. The MCS should be initiated when the patient is off CPB or at minimal flows (e.g., <2 liters). Devices are started at speeds appropriate for each device. Adequate aortic perfusion pressure (afterload > 60mmHg) should be maintained to avoid excess unloading of the LV by the rotary pump which will lead to interventricular septal shift

and compromise of RV function. Once the patient is completely weaned from CPB, the device speed is gradually increased according to specific device recommendations. Throughout this process, the deairing hole in the outflow graft is kept open to allow for additional deairing. Excessive LVAD speeds aimed at improving LVAD output may lead to increased venous return and overwhelm the dysfunctional right ventricle. Thus, it is suggested that LVAD speeds be maintained at a level sufficient to attain satisfactory hemodynamic support with optimal LV decompression (absence of significant mitral regurgitation), and without leftward intraventricular septal shift. Correction of more than moderate tricuspid regurgitation has been suggested to avoid right ventricular overload. In the past, the use of right atrial-to-left ventricular shunt²⁶ or direct volume infusion into the left atrium via a catheter in the right superior pulmonary vein²⁷ to minimize right ventricular volume overload have been suggested, but these approaches are seldom used presently.

The transthoracic echocardiogram is viewed to assess the degree of LV decompression and degree of mitral regurgitation, evaluate the flow across the inflow and outflow cannulae, rule out aortic insufficiency, assess right ventricular function, and evaluate the interventricular septum to make sure it is not bowing. The echocardiographic findings guide the speed setting of the LVAD, whether to take more volume, and/or to increase inotropes.

The cornerstone in the management of right ventricular dysfunction is its avoidance. Prior to separation from CPB and thereafter, it is essential that optimal oxygenation is maintained, and acidosis and hypercarbia be avoided. Hypoxia, hypercarbia, and acidosis can lead to pulmonary vasoconstriction resulting in increased afterload to the right ventricle. Preload management is critical, and it requires vigilant monitoring of the central venous pressure by the surgeon, cardiologist, and anesthesiologist. In general, a central venous pressure of ≤ 14 mmHg is desirable. Rapid administration of large amounts of intravenous fluids or blood products should be avoided. If the latter are necessary, they should be administered in combination with diuretics.

Afterload management can be achieved by the use of non-selective (milrinone) and selective (inhaled nitric oxide²⁸⁻³¹ or inhaled prostaglandin³²) pulmonary vasodilators. As outlined previously, efforts to lower pulmonary vascular resistance by judicious use of the ventilator to optimize oxygenation and maintain normo- or mild hypercarbia are essential.

Right ventricular contractility can be enhanced by the use of β_2 -agonists like dobutamine, isoproterenol, or epinephrine. The use of one of these agents with a pulmonary vasodilator is likely synergistic, and such combinations are now routinely initiated as CPB support is weaned and the LVAD is actuated.

Atrioventricular pacing can enhance right ventricular function and should be attempted if bradyarrhythmias exist.

Establishing Hemostasis

Bleeding remains the most common complication following LVAD implantation.³³ Several factors contribute to the unequivocal propensity for perioperative bleeding during and immediately following LVAD surgery. These include poor nutritional status, preoperative use of anticoagulants, antiplatelet agents and herbal medicines known to affect platelet function,³³ hepatic dysfunction, hypothermia, dilutional thrombocytopenia, and the interaction between blood and blood-contacting surfaces of the MCSD.

Bleeding is often accompanied by the need for transfusions, which is associated with important clinical implications. First, several studies suggest that blood transfusion induces an immunosuppressive state that can contribute to the development of nosocomial infections.³⁴⁻³⁸ Second, blood transfusions have been associated with pulmonary insufficiency. Transfusion associated lung injury (TRALI),³⁹ is thought to be induced by passive transfusion of complement activating antibodies.⁴⁰ Third, and most relevant to LVAD recipients, is the association of transfusions with right heart failure, resulting from right heart distension which leads to congestive hepatopathy and worsening coagulopathy.⁴¹ In addition, blood product transfusion can result in proinflammatory cytokine release, pulmonary hypertension, and secondary right heart failure. Of particular concern to MCSD recipients awaiting transplantation is the fact that each unit of blood transfused increases the risk of allosensitization. This may result in elevated panel reactive antibodies that can complicate or even preclude transplantation. Lastly, though modest in risk, transfusion can result in the transmission of emerging pathogens not currently tested for routinely that can render the MCSD recipient unacceptable for cardiac transplantation.⁴² Thus, focused effort must be placed on minimizing perioperative bleeding and the need for transfusion.

Medical Aspects of Hemostasis. Several strategies are used to reduce the chance of coagulopathy and the need for blood product replacement. If possible, removal of 1-2 units of whole blood prior to heparinization and institution of CPB allows return of platelet- and factor-rich autologous blood to the patient after protamine reversal. Reduction in the surface area priming volume of the CPB circuit can reduce the incidence of allogeneic blood transfusions and can be achieved by the use of minimized circuits.⁴³ Following cannulation, retrograde autologous priming should be undertaken to further reduce hemodilution.⁴⁴ The use of biocompatible tubing surface technology not only mitigates

the proinflammatory effects of extracorporeal circulation,^{45,46} but it is also platelet preserving.⁴⁷

While the use of aprotinin had been shown to reduce bleeding and transfusion requirements for patients undergoing MCS implantation,⁴¹ this agent is no longer available. Nonetheless, other antifibrinolytics (aminocaproic acid, tranexamic acid) are routinely used, and complete heparin reversal with protamine to achieve a normal ACT is applied. Prompt and judicious use of blood products should be used if coagulopathy is encountered after full protamine reversal. In patients with renal insufficiency, the use of desmopressin should be considered.^{48,49} Thromboelastography and rotational thromboelastometry are increasingly used as point-of-care tests during cardiac surgery for blood product sparing,⁵⁰⁻⁵³ and they should be studied for patients undergoing MCS implantation.

Minimizing total CPB time may reduce the unfavorable extracorporeal-induced trauma of blood elements. This can be accomplished by constructing the outflow graft anastomosis prior to institution of CPB with the aid of a partial occluding cross-clamp on the lateral ascending aorta.

Surgical Aspects of Hemostasis: Non-MCSD Related. Potential sites for surgical bleeding not specifically related to the MCS pump include the right atrial (or caval) cannulation sites, the sternal edges, the pleural fat pads, and, in reoperative cases, torn adhesions between the epicardium, pericardium, and exposed lung surfaces. To minimize bleeding from the cannulation sites, autologous or Teflon pledgeted sutures should be used. This is particularly important for the right atrium, which often is tensely dilated and friable due to preexisting right heart failure. Placement of a pledget with every bite of the right atrium purse string creates a perfectly hemostatic rosette of pledgets that is resistant to the common postoperative elevations in central venous pressure.

Under the distal right hemisternum, a space is often created to comfortably house the outflow cannula and graft. This area is rich in small arterial vessels derived from the right internal mammary artery. Troublesome bleeders in this area often retract and then reopen upon rewarming in the intensive care unit, and they can result in significant postoperative bleeding. Therefore, thorough use of the electrocautery in this area is warranted. As in any cardiac surgical case, meticulous attention should be paid to sternal edge and wire-hole bleeding and avoidance of sternal wire injury to the internal mammary or intercostal arteries behind closed pleurae.

Surgical Aspects of Hemostasis: MCSD Related. Device related bleeding sites include the preperitoneal pocket, the apical inflow site, and the outflow graft and graft-aorta anastomosis. The pocket should be created prior to administration of systemic heparin. Particular care should be taken to control the inferior epigastric vessels if visible, since

friction with the implanted device can lead to erosion into these vessels and bleeding. Peritoneal entry should be averted as ascitic fluid is rich in tissue plasminogen activator,⁵⁴ which can promote fibrinolysis.

After securing the inflow cannula to the LV apex, bioglue is routinely applied in this area to reduce the chance of bleeding. The latter is encountered infrequently, because the inflow cannula is a low-pressure connection. Care should be taken to preclot the inflow conduit and outflow grafts as suggested by the device manufacturer, since these conduits may be porous and prone to bleeding.

Most investigators suggest wrapping the outflow graft with an additional layer of either Gortex membrane or bovine pericardium to enhance hemostasis and to reduce the chance of outflow graft injury during sternal reentry for transplantation. If possible, the outflow graft should be kept within the confines of the pericardium so that migration into an open right pleura does not occur. The latter could lead to erosion into the right internal mammary artery or its branches resulting in significant bleeding. Re-approximation of the inadvertently opened right pleura prior to closure can be easily achieved with interrupted absorbable suture.

Perhaps the most common site of MCSD related bleeding remains the outflow-aortic anastomosis. Multiple suturing techniques have been used successfully, including continuous running, interrupted, and interrupted pledgeted. The key is to ensure **absolute** hemostasis at this site before chest closure. Even mild oozing from the suture line can result in significant accumulation of blood in the pericardial cavity. In our experience, the use of interrupted double-pledgeted 4-0 prolene sutures achieves best eversion and hemostasis at this site.

In the event of persistent coagulopathy, packing the mediastinum and returning to the operating room within 24 hours for unpacking and sternal closure is warranted. The advantages of this approach are that it reduces the need for reopening the sternum (and hence additional sternal trauma from rewiring), and it allows for removal of residual clot, thus removing potential nidus for future infection. This practice often leads to successful correction of coagulopathy and patient rewarming without an increase in infectious sternal wound complications.

Closing Sternotomy and Preperitoneal Pocket

A Gor-tex pericardial membrane (Gore Medical Products, Flagstaff, Arizona.) or similar barrier is sutured to the pericardial edges to minimize re-entry injury on the reoperation. Chest tubes are placed and generally include 2 mediastinal tubes (1 for drainage of the anterior mediastinum and 1 for drainage of the posterior mediastinum), and 2 Blake drains for the MCS pocket, although this is variable

depending on the size of the pocket. If the left pleura has been violated, an angled chest tube should be placed lying against the diaphragm to capture blood escaping the mediastinum and to reduce left lower lobe collapse. The sternum is closed in the standard fashion with simple, interrupted steel wires. The abdominal portion of the incision is closed with interrupted figure of eight #1-Prolene sutures, with careful attention to obtain adequate purchase of the fascia and avoid a future wound dehiscence. The superficial soft tissue and skin are closed in the standard fashion.

Concomitant Procedures Along With Implantation of LVAD

Patent Foramen Ovale

If the patient has a patent foramen ovale (PFO), it must be closed at the time of MCS D implantation to avoid postoperative right-to-left shunting and systemic hypoxemia. This requires bicaval cannulation, and primary suture closure of the PFO. This procedure is best performed after institution of CPB and before creation of the outflow graft anastomosis as the outflow can preclude easy access to the right atrium once it is secured in place.

Management of Co-Existing Valvular Disease

Not uncommonly, patients scheduled to undergo MCS D implantation are discovered to have coexisting valvular pathology that, if uncorrected, can affect MCS D filling and emptying.⁵⁵ Refer to Section 1 for specific recommendations on managing concomitant valvular disease.

Tricuspid Valve Insufficiency. In light of the negative impact of right heart failure on early and late outcomes following MCS D implantation, it has been suggested that presence of more than moderate tricuspid regurgitation should be addressed with an annuloplasty repair. This procedure can be performed quickly and easily with the heart beating through a generous right atriotomy with selective bicaval cannulation and with snares. Occasionally however, a short period of cardioplegic arrest may be necessary to attain optimal exposure to the tricuspid valve. Care should be taken to avoid damage to the AV node within the triangle of Koch, and to avoid entrapment of the Swan-Ganz catheter or existing pacemaker defibrillator leads. The presence of mild-to-moderate regurgitation is considered to be hemodynamically insignificant, and it is likely to resolve with LV unloading and ensuing reduction in right ventricular afterload. However, the degree of pulmonary hypertension and importantly, the degree of the elevation in pulmonary vascular resistance should be taken into consideration whether MCS D therapy will provide significant or modest reductions in right ventricular afterload.

Mitral Valve Insufficiency. Functional mitral regurgitation commonly accompanies end-stage

cardiomyopathies.^{56,57} Unloading of the LV with the functioning MCS D will invariably result in a decrease in LV size and reduction or disappearance of functional mitral regurgitation. Moreover, manipulation of MCS D speeds in continuous flow pumps can be undertaken to optimize LV unloading and minimize mitral regurgitation. Recent discussion suggests that severe mitral regurgitation may need to be addressed with a reduction annuloplasty ring to ensure lower left atrial pressures and hence, lower RV afterload.

Mitral Valve Stenosis. Mitral valve stenosis is infrequently encountered in patients with advanced LV dysfunction. Significant mitral stenosis must be dealt with at the time of surgery, because it limits MCS D filling and maintains left atrial and pulmonary hypertension.

Aortic Valve Stenosis. Aortic valve stenosis does not preclude optimal MCS D functioning as LV blood is diverted to the aorta via the implanted pump. Often however, significant stenosis coexists with some degree of regurgitation as the immobile leaflets of aortic stenosis do not coapt during diastole which results in regurgitation. This insufficiency may worsen over time with the institution of MCS D flow as these diseased leaflets are now newly exposed to high aortic-side pressures. Hence, unless good coaptation of the stenotic valves can be demonstrated, consideration should be given to management of this valve as suggested in the section on aortic insufficiency below. Lastly, if the possibility of LV recovery is being entertained, aortic valve replacement should be strongly considered as persistent valvular stenosis will impede device weaning and full ventricular functional recovery.

Aortic Valve Insufficiency. Significant aortic valve insufficiency leads to the creation of a circuitous blood flow loop. Blood leaving the LV via the implanted pump exits into the ascending aorta and then back through the regurgitant valve into the low pressure LV. The result of this flow disturbance is systemic hypoperfusion in the presence of normal or supranormal MCS D flows. Final assessment of the degree of aortic insufficiency can be made with intraoperative TEE, but this assessment should be made in the setting of a reasonable mean blood pressure, otherwise it may be underappreciated.

Emerging consensus is that patients with more than mild insufficiency should undergo surgical repair or biological prosthetic valve replacement, particularly if the patient is likely to be supported for an extended period of time. It is now felt that prolonged MCS D support with a continuous flow pump can lead to worsening of pre-existing insufficiency or development of *de novo* regurgitation due to commissural fusion.⁵⁸⁻⁶¹ Options for the management of the insufficient aortic valve include sewing the leading edges together,⁶²⁻⁶⁴ sewing a prosthetic patch to the annulus effectively obliterating the LV outflow, or replacing the valve with a

biological prosthesis.⁶⁵ These approaches differ depending on the likelihood of insufficiency recurrence, potential for thrombus formation, and the ability to allow LV ejection in the event of LVAD failure or LV recovery. Hence, individualized decision-making is required to determine the optimal strategy for management of the insufficient aortic valve.

Prosthetic Valves. The presence of mechanical prosthetic valves (usually mitral or aortic) may complicate management of the MCS recipient. It has been suggested that a mechanical aortic prosthesis be addressed with a patch sewn to the annulus thus rendering the valve non-functional. Mechanical valves may be partially or fully immobile because the LV is unable to contract sufficiently to open the valve. This immobility may create an area of subvalvar stasis and poor washing that can lead to thrombus formation with subsequent risk of embolization.⁶⁶ A second option, involves replacement of the mechanical prosthesis with a biological one. This approach requires a longer ischemic arrest and explantation of a well-incorporated mechanical valve which may be technically difficult.

Hence, the current recommendation is for mechanical aortic valve prosthesis to be oversewn with a patch if the patient is a bridge to transplant. If recovery is a consideration or destination therapy is the strategy, replacement with a biological prosthesis should be undertaken. It is important to note however, that thrombus, pannus, and complete fusion and closure of the bioprosthetic valve have been described in recipients of MCSDs.^{65,67,68}

Because of the greater technical complexity required to exchange a mechanical mitral valve, most investigators recommend leaving these prostheses in place. The high transvalvular flow associated with an apical inflow LVAD ensures thorough washout and hence, the presence of a mechanical valve in this position is not felt to increase chance of embolization. However, higher maintenance international normalized ratio (INR) may be warranted.

Implantation Technique for Pulsatile Intracorporeal Biventricular Support

A pocket is created in both upper quadrants to house the devices. The RVAD driveline is tunneled alongside the LVAD driveline, extending 2-3 cm laterally to the exit site of the LVAD driveline. The LVAD outflow graft is cut to length and anastomosed end-to-side to the ascending aorta. CPB is commenced while maintaining patient at normothermia and with the heart beating. The LV is cored, horizontal mattress sutures are placed around the ventriculotomy, sutures are placed through the sewing ring of the inflow cannula, sutures are tied and cut, and the cannula is secured. The cannula is then connected to the outflow housing.

For the RVAD, two pursestrings are created in the body of the right atrium using 2 4-0 Prolene pledgeted sutures, with a pledget used for each bite of atrial tissue. An atrial cannula designed for the implanted ventricular assist device (IVAD) is then inserted into the right atrium. The outflow graft for the RVAD is then anastomosed end-to-side to the pulmonary artery using 5-0 Prolene suture.

Outflow cannulas are connected to the outflow housings. A hole is made in the outflow grafts for deairing. Volume is allowed into the heart and the patient is ventilated to allow for deairing. The device is hand pumped, and the TEE is evaluated for air. When the deairing is complete, the driveline is connected to the dual-drive console, which is set to automatic mode (fill to empty) with initial drive pressure of 80 mmHg. The console vent is opened to air. Vacuum is not used to assist VAD filling to avoid air entrapment. The drive pressure is slowly increased to 75-100 mmHg above the systolic blood pressure of the patient to ensure complete emptying of the device. CPB is then discontinued.⁶⁹⁻⁷²

Topic 3: Special Considerations for VAD Implantation

Repeat Sternotomy

The patient is prepared for surgery in the same way as previously described. If clinically appropriate, a chest computed tomography (CT) scan should be routinely performed to assess relationship of RV to the posterior sternal table. The femoral vessels may be exposed and an umbilical tape or vessel loop placed around the artery to facilitate emergent initiation of CPB, if necessary. If there are no serious adhesions anticipated in the chest, the groin is not exposed, but transcatheter lines may be placed into both the artery and vein to allow for emergency cannulation. Alternately, the right subclavian/axillary artery can be isolated and a 8mm graft anastomosed to it to serve as arterial perfusion site.

A midline incision is then made and carried down to the sternum. The wires are cut and removed. The xyphoid is identified and divided. Big towel clips are placed on both sides to allow for lifting the sternum. The sternum is opened with an oscillating saw, followed by achievement of hemostasis. First, the right side of the sternum is separated from the retrosternal adhesions. Care is taken to avoid injury to the vena cava and bypass grafts. The ascending aorta is identified and freed up into the aortic arch to allow for cannulation. Subsequently, the right atrium is dissected free.

At this point, when cannulation access is adequate, the device pocket is formed. The heart dissection is performed after the pre-peritoneal pocket is completed. During further dissection, particular care is taken to preserve the left internal

mammary artery (LIMA) and to achieve adequate mobility of the heart to obtain sufficient exposure of the apex. The team should be prepared for groin cannulation, but it should be avoided if possible.

Bridge-to-Bridge Transition

If the patient is supported with an intraaortic balloon pump (IABP), it may be left in place and removed in the intensive care unit (ICU) after MCS implantation or at the time of surgery at the discretion of the surgeon. If the patient is supported with a Tandem Heart VAD[®] (CardiacAssist, Inc., Pittsburgh, PA) in an LVAD configuration, a standard approach is used for implantation. The femoral artery cannula of the circuit can be used as the cannula for the heart lung machine circuit and is otherwise removed at the end of the MCS implantation. An assessment for an ASD should be performed and consideration of surgical closure if the surgeon believes this will be hemodynamically significant.

Lateral Implantation

Because this approach relies on an anastomosis to the descending aorta, preoperative imaging should be obtained to ensure absence of significant atherosclerotic disease that would preclude safe outflow graft anastomosis creation. The patient is intubated using a double lumen tube. Arterial lines are placed in both the radial and the right femoral artery. The patient is turned to the right side for a left anterior thoracotomy (similar to the position for thoracoabdominal aneurysm repair). The left groin is exposed, and after prepping and draping, the femoral vessels are exposed. A left anterior thoracotomy is executed, and the chest is entered in the 5th intercostal space. Usually, exposure of the LV apex is excellent through a simple thoracotomy. Occasionally, the incision is extended across the costal margin for better exposure. Two regular chest spreaders are used. Alternatively, self-retaining retractors mounted to the table may be employed. A preperitoneal pocket is then created.

The left lung is deflated, and the aorta is freed from the surrounding fat tissue. It is important to identify a non-calcified segment. The preferred approach is to find a position as high as possible on the descending aorta, since a more proximal anastomosis appears less likely to lead to aortic root stasis, which can result in aortic root thrombosis and/or embolization.

Heparin is given, and a side-biting clamp is placed on the aorta. If clamping the aorta is not tolerated, extra-corporeal circulation is initiated through cannulation of the femoral vessels. The aorta is opened with a knife and further opened with Potts scissors. A 12 mm sealed Dacron graft is used, or the outflow graft of the pump may be used. After cutting the graft into the appropriate length, an end-to-side anastomosis is

performed with 4-0 Prolene. The clamp is removed, and the anastomosis is tested for hemostasis.

Sutures are then placed at the apex of the LV in the usual fashion. The apex is then cored and the pump inserted. The pump is secured in place, and the outflow graft is either attached, or if a separate graft was used earlier, an end-to-end anastomosis using 5-0 Prolene is executed.

Minimally Invasive Approach

For this procedure, the patient is in a supine position, and a double lumen tube is placed. The groin is prepared for cannulation, and the apex of the LV is exposed through a left anterior minithoracotomy.

A pocket for the pump is created through this incision behind the rectus sheet. This can be approached through the diaphragm from the inside. If desired, CPB is started through femoral-femoral bypass, after full heparinization. Sutures are placed at the apex, the core is removed, and the pump inserted and secured in place. The pump is positioned in the pocket. The driveline is tunneled to the outside, and the outflow graft is tunneled to the right chest wall at the level of the 3rd intercostal space. An incision is made at this location, and the ascending aorta is exposed. A side-biting clamp is placed on the ascending aorta, and the aorta is opened. An end-to-side anastomosis is performed. Exposure of the ascending aorta can be completed before heparinization to reduce the risk of bleeding.

Topic 4: Explantation Techniques: Explantation of LVADs for Heart Transplantation

Preoperative Considerations

The use of MCSs as a bridge-to-transplant (BTT) are increasing. In some reports, an increase in perioperative transplant mortality was observed in BTT recipients who received pulsatile devices compared to patients who did not require support⁷³, although current series with continuous flow devices have not demonstrated worse survival in those who had MCS as a BTT.⁷⁴ Reasons for an increase in perioperative mortality may include presence of extensive adhesions after MCS placement, challenges in safe mediastinal exposure, as well as increased bleeding tendency in these patients.

The availability of modern MCSs allows for extended bridging periods. In some countries, this has led to the decision that stable MCS patients no longer have a priority status on the waiting list for heart transplantation. In other countries, priority status still exists based on the experience with older, less reliable MCSs. The time allocated for patients to recover from MCS surgery, achieve lower

pulmonary vascular resistance, improve end organ function and complete rehabilitation programs prior to the heart transplant procedure varies greatly between programs.

These different approaches may impact the risk of heart transplantation in MCS patients and may explain, in part, divergent results between centers and countries. The length and complexity of the transplant surgery is also an important consideration. Explant of the heart and the MCS requires careful attention to adhesions and hemostasis, which may prolong the procedure and thus the ischemic time, which, in turn, may lead to an increased risk of allograft dysfunction. It is ideal to remove both the heart and the device when the graft arrives in the operating room. However, the device may be left in place and be explanted later to allow for the transplant to proceed in a timely manner.

Mediastinal Exposure, Cannulation, and Cardiopulmonary Bypass

The procedure is usually carried out with a median sternotomy as previously described. Preoperative CT scans aid in planning for this step. The surgeon may choose to 1) perform the sternotomy first; or 2) dissect the adhesions to prepare cannulation sites within the thorax; or 3) choose to cannulate femoral vessels and go on CPB before sternotomy. The third option is the safer approach, but it also leads to prolonged CPB times and may be disadvantageous in the case of atherosclerosis. Some surgeons use the subclavian artery for cannulation.

After sternotomy, the most severe adhesions are anticipated at the anterior surface of the heart and surrounding all internal device components. In some patients, pericardial membranes were placed during MCS implantation to allow easier entry at this point. Care must be taken to avoid injury to the outflow graft and to the right ventricle. Maintenance of hemostasis is required at this point, especially when CPB is not in use. Unexpected severe bleeding should lead to immediate institution of CPB. The outflow graft itself represents an excellent option for arterial cannulation of CPB in case of emergency.

The pleural space may be opened to optimize exposure. The preparation of the aorta is usually done first. The outflow graft can be used as a lead structure to the ascending aorta. In many cases, the distal aortic anastomosis of the outflow does not provide sufficient space for cannulating, clamping, and anastomosis of the future graft. Therefore, when peripheral cannulation is not performed, the aortic arch may be the most suitable place. In circumstances where space is inadequate for clamping and safe anastomosis, a short period of circulatory arrest may be required later, and preparations can be made at this point.

Device Explanation

Bicaval venous drainage is required for heart transplantation. The preparation of the superior and inferior vena cava is the next step. Severe adhesions may prolong this task. This step is the latest point of the procedure when CPB should be instituted. The MCS is stopped, and the outflow graft is divided after proximal and distal clamping. The aorta can be cross-clamped, and the adhesions at the diaphragmatic aspect are dissected. Thereafter, less severe adhesions can be expected at the posterior wall of the LV. When the heart is dissected free, it is usually removed to give more exposure to the pump pocket. Care should be taken when the ascending aorta is excised. The outflow graft should be completely removed, and enough space proximal to the crossclamp should be provided for safe anastomosis of the donor heart. The apical connection can be opened when access to the apical cannula is easy. In other cases, the apical part of the LV may be cut off to allow removal of the heart with an optimum exposure to the ventricular cannulation site. Careful dissection of the device from the pocket without opening of the peritoneal cavity follows. Care should be taken to avoid injury to the left phrenic nerve, when adhesions are extensive. The driveline should be cut close to the device to allow removal of the pump. The last step is the removal of the percutaneous lead. The extent of this process depends on the implant, the duration of MCS support, and possible infection. Removal may be via a tunnel from the mediastinum subcutaneously to the right upper quadrant. Alternatively, a tunnel may be made down the sheath of the rectus muscle with an inch turn cranial to the umbilicus, followed by a subcutaneous tract from there to the exit site at the left or right upper quadrant.⁷⁵ If a short subcutaneous tunnel was used, an intrathoracic dissection of the lead, followed by an approach from the exit site may be sufficient to pull out the lead. It should be noted that the exit site may not be sterile, and appropriate measures should be undertaken to avoid contamination. These steps may be done at a later time in order to avoid postponing graft implantation.

MCS Removal in Bridge to Recovery Patients

Most aspects described above also apply for this procedure, although two additional tasks are required for isolated MCS removal. The heart should not be injured, and safe closure of the apical cannulation side is required. This procedure may be technically demanding using the standard approach of median sternotomy. Full exposure of the apical cannulation site requires dissection of most parts of the LV to allow elevation of the apex. This procedure must be done with CPB. Fibrillation of the heart may be useful for inspection of the LV cavity for possible thrombus formation. Closure of the apex can be performed in a similar fashion to that described

for transapical valve procedures with strong felt strips supported by purse-string sutures. Alternatively, the sewing ring of the device may be left in place and used to support strong U – sutures for closing the defect. Implantation of a Dacron patch is only required in cases of extensive trauma to the apical myocardium. More recently, investigators have used a felt or titanium plug secured to the inflow cuff that facilitates explant and reduces apical myocardial trauma and remodelling.^{76,77} The outflow graft can be clamped as close to the aorta as possible and oversewn or even closed with a stapler.

Because of the invasive and high-risk nature of this procedure, a limited approach with multiple incisions to expose the apex, the pump and the outflow graft avoiding median sternotomy and dissection of the heart has been described.⁷⁸ In experienced hands with suitable position of the internal device components, this alternative may be favored.

Bleeding Complications and Coagulopathy

Severe impairment of the coagulation system is to be expected in all cases of removal of rotary blood pumps. Anticoagulation treatment, use of platelet inhibitors, and acquired von Willebrand disease appear to be present in all of these patients.⁷⁹ Impaired primary hemostasis leads to excessive bleeding from suture lines and wound surfaces. In addition, infusion of coagulation factors may be helpful. Since this process is self limiting, packing the mediastinum with rolls of gauze after removal of the device may be required to control excessive bleeding. Usually, coagulopathy resolves within 24 hours after surgery. Removal of the remaining percutaneous lead components or implanted ICD/cardiac resynchronization therapy (CRT) devices may be performed when the patient returns to the operating room for removal of gauze and closure of sternotomy.

Topic 5: Early Post-Operative Management: Hemodynamic Management

The preexisting sequelae of advanced heart failure, hemodynamic variability of the pump, and the effects of major cardiac surgery on an already weakened body often complicate early post-operative management of the MCS patient. However, post-operative management of these patients should be kept simple, focusing on their most relevant clinical needs. The primary objectives of early post-operative management are to optimize RV function and to support end-organ recovery through optimization of organ perfusion.

Monitoring

Invasive monitoring of the post-operative MCS patient is required in order to ensure adequate optimization of

hemodynamic support. Techniques should include invasive arterial blood pressure, pulmonary arterial pressure, central venous pressure, pulmonary capillary wedge pressure, mixed venous saturation, and cardiac output and index monitoring.

Cardiac Output and Index, Arterial Blood Pressure and Mixed Venous Saturation

In patients support with an LVAD only, cardiac output (CO) and index (CI) is close correlated to pump output *only* in the case of complete LV unloading (absence of aortic valve opening). CO and CI exceed pump output to a variable degree as pump flow is adjusted to allow for aortic valve opening. Utilization of a Swan-Ganz catheter that allows for continuous monitoring of cardiac output may therefore be useful in the early post-operative period.

CI of the post-operative MCS patient should be ideally maintained above 2.2 l/min/m² while keeping the MAP between typically between 70-90 mmHg.^{75,80,81} Lower blood pressures (e.g. MAP of 60) can be tolerated as long as the patient is still producing urine and demonstrates no signs of acidosis through blood gas analysis. Mixed venous saturation goals should if possible should be >60% with differences between arterial and mixed venous saturations of <40%.

Central Venous Pressure Monitoring

Central venous pressure (CVP) levels vary from patient to patient and should be determined individually based on right heart function. A balance must be achieved to maintain appropriate intravascular volume while avoiding anemia, hypovolemia, and right heart overload. Target CVP levels should allow for a CI of >2.2 l/min/m² while maintaining a MAP of 70-90 mmHg. CVP measurements taken in the operating room after the chest has been closed can be helpful in the initial determination of target CVP levels. Significant deviation from a patient's target CVP (± 4 mmHg) or levels above 18 mmHg with inadequate CO requires further investigation. Echocardiography is helpful in determining extrinsic compression and a general sense of ventricular filling.

Calculation of pump outflow index helps to direct the specific management of the BiVAD patient. In patients supported with a biventricular assist device (BiVAD), the CVP should be targeted to maintain an LVAD pump index of >2.2 l/min/m². A CVP >20 mmHg with an inadequate pump index requires echocardiographic studies to rule out tamponade or other technical issues.

Pump Output

In LVAD patients without technical problems, pump output is dependent on a combination of right heart function; pump speed (pump rate), volume load (CVP), preload, and

afterload. Pump speed should be adjusted to maintain a pump output that provides the patient with adequate CI and MAP while avoiding LV suction and septum deviation to the left. Suction events indicate that there is inadequate blood volume entering the pump and must be investigated for root cause (right heart failure, hypovolemia, inflow or outflow obstruction). The need for aortic valve opening in the early post-operative period is still an issue that requires further investigation.

Patients supported by BiVADs require added attention to outputs on both the left and right pumps. Left pump flow should be maintained at a level that promotes patient organ recovery (pump outflow index >2.2 l/min/m²). Right pump flow is generally lower than left pump flow due to cannulation

technique (typically right atrial cannulation) and an effort not to minimize pulmonary congestion. Additionally, right pump flow should be adjusted to allow adequate blood washout to prevent embolic complications.

Blood Pressure

In order to achieve adequate pump output to support organ recovery, MAPs should ideally be maintained between 65 and 90 mmHg. Different clinical scenarios may require the addition of vasopressors, inodilators and inotropes to achieve this goal.

The most common hemodynamic scenarios with treatment recommendations are outlined in Table 1. Treatment scenarios assume that hypovolemia has been corrected.

Table 1 Treatment Recommendations for Early Post Operative Hemodynamic Management

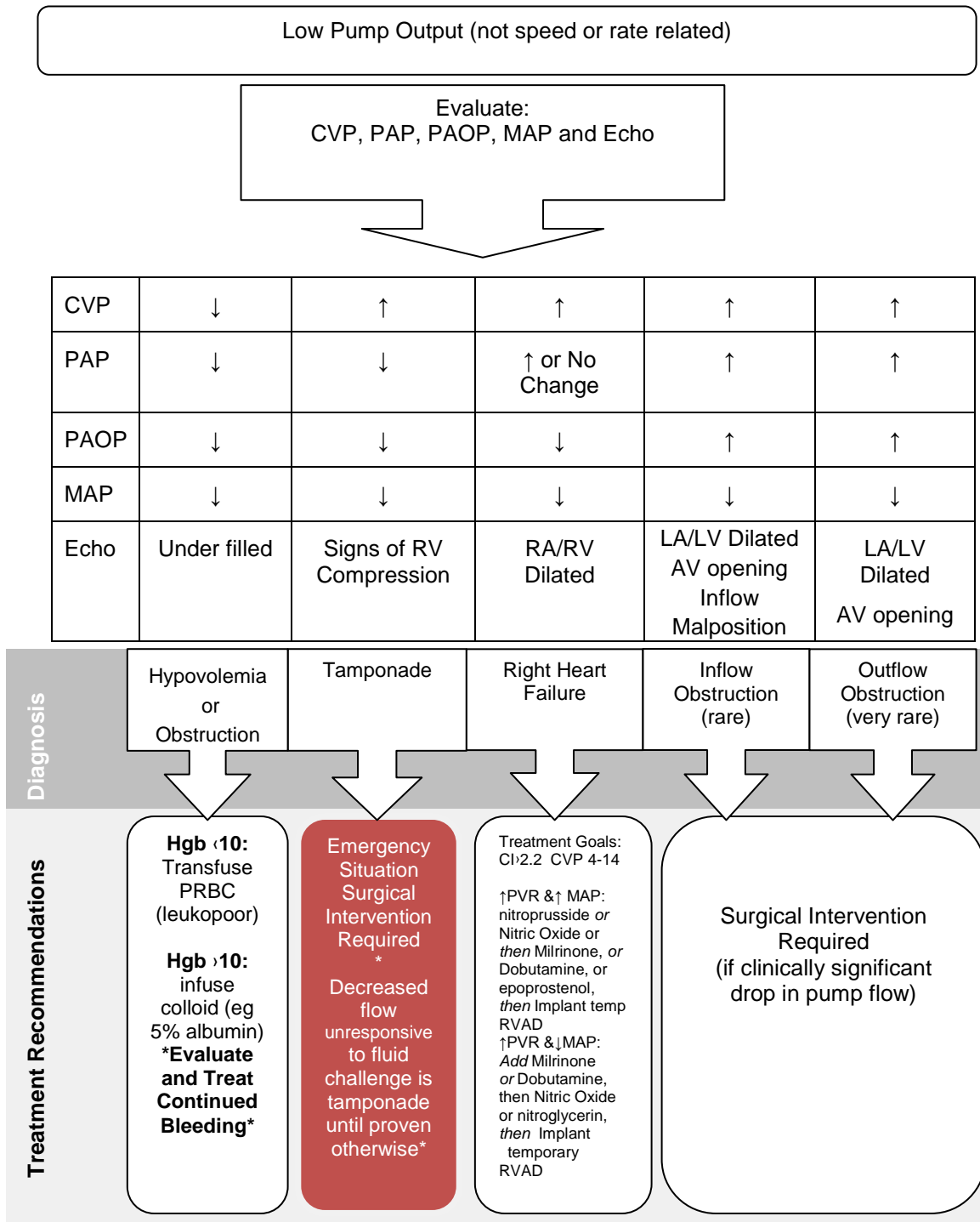
CI (l/min/m ²)	MAP (mmHg)	LV ejection	Primary Recommendation	Alternative
<2.2	<65	No	Epinephrine, Vasopressin, Norepinephrine,	Dopamine
		Yes	Increase Pump Speed	Volume for low CVP
	>65	No	Dobutamine	Milrinone
		Yes	Increase Pump Speed	
	>90	No	Milrinone	Sodium Nitroprusside/
		Yes	Sodium Nitroprusside Nitroglycerin, Hydralazine	Milrinone Nicardipine
>2.2	<65	No	Norepinephrine	Vasopressin
		Yes	Norepinephrine	Vasopressin
	>65 and <90	No	No Intervention	
		Yes	No Intervention	
	>90	No	Sodium Nitroprusside Nitroglycerin, Hydralazine	Milrinone Nicardipine
		Yes	Sodium Nitroprusside	Nicardipine

Low Pump Output

Low pump output is defined as inadequate pump flow to support organ recovery. Causes of low pump output include hypovolemia, tamponade, right heart failure, and in rare cases, inflow or outflow obstruction. Pump output should be monitored and documented at least hourly for the first 12

hours after implantation. Unstable patient hemodynamics at any time requires more frequent monitoring and documentation until stability can be achieved. Figure 1 outlines the decision process for determining and treating a low pump output state.

Figure 1 Low Pump Output Treatment Algorithm



Bleeding

Hemoglobin Levels

Anemia of chronic disease is commonly present preoperatively in patients receiving MCS therapy due to advanced heart failure. Hemodilution and blood loss both intra- and post-operatively add to a decreased hemoglobin level in the early post operative setting. Despite increasing evidence that a hemoglobin of 7g% is safe in stable patients following CPB, critically ill patients may require higher hemoglobin levels to promote organ recovery (especially in the initial post-op setting).⁸² Therefore, the hemoglobin at which a blood transfusion is necessary (transfusion threshold) should be individualized for each patient based on the clinical scenario but consider organ perfusion (MVO₂ and the degree of post-operative bleeding). Minimum recommended hemoglobin levels are 8g% in BTT patients and 10g% in destination therapy (DT) patients in the early post-operative period.

Management of Bleeding

Management of bleeding starts with careful patient selection and meticulous intra-operative hemostasis. Post-

operative bleeding is one of the most frequent complications following MCS implantation, and it may be classified as either surgical or medical. Standard coagulation testing should be performed to determine the cause of post-operative bleeding. Medical bleeding can be controlled by correction of coagulopathies using appropriate blood products. Surgical bleeding occurs despite correction of coagulopathies and requires that the patient be returned to the operating room to identify the source. Uncontrolled bleeding (chest tube output greater than 400cc for more than 3-4 hours) should be surgically evaluated and exploration considered (see Topic 2 of this same section).

Anticoagulation Management

Recommended post operative anticoagulation management strategies for MCS patients are outlined in Tables 2-4.^{75,83-87} It should be noted that in patients who test positive for heparin induced thrombocytopenia (HIT), heparin should be stopped and anticoagulation continued using argatroban, bivalirudin or oral anticoagulants.⁸⁷⁻⁹¹

Table 2 Early Post-Operative Anticoagulation Management of HeartMate II™ Patients Using Heparin

Timing	Action	Target
After CBP- leaving operating room	Complete reversal of heparin	n/a
ICU admission – 24 hrs	No action required, consider ASA	n/a
Post-operative day 1-2	Patients with other indication for anticoagulation therapy should be treated with IV heparin or suitable alternative if there is no evidence bleeding	PTT (40-60 seconds)
Post-operative day 2-3	Patients with another indication for anticoagulation: Continue with heparin No other indication for anticoagulation: warfarin and aspirin (81-325mg) after removal of chest tubes	PTT (60-75 seconds) INR (1.5-2.5)

PTT = partial thromboplastin time; INR = international normalized ratio

Table 3 Post Operative Anticoagulation Management for Implantable Centrifugal Pumps

Timing	Action	Target
After CBP- leaving operating room	Complete reversal of heparin	n/a
ICU admission – 24 hrs	No action required, consider ASA	n/a
Post-operative day 1-2	IV heparin or alternative anticoagulation, if no evidence bleeding	PTT (40-60 seconds)
Post-operative day 2-3	Continue heparin	PTT (60-80 seconds)
	Start warfarin and aspirin (81mg-325mg daily) after removal of chest tubes	INR (2.0-3.0)

PTT = partial thromboplastin time; INR = international normalized ratio

Table 4 Post Operative Anticoagulation Management for Pulsatile MCSDs

Timing	Action	Target
After CBP- leaving operating room	Complete reversal of heparin	n/a
ICU admission – 24 hrs	No action	n/a
Post-operative day 2	Start IV heparin if no evidence bleeding	PTT (40-60 seconds)
Post-operative day 3	Continue heparin	PTT (60-80 seconds)
	Start warfarin and aspirin (81mg-325 mg daily) after removal of chest tubes	INR (2.5-3.5)

PTT = partial thromboplastin time; INR = international normalized ratio

Discontinuation of Invasive Lines and Drains

Infection risk from invasive lines and drains remains a major complication with devastating outcomes if the implanted device becomes infected. For this reason, all invasive lines and drains should be removed as soon as the patient's condition is stable. Table 5 provides guidelines for removal of invasive lines and drains in a stable postoperative MCS patient.

Respiratory Management

Pulmonary complications immediately after anesthesia and CPB vary from mild to severe and include atelectasis, bronchospasm, hemothorax, pneumothorax, prolonged endotracheal intubation, mucous plugs or blood clots in the endotracheal tube, and pulmonary edema.⁹² A midline sternotomy (or thoracotomy) causes significant reductions in

total lung capacity, forced vital capacity (FVC), forced expiratory volume in 1 second (FEV₁), and functional residual capacity.⁹³ These changes often result in postoperative atelectasis and mild hypoxemia.

Recommendations for immediate post operative respiratory management include a period of controlled ventilation to avoid post-operative hypoxia and hypercapnea. This time allows for patient re-warming, emergence from anesthesia, optimization of cardiac function, hemodynamic stabilization, and correction of bleeding issues. Ventilation parameters for the early post operative period are outlined in Table 6.

Endotracheal extubation should be attempted within 24 hours following MCSD implantation in patients who are hemodynamically stable, neurologically intact, have no bleeding issues and show acceptable blood gas analysis.⁸¹

Early extubation improves right heart performance, reduces the risk of pulmonary infection, and reduces ICU length of stay.⁹⁴

should focus on feeding, mobility issues, and discharge preparation. Table 7 outlines suggested guidelines surrounding these issues.

Other Considerations

Once patient stabilization occurs, post-operative management of the patient implanted with an MCS device

Table 5 Guidelines for Removal of Invasive Lines and Drains in the Non-Complicated Postoperative MCS Patient

Type of Line/Drain	Time to Discontinuation	Notes
PA catheter	24-48 hrs	Must remain in place for severe right heart failure requiring high doses of inotropes
Arterial line	48-72 hrs	Must remain in place until all vasoactive medications are weaned
Central venous line	Until no longer needed	Must remain in place until all vasoactive medications are weaned
Chest tubes	48 hrs; or when drainage is <100 cc in the previous 6 hours	Preferably after patient has sat up to assure that drainage is not positional
Pocket drain	72 hrs; or when drainage is <100cc for the previous 8 hours	May be removed sooner if pocket communicates with left pleural space and if the left sided chest tube remains in place.

Table 6 Parameters for Post Operative MCS Patient Ventilation⁹⁵

Mode	Assist / Control
Rate	10-12 breaths/minute
Tidal Volume	6 -8 mL/Kg
PEEP	5 cm H ₂ O

PEEP = positive end expiratory pressure

Table 7 Mobility and Feeding Guidelines

Activity	Goal
Out of Bed to Chair	Post operative day 1
Feeding	Post operative day 1
Discharge from ICU	Post operative day 3-5

ABBREVIATIONS

ACE = angiotensin converting enzyme
 ACT = activated clotting time
 ASD = atrial septal defect
 AV = atrioventricular

BiVAD = biventricular assist device
 BTT = bridge-to-transplant
 CI = cardiac index
 CO = cardiac output
 CPB = cardiopulmonary bypass

CRT = cardiac resynchronization therapy
 CT = computed tomography
 CVP = central venous pressure
 CVVH = continuous veno-venous hemofiltration
 DT = destination therapy
 FEV1 = forced expiratory volume at 1 second
 FVC = forced vital capacity
 HIT = heparin induced thrombocytopenia
 IABP = intraaortic balloon pump
 ICD = implantable cardioverter defibrillator
 ICU = intensive care unit
 INR = international normalized ratio
 IVAD = implanted ventricular assist device
 IVC = inferior vena cava
 LIMA = left internal mammary artery
 LV = left ventricular
 LVAD = left ventricular assist device
 MAP = mean arterial pressure
 MCS = mechanical circulatory support device
 MCS = mechanical circulatory support
 MVO2 = mixed venous oxygen saturation
 PEEP = positive end expiratory pressure
 PFO = patent foramen ovale
 PVR = pulmonary vascular resistance
 RA = right atrium
 RCA = right coronary artery
 RV = right ventricular
 RVAD = right ventricular assist device
 SVC = superior vena cava
 TEE = transesophageal echocardiography
 TRALI = transfusion associated lung injury
 VAD = ventricular assist device

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The 2013 International Society of Heart and Lung Transplantation Guidelines for Mechanical Circulatory Support

Task Force 4: Inpatient Management of Patients with Mechanical Circulatory Support Devices

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Introduction

Inpatient management of patients with mechanical circulatory support (MCS) is divided into two phases: 1) management during the implantation hospitalization, and 2) subsequent re-admissions over the duration of support. Not all admissions are for device related complications, particularly in the current era of long-term support. Patients are often readmitted to the implanting hospital for non-device related medical and surgical issues, due to a lack of expertise or comfort with managing patients on MCS.

Management of the MCS Inpatient following the Initial Implant: Post ICU

Early post-surgical management is covered in Task Force 3. After the initial hemodynamic stabilization in the cardiothoracic surgical intensive care units (ICU), the patient is then transferred to a lower acuity setting for the remainder of their implant hospitalization. At this juncture, the primary team may be led by either the implanting surgeon or the MCS cardiologist, although ideally management should continue to be collaborative and include the other members of the multidisciplinary team.

Hemodynamic Considerations: Right Heart Function, Pulmonary Hypertension, and Blood Pressure

This section addresses post-operative management of right heart function, pulmonary hypertension and blood pressure in the post-ICU patient. Even after the initial transfer from the ICU, patients initially require close monitoring, utilizing non-invasive information from the patient's vital signs, physical examination, and device parameters. Right heart function may continue to be supported with inotropic agents or pulmonary vasodilators. Volume status should also be carefully monitored by clinical exam and device parameters, as edema may be a less reliable indicator of the

patient's intravascular volume due to hypoalbuminemia as a result of chronic heart failure and post-operative state.

Postoperative pharmacologic therapy is an essential adjunct to device therapy. Prolonged (>14 days) use of inotropes may be necessary to support right ventricular (RV) function following mechanical circulatory support device (MCS) implantation, or to enhance left ventricular (LV) function if device speeds are temporarily set lower to prevent septal shift. Milrinone is an important inotrope for perioperative myocardial support. It enhances contractility as well as vasodilation, particularly of the pulmonary bed, which can reduce RV afterload. Dobutamine can also be used in the telemetry unit with minimal monitoring to provide beta agonist support and enhance contractility. Weaning of inotropic support should be initiated once the patient is euvolemic and is clinically guided by the physical examination with close monitoring of device parameters. Ideally, this is accomplished by initiating oral heart failure therapies with up-titration as tolerated before the inotrope weaning process. Diuretics and/or mechanical volume removal may be necessary to achieve optimal volume status. As inotropes are weaned, the clinician should evaluate for evidence of RV dysfunction including:

- Increasing edema
- Elevation of jugular venous pressure (JVP) or CVP as monitored by a central venous catheter. CVP should be maintained <15mmHg
- Evidence of low cardiac output including hypotension (mean arterial pressure <60 mmHg for continuous flow devices), cool extremities, or decrease in mixed venous oxygen saturation (Svo₂) as drawn from a central venous catheter
- Manifestation of end-organ dysfunction as a consequence of venous congestion or low cardiac

output (e.g. rising creatinine, BUN, or decreasing urine output)

- Change in device parameters including decrease in flows and loss of pulsatility

Pulmonary vasodilators are an important adjunct therapy following MCS implantation to optimize hemodynamics, enhance right heart performance, and aid in weaning inotropic support. Phosphodiesterase 5 (PDE-5) inhibitors such as sildenafil have been shown to improve pulmonary vascular resistance in patients with left ventricular assist devices (LVADs)¹ and may be started while the patient is still in the ICU setting in combination with inhaled nitric oxide. The co-administration of nitric oxide and sildenafil may have additive benefits on mean pulmonary artery pressure and pulmonary vascular resistance (PVR) without systemic hypotension and ventilation/perfusion mismatch.²

Afterload reducing vasodilators including angiotensin converting enzyme (ACE)-inhibitors, angiotensin receptor blockers (ARBs), nitrates, and hydralazine are the cornerstone of treatment of heart failure patients, but their role is less well defined in the patient on MCS. Generally, resumption of afterload reduction with ACE-inhibitor or ARB is recommended in the post-operative period for the goals of treating hypertension, optimizing RV function, averting the development of aortic insufficiency (a long-term complication), preventing other vascular complications, affording renal protection, and maximizing the potential for LV myocardial recovery. Hypertension for a continuous flow ventricular assist device (VAD), typically defined as a mean arterial pressure (MAP) >90mmHg (measured by Doppler or arterial line tracing), is essential to treat for optimal device performance. Once pressors are weaned, an ACE-inhibitor or ARB may be initiated at low doses and slowly increased in a step-wise fashion. Hydralazine and nitrates may be introduced thereafter as additional afterload reducing agents if blood pressure targets have not been met, although nitrates should not be given if the patient is already being treated with a PDE-5 inhibitor. If there is right heart dysfunction or chronotropic incompetence, beta blocker use may be limited. Permanent pacing may be necessary to remedy heart rate issues. After stabilization of blood pressure, heart rate, and volume status, beta blockers may be initiated either in the hospital or early in the outpatient setting. Once again, there are insufficient data to support evidence-based recommendations for the resumption of beta blockers post MCS, but the rationale for starting them is similar to that for ACE-inhibitors and ARBs. Beta-blockers may also be helpful in the treatment of arrhythmias. Cardiac

glycosides and mineralocorticoid receptor antagonists (MRA) may be resumed to help support right ventricular function and attenuate myocardial fibrosis.

Hypotension may recur in the post ICU setting, due to either device related or non- device related causes. An algorithm to assess hypotension post MCS implant is presented in Figure 1. Tamponade is a real, although unlikely, cause of hypotension once patients are stable and out of the ICU. It should always be considered as the treatment is emergent and invasive. Although tamponade is covered in Task Force 3, it is worth reiterating that echocardiography is not always reliable in the diagnosis of tamponade post-operatively, and there should be a low threshold for surgical consultation when it is suspected.

Recommendations for the Treatment of Right Heart Dysfunction in the Non-ICU Post-Operative Period:

Class I:

1. Inotropic support may need to be continued into the remote postoperative period (>2 weeks) when there is evidence for right heart dysfunction such as elevated JVP, signs of venous congestion, decreased VAD flows (or low pulsatility in continuous MCS) or end-organ dysfunction. Once euvolemic, inotrope wean should be done cautiously with ongoing examination for recurrent signs and symptoms of RV dysfunction.

Level of Evidence: C.

2. Diuretics and renal replacement therapy such as continuous veno-venous hemofiltration (CVVH) should be employed early and continued as needed to maintain optimal volume status.

Level of Evidence: C.

Class IIb

1. Cardiac glycosides may be used to support right ventricular function.

Level of Evidence: C.

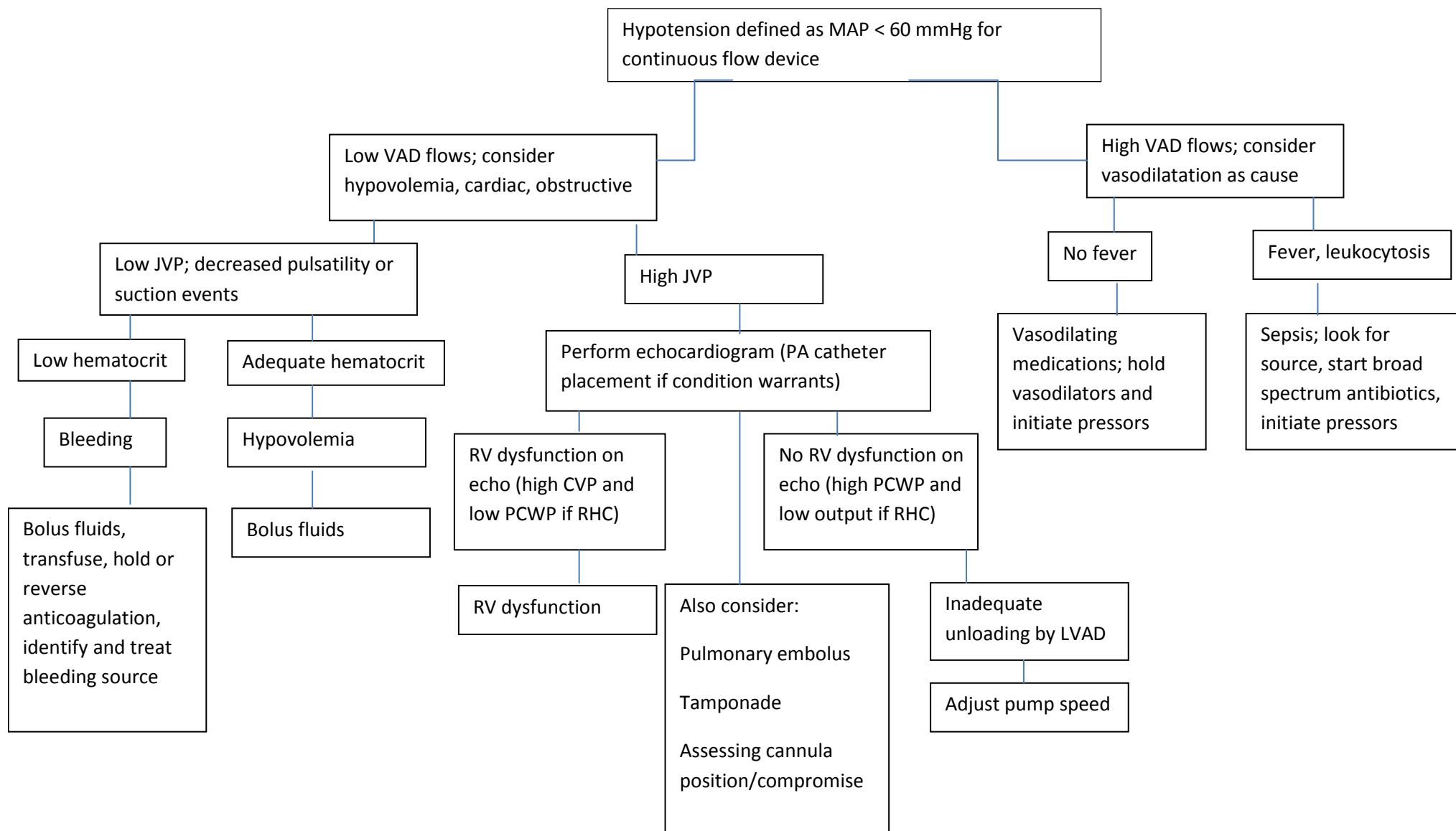
2. For patients with persistent pulmonary hypertension who exhibit signs of RV dysfunction, pulmonary hypertension-specific therapies such as PDE-5 inhibitors should be considered.

Level of Evidence: C.

3. Pacemaker therapy can be used if the heart rate is not optimal to support hemodynamics.

Level of Evidence: C.

Figure 1 Algorithm for Assessment of Hypotension Post-Implant



Recommendations for Managing Hypotension in the non-ICU Post-Operative Period:

Class I:

1. A systematic approach to hypotension should be employed as shown in Figure 1.

Level of Evidence: C.

Recommendations for Neurohormonal Blockade and the Treatment of Hypertension Post MCS Implant:

Class I:

1. Pharmacotherapy with heart failure medications (ACE - inhibitor, ARB, beta blocker, hydralazine, nitrates) is preferred for blood pressure management.

Level of Evidence: C

Echocardiography

Echocardiographic guided adjustment of speed may allow the lowest RPM setting to achieve optimal LV unloading. Intermittent aortic valve opening, and optimal left ventricular septal position may achieve enough left ventricular decompression to minimize the degree of mitral regurgitation and thus RV afterload. Opening of the aortic valve with every beat and presence of significant mitral insufficiency may represent inadequate unloading of the left ventricle and higher device RPM's may be needed. With very severe LV dysfunction, the aortic valve will not open even at low device RPM speeds. Maintaining intermittent aortic valve opening postoperatively may reduce the risk of late aortic valve thrombosis and late development of aortic valve insufficiency.³ Reports have documented that the development of late aortic insufficiency in patients with MCS occurs with greater frequency in patients with no aortic valve opening, and it is associated with worse long term outcomes.⁴ Additionally, aortic valve fusion and anecdotal reports of aortic valve thrombus have been reported in patients with persistent closure of the aortic valve during MCS.⁵ Chronic care of the device and routine assessment with echocardiography is addressed in the outpatient setting. However, in the post-operative period as the patient becomes active and ready for discharge, it is important to define an optimal pump speed for hemodynamic support, RV function, and valvular competency.

Recommendations for Echocardiography in the non-ICU Postoperative Period:

Class I:

1. Echocardiography is an integral part of determining the RPM of continuous flow pumps. Common goals include adequate LV unloading while maintaining the LV septum in the midline and minimizing mitral regurgitation.

Level of Evidence: C.

Class IIb:

1. Post operatively, the RPM of continuous flow pumps should be set low enough to allow for intermittent aortic valve opening.

Level of evidence: B.

2. Long-term, maintaining intermittent aortic valve opening may reduce the risk of aortic valve fusion and the risk of late aortic valve insufficiency.

Level of evidence: B.

Anticoagulation Management

Clinically significant thromboembolic or bleeding events are devastating complications of MCS. Despite advances in cardiac assist device technology, monitoring and management of coagulation factors continues to be a challenge. Embolic and hemorrhagic stroke are a prominent adverse event in MCS trials, and the risk of such events has greatly influenced clinical practice. Furthermore, each device has its own unique recommendations for anticoagulation management. This section's recommendations should be used in tandem with the manufacturer patient management guidelines for each specific device. Sepsis and other inflammatory states clinically alter the patient condition and should also be taken into consideration for optimal anticoagulation management.

Initiation of Anticoagulation or Antiplatelet Therapy Post-Operatively. In the early post-operative period, anticoagulation and antiplatelet therapy is initiated as discussed in Task Force 3. Some surgeons elect to forgo the use of heparin and heparin substitutes completely, and they prefer to start warfarin plus one or more of aspirin, clopidogrel, and/or persantine via nasogastric tube, within the first 24 post-operative hours.⁶ After transfer out of the surgical ICU, warfarin is continued targeting the international normalized ratio as specified for each particular device. Starting doses for antiplatelet therapy in MCS patients are as follows: aspirin 80-325 mg daily, dipyridamole 100 mg three times daily, and clopidogrel 75 mg once daily. Antiplatelet effect can be evaluated (platelet aggregation, PFA100, accumetrics, TEG®) with dose adjustments titrated to the desired level of platelet inhibition. Although variability exists between centers in anti-platelet management with regard to dosing, use of combination therapy, and laboratory monitoring of platelet inhibition, few data support one approach over another. Newer oral anticoagulant and anti-platelet agents such as rivaroxaban, dabigatran, ticagrelor and prasugrel have not been studied in MCS patients and cannot be recommended.

Treatment of Bleeding Events. Depending on the site and severity of bleeding, either reduction in intensity or discontinuation of anticoagulation/antiplatelet therapy may be

necessary. Supratherapeutic INR may be acutely corrected by transfusion of fresh frozen plasma. Cautious administration of vitamin K may also be undertaken, balancing the risk of pump thrombosis. Supportive management with transfusion of packed red cells to maintain adequate hematocrit, administration of fluids to maintain circulating volume, and vasopressors to maintain blood pressure should be instituted. Once the source of significant bleeding is identified, maneuvers to quell bleeding at that site are performed as indicated.

Recommendations for Anticoagulation and Antiplatelet Therapy Post MCS:

Class I:

1. Anticoagulation and antiplatelet therapy initiated post-operatively in the ICU setting should be continued with the aim of achieving device-specific recommended international normalized ratio for warfarin and desired antiplatelet effects.

Level of Evidence: B.

2. Bleeding in the early post-operative period during the index hospitalization should be urgently evaluated with lowering, discontinuation, and/or reversal of anticoagulation and antiplatelet medications.

Level of Evidence: C.

Infection Control. Infections in the MCS recipient are divided into three categories: a) MCS-specific including pump and/or cannula, pocket, and percutaneous infections; b) MCS-related, including infective endocarditis, bloodstream, and mediastinitis; c) non-MCS-related.⁷ Patients undergoing MCS surgery are often debilitated with co-morbid conditions including diabetes, renal insufficiency, and malnutrition secondary to a long history of heart failure.^{8,9} Immunological deficiencies related to T-cell response and cytokine imbalances may also be present in the population, both of which increase patients' susceptibility to infection.¹⁰

The most common pathogens causing infection in the MCS recipient include *Staphylococcus* species, *Pseudomonas* and *Enterococcus*. *Candida* is the most common etiology of fungal infections. These isolates can adhere to foreign device material and form biofilm, and therefore evade the immunological system, thereby becoming very hard to eradicate.¹¹⁻¹³ *Candida* fungemia has been associated with very high mortality in MCS recipients.^{9,14} These organisms are the major ones involved in MCS-specific and MCS-related infections and should be taken into consideration when peri-operative antimicrobial prophylaxis is evaluated. MCS recipients have many lines and drains, including central lines and chest tubes, and therefore their risk of infection in the

immediate post-operative course is substantial.⁸ They also have fresh wounds, and at times their mediastinum remains temporarily open because of edema and bleeding. It should therefore be intuitive that the need to practice meticulous line and wound care is crucial in order to prevent infection.¹⁵⁻¹⁸

Infection Control Measures Before and After MCS. The wound after MCS placement is classified as clean (Class I). Local guidelines for prevention of surgical site infection should be followed in MCS implantation operations, for example The Hospital Infection Control Practices Advisory Committee.¹⁸ Most patients were hospitalized for some duration prior to MCS; hence, their skin is colonized with hospital organisms. Simple washing of the skin with antimicrobial soap before MCS surgery is advised.¹⁹ Preoperative skin cleansing with chlorhexidine-alcohol is superior to povidone-iodine in clean-contaminated operations for prevention of superficial and deep wound infections.²⁰

During surgical creation of the pocket (if needed) and placement of a MCS, organisms may be inoculated and later cause infection. Therefore, it is crucial to follow meticulous antiseptic techniques in the operating room. High-efficiency particulate air (HEPA) filters and laminar air flow in the operating room is suggested to maximize sterile ventilation.²¹ Movement of personnel should be restricted, and people present in the operating room should use double gloving and headgear to completely cover their hair.²¹ Antibiotic-soaked pads should cover the pump and cannulas, and the pump should be extracted from its sterile packing shortly before its placement in the pocket,²¹ in order to minimize potential contamination. Adequate hemostasis is important since hematomas may serve as culture media for bacteria. Irrigation of the mediastinum with antibiotic solutions (vancomycin and gentamicin) may be performed before wound closure.²¹

Post-Operative Routine Prophylaxis. Antibiotic prophylaxis beyond 24-48 hours after surgery is generally unnecessary.²² Some centers continue prophylaxis until chest tubes are removed, or in the setting of delayed chest closure. Prolonged use of vancomycin in high-risk general cardiac surgery patients was not beneficial in reducing infection.²³ Also, in a retrospective study, decreasing the duration of vancomycin prophylaxis by more than half was not associated with an increase in infection rate after MCS placement.²⁴ The use of nasal mupirocin to reduce methicillin-resistant *Staphylococcus aureus* (MRSA) colonization and secondarily reduce staphylococcus infection is practiced by many centers.^{25,26} The optimal regimen for antibiotic prophylaxis in patients undergoing MCS placement is not known, but many centers use a combination of intravenous vancomycin, rifampin, levofloxacin, and fluconazole as recommended in the Randomized Evaluation of Mechanical Assistance for the Treatment of Congestive Heart Failure (REMATCH) trial.^{27,28}

An important consideration to take into account is the antibiotic resistance-profile of organisms in the medical center performing the MCSD implant.

Secondary prophylaxis given for procedures (dental, respiratory, genitourinary, gastrointestinal) have not been studied in MCSD recipients. In general, prophylaxis has not been recommended for cardiac patients except in certain high risk groups such as those with prosthetic valves, forms of congenital heart disease, and with valvulopathy after cardiac transplantation.²⁹ It should be noted that patients with MCS were not specifically addressed in this consensus statement. Since the burden of developing bacteremia is high in patients with MCS, secondary prophylaxis is reasonable and remains at the discretion of the physician.

Driveline Care. Drivelines and external cannulas are usually covered with Dacron-velour which stimulates subcutaneous growth and sealing of the skin.⁸ Due to concerns that the velour may promote settling of bacteria at the skin incision and result in infection, some surgeons have elected to bury the velour beneath the skin and bring the silastic coated part of the driveline through the incision. It is important for the wound around the driveline to heal without gaps so pathogens cannot penetrate. The purse string suture around the driveline should be left in place for up to 30 days.

Most driveline infections start with local trauma that disrupts the integrity between the driveline and surrounding skin, usually by accidental pulling of the driveline.³⁰ Patients have to be educated to care for their drivelines and avoid trauma. Immobilization of the driveline is important, and in case of local trauma, the VAD-coordinator has to be notified so infection prevention measures can be taken.³⁰ In some centers, immobilization of drivelines is performed immediately after the device is placed and before the patient leaves the operating room.³¹ A Foley catheter anchor may be used to secure the driveline, and often two anchors are applied to minimize movement at the exit site. The driveline site should be covered during bathing or showering until the wound is completely healed;⁸ some advocate no showering for 30 days after surgery or until the driveline site is completely healed.³² When there is formation of a gap between the driveline and surrounding tissue, it will not form new epithelium and healing would be impossible unless the tissue is debrided.³⁰

Protocols for the Care of the Driveline Exit Site. There are no universally accepted protocols that address wound care of the driveline exit site. Dressing changes should be done daily or every other day, and the site should be monitored carefully for any sign of infection.³² Most commonly, cleaning is done with chlorhexidine and gauze is placed to cover the exit site.³³ For patients sensitive to chlorhexidine, hydrogen peroxide may be substituted. At the University of

Pittsburgh Medical Center, a protocol for dressing changes was adapted from management of long-term hemodialysis catheter care.³⁴ The same technique is used daily by nurses for median sternotomy, chest tubes, drivelines, and abdominal pocket wounds. Nurses apply hat, mask, sterile gloves and gown, and while the dressing change is in progress, no one is allowed to enter the room. The dressing change protocol includes 4 steps: 1) gauze soaked with anti-septic solution is used to cleanse the exit site and surrounding skin; 2) The area is rinsed with gauze soaked with sterile water; 3) The area is dried with gauze; 4) 2 x 2 gauze is applied and then covered by transparent occlusive dressing.³⁴ At some centers, antiseptics or antibiotics are applied around the driveline site such as povidone-iodine, silver sulfadiazine, and chlorhexidine to inhibit growth of colonizing bacteria.⁸

Treatment of Device-Related Infections. Most device-related infections occur in the later phase of MCS therapy, and management of these is reviewed elsewhere in these guidelines. However, early occurrence is possible. The general measures outlined in this section, such as appropriate management of lines and tubes, careful stabilization of the driveline, and judicious care of the driveline exit site serve to reduce early risk of infection.

Recommendations for Infection Prevention Post MCS Therapy:

Class I:

1. The driveline should be stabilized immediately after the device is placed, and throughout the duration of support.

Level of Evidence: C.

2. A dressing change protocol should be immediately initiated post operatively.

Level of Evidence: C.

3. Secondary antibiotic prophylaxis for prevention of endocarditis has not been studied in the MCS population, but it would be considered reasonable due to the risk of bacteremia in this group.

Level of Evidence: C.

Nutrition

The main goals of a post-operative nutritional plan are to promote surgical wound healing, optimize immune function, and improve the macro- and micronutrient substrate conditions.³⁵ A formal nutritional consultation should be completed for all patients undergoing MCS with establishment of goals for those diagnosed with nutritional deficits. Pre-operative parameters should be obtained including pre-albumin, C-reactive protein, lipid profile, thyroid profile, serum iron, transferrin, folate, B12 and trace elements. Pre-

albumin and C-reactive protein can be monitored on a weekly basis post-operatively.³⁶ Trace elements such as zinc, manganese, selenium and copper can be checked every three months as needed. A goal of 20-25 kcal/kg/d with 1.2-1.5 g/kg/day protein should be targeted for critically ill patients. Calorie intakes should be advanced gradually based on medical status.³⁷ Ambulatory and non-critically ill patients need 30 to 35 kcal/kg/day to meet energy needs.³⁶

Ideally, feeding should begin within the first post-operative hours, enterally if possible. Enteral nutrition supports gut integrity, modulates the immune system, and is associated with a lower risk for infection than parenteral nutrition.³⁸ Early versus late enteral nutrition is associated with a decreased risk for mortality in ventilated patients with unstable hemodynamic conditions and on vasopressors.³⁹ Placement of a nasogastric tube should be considered to improve enteral nutrition tolerance and decrease the risk for aspiration.³⁶ Enteral nutrition formulas should be adjusted based on tolerance.³⁶ Parenteral nutrition should be reserved for patients who are unable to tolerate enteral nutrition adequately due to the high risk for fungal infection.⁴⁰

Recommendations for Optimization of Nutritional Status:

Class I:

1. Consultation with nutritional services should be obtained at the time of implantation with ongoing follow up post-operatively to ensure nutrition goals are being met.

Level of Evidence: C.

2. Post-operatively, for those unable to meet nutritional goals orally, feeding should be started early and preferably through an enteral feeding tube. Parenteral nutrition should only be started if enteral nutrition is not possible and under the guidance of nutritional consultation.

Level of Evidence: C.

3. Pre-albumin and C-reactive protein can be monitored weekly to track the nutritional status of the post-operative patient. As nutrition improves, pre-albumin should rise and C-reactive protein should decrease.

Level of Evidence: C.

Device Related Education

Health Care Provider Education. MCS education is an essential component of a MCS program. To safely manage MCS patients, a broad range of in-hospital health care professionals need to be educated including physicians, nurses, and other multi-disciplinary team members (e.g., physical therapy and occupational therapy). A plan for

comprehensive training of the majority of nurses in the hospital areas involved in the care of MCS patients will ensure that there are enough competent nurses to care for these patients.

Orientation to MCS should incorporate both theory and practical sessions with the use of a training simulator, allowing the staff to have hands on experience with the equipment. Education regarding acute management should address the indications for MCS implantation, components of the device(s), post-operative hemodynamics and daily management (including driveline exit site dressing changes), recognition and management of MCS alarms, emergency responses, medications, and MCS adverse events.⁴¹ Providing literature on new devices will help to prepare nurses to care for patients with these devices.⁴² After orientation to MCS, many institutions provide refresher courses and require semi-annual or annual assessment of MCS competencies. Regular competency assessment may help to maintain the nurse's confidence and knowledge in the care of MCS patients.⁴¹⁻⁴³ Learning styles of staff members need to be considered in the education program.⁴⁴ Ensuring nursing accessibility to guidelines and protocols promotes consistent and safe management when caring for MCS patients. A device checklist or flow sheet, based on guidelines for monitoring MCS and providing care, facilitates guideline adherence.

Patient Education. A collaborative multi-disciplinary approach to education of the patient, family, and friends is essential to the safe discharge of a MCS patient. An explanation of the surgical implant, post operative course (including recovery, rehabilitation, and outpatient management), lifestyle implications (including possible driving restrictions), device-related complications, post implant expectations and responsibilities of the patient and caregivers should be provided as part of the informed consent process to both the patient and family, if possible. Providing device-specific education materials as well as showing models of devices increases patient and family awareness of the surgery and postoperative expectations.⁴⁵⁻⁴⁷ It may also be beneficial to have a patient with a MCS visit with the patient and family while they are considering options.

After surgery, the patient and caregivers should learn about device management, initially at a basic level, and then with increasing complexity as they are able to demonstrate an understanding of MCS knowledge and skill.^{45,47,48} Patient and caregiver education includes daily management (e.g., maintenance of batteries and other MCS equipment, recognition and management of MCS alarms, anticoagulation monitoring, wound care and dressing procedures, and recognition of signs and symptoms of complications including infection and neurological dysfunction). Patients also need to understand possible lifestyle restrictions after MCS implant.⁴¹

The patient and caregivers should be provided with a device-specific education manual so that they can continue to learn and reinforce what has been taught on their own time. To promote safe MCS patient discharge, both the patient and caregivers should complete a written competency test and demonstration of skills (e.g., dressing change procedures) to ensure competent learning prior to discharge.⁴⁵

Bedside nurses should be encouraged to reinforce patient and caregiver education by MCS coordinators and / or provide education to the patient as part of their routine daily care. Education needs to be repetitive and reinforced regularly to promote patient and caregiver competence and confidence.⁴⁹ Education tools can assist nurses in the education of MCS patients and facilitate consistency among the nursing staff in the safe management of the device. These tools also serve as a useful way of monitoring patient progress.⁴⁵

Lastly, it is important to note that education needs to be individualized with assessment of the MCS patient's learning ability, educational level, and possible barriers to learning.⁴⁵ For older patients who may have cognitive dysfunction or for those patients with learning disabilities, Bond et al. suggest introducing patients to lists and reminder cards to prompt patients with their daily management of MCS.⁵⁰ Shorter, more frequent sessions may also facilitate learning. Educating MCS patients and their caregivers may contribute to increased understanding of MCS, prevention and better management of symptoms, fewer adverse events, and decreased hospital readmissions.

Documentation. Device specific MCS parameters should be charted in the patient's medical records, similar to documentation of other hemodynamic parameters. Ranges of acceptable values and triggers for physician notification should be established.

Recommendations for Health Care Provider and Patient Education:

Class I:

1. Health care providers should be trained in MCS therapy with opportunity to attend refresher classes and ongoing assessment of competency.

Level of Evidence: C.

2. Patient and caregiver education should be initiated shortly after surgery and reinforced by the nursing staff. Educational strategies should employ written, verbal and practical methods.

Level of Evidence: C.

Recommendations for Documentation of Device

Parameters:

Class I:

1. MCS parameters should be recorded in the medical chart at regular intervals with established criteria for ranges outside of which physician should be notified.

Level of Evidence: .C

2. Changes in parameters outside of normal ranges should be thoroughly evaluated and treated appropriately.

Level of evidence: C.

Device monitoring

During the index hospitalization, the patient and caregivers should begin garnering experience with monitoring MCS parameters. Normal values should be established, and parameters should be documented at regular intervals by the nursing staff with triggers for notification of the physician. While there are considerations unique to each device, commonly displayed parameters with continuous flow devices include speed (revolutions of the impeller per minute or RPM), flow (liters/minute), and power (Watts). Pulsatility, which is the size of the flow pulse generated by the pump is also displayed either numerically or visually. Table 1 summarizes causes of deviation from "normal" device conditions. Alarms are device specific, and the user's manual should be referenced for explanation of these.

Table 1 Causes of Deviation from Normal Device Conditions

Device condition	Causes	Interventions
High flows	Vasodilation Sepsis	Reduce or hold vasodilators Add pressor support Look for underlying source of sepsis and treat appropriately
Low flows	Hypovolemia Bleeding Arrhythmias	Bolus fluids Transfuse and address source of bleeding Treat arrhythmias
High powers	Pump thrombosis	Add additional anti-platelet and anti-coagulants Consider thrombolytic Emergent pump exchange if needed
High pulsatility index (PI)	Recovery of LV function Percutaneous lead damage	Look for evidence of recovery Assess VAD components as appropriate
Low PI	Hypovolemia Very poor native ventricular function Excessive pump speed	Bolus fluids Add inotropic support Adjust pump speed
Suction event (“suckdown” or “PI event”): Collapse of ventricular cavity around device inflow Usually due to under filled ventricle May manifest as low flows, low PI, or alarms	Hypovolemia Excessive unloading of ventricle by device Arrhythmias	Bolus fluids Lower pump speed Treat arrhythmias

Psychological and Psychosocial Considerations

Post operative management of MCS patients should include addressing psychosocial issues by social work, psychology, and psychiatry. MCS patients may have difficulty adjusting to MCS early after surgery. Adjustment issues may differ for patients with chronic advanced heart failure versus those whose heart failure occurred subsequent to a more recent, acute, catastrophic event.⁵¹ Additionally, patients may suffer mental status changes (e.g., delirium, mood changes, and cognitive dysfunction including memory deficits) related to pre-implant catastrophic events, surgery, or early post implant adverse events (e.g., stroke).⁵¹ Furthermore, the occurrence of early adjustment disorders may be related to implant strategy, (i.e., destination therapy) as patients learn to live with MCS for the rest of their natural lives. Adjustment disorders may also be related to the type of MCS device. For example, biventricular assist devices (BiVADs) may affect independence from a “lifestyle” perspective, as patients are tethered to a machine or must use a driver on a wheeled cart.

As a result, these patients are less able to function independently. In contrast, patients with LVADs who are discharged with a “wearable system” carry the external components in a fanny pack.⁵² Finally, psychosocial support may be indicated for patients and families while learning to manage and troubleshoot the MCSD, if they have concerns about their knowledge of MCS, lack confidence in MCSD management, or become overwhelmed.⁵¹

There is also evidence in the literature regarding psychological sequelae early after MCS implantation. Anxiety, lack of control over one’s life, and depression have been reported in hospitalized patients after MCS implantation.⁵³⁻⁵⁵ Patients have also reported moderate levels of stress related to having advanced heart failure, being hospitalized and away from family, the need for MCS, and post-operative pain.⁵⁴ Uncertainty may also be an important factor causing stress, especially for “bridge to candidacy” patients. Furthermore, family distress also requires monitoring and intervention. Psychiatric symptoms may

predict nonadherence to the medical regimen, unhealthy lifestyle (including substance abuse), poor medical outcomes, and poor health related quality of life after discharge.⁵¹

Despite the stress associated with hospitalization for MCS, patients have also generally reported that they were coping fairly well, although not as well as their self-report of overall coping prior to surgery.⁵⁴ At 2 weeks after MCS (while still hospitalized), patients used more positive coping styles (e.g., optimistic, self-reliant, and supportant) than negative coping styles (e.g., fatalistic, evasive, and emotive), and positive coping was more effective than negative coping.⁵⁴ Importantly, psychological assessment and intervention is needed for patients who use negative coping strategies. Interestingly, at both 2 weeks and 1 month after surgery (while still hospitalized), the vast majority of bridge-to-transplant (BTT) patients reported no regret regarding having undergone MCS implantation, citing that the MCS saved their lives.^{54,55} This “honeymoon phase” may be related to relief regarding surviving surgery, denial, and not considering the demands of self-care, prognosis [especially for destination therapy (DT) patients], and the possible complications of MCS (e.g., stroke) on lifestyle and long-term quality of life.^{51,54,55} It is important to note that the literature on psychological sequelae early after MCS implantation is primarily in BTT patients who received pulsatile assist devices, and it is limited by small sample sizes and missing data.

Recommendations for Psychosocial Support While Hospitalized Post MCSD Implantation:

Class I:

1. Routine support should be available from social work, psychologists, or psychiatrists as patients and families adjust to life changes after MCS.

Level of Evidence: B

2. Routine surveillance for psychiatric symptoms should be performed. If symptoms develop, consultation with specialists (including social work, psychology, and / or psychiatry) for diagnosis, treatment, and follow-up is recommended.

Level of Evidence: B.

Role of the Extended Multidisciplinary Team

Social Work. As an integral member of the multidisciplinary team, healthcare social workers identify the unique needs of each individual patient, thereby facilitating adherence to the treatment recommendations of the MCS team. In preparation for discharge, the social worker evaluates the environmental, financial, and psychosocial resources of each patient, as well as behavioral risk factors. Barriers to treatment success are often identified before discharge so the

treatment plan can be modified to address potential obstacles before they affect patient outcomes.⁵⁶

Psychiatry. Depression in heart failure patients is associated with decreased survival.⁵⁷ The adverse effects of depression in heart failure patients are profound and provided the impetus to design and initiate the Sertraline Against Depression and Heart Disease in Chronic Heart Failure (SADHART-CHF) Trial.^{58,59} In one study, cardiac rehabilitation participants who did not complete the program had significantly higher mean scores on the Beck Depression Inventory (BDI) and the Beck Anxiety Index (BAI) compared to patients who completed the program.⁶⁰ To enhance adherence with medications, dietary restrictions, rehabilitation, and follow-up appointments after discharge from MCS implant, it is imperative to address psychological disorders during the index hospitalization.

Physical Therapy/Rehabilitation/Occupational Therapy. Evidence suggests that early mobilization and progressive exercise training in MCS patients is safe and reduces adverse events.⁶¹ The patient should be assessed by physical therapy/occupational therapy as soon as the patient is medically stabilized post operatively and transferred to the non-ICU setting. A specific rehabilitation plan should be established with documentation of goals. Prior to discharge from the hospital following MCS implantation, patients should exhibit hemodynamic stability with exertion. In addition to in-hospital exercise training provided by physical therapists, occupational therapists can assess and assist patients with fine motor skills, which are important in “hands on” device management, and return to activities of daily living, including use of MCS shower kits. Patients who are unable to meet these goals in the hospital may need referral to an inpatient rehabilitation facility which is able to support MCS patients.

Palliative care. Finally, an important member of the MCS multidisciplinary team a provider of palliative care. Palliative care is focused on relief of symptoms and holistic interdisciplinary support for the patient and their family.⁶² During the informed consent process, palliative care services (e.g., management of distressing symptoms, provision of psychological and spiritual support, and provision of support to caregivers) can be shared, regardless of whether patients choose MCS or medical therapy.^{62,63} End of life and device deactivation may also be useful to discuss at the time of informed consent, especially for DT patients.^{63,64} After MCSD implant, in-hospital palliative care services may include symptom relief, especially management of pain, and psychosocial support. If a catastrophic complication of MCS occurs prior to discharge, palliative care team members may play a more prominent role in patient management, including providing patient comfort measures and supportive care, and helping family members with coping, anticipatory grief

counseling, and elective device deactivation to allow for a natural death.^{65,66}

Recommendations for Inpatient MCS Care by a Multidisciplinary Team:

Class I:

1. A multidisciplinary team lead cooperatively by cardiac surgeons and cardiologists, and composed of subspecialists (i.e., palliative care, psychiatry, and others as needed), MCS coordinators, and other ancillary specialties (i.e., social worker, psychologist, pharmacist, dietitian, physical therapist, occupational therapist, and rehabilitation services) is indicated for the in-hospital management of MCS patients.

Level of Evidence: C.

Quality of Life Assessment

Patients have reported that they were quite satisfied with their health-related quality of life (HRQOL) while still hospitalized after MCS implantation.^{54,55} Patients further reported that they were quite satisfied with the outcome of MCS and were doing quite well after surgery.^{54,55} These reports on “overall” HRQOL may reflect a “honeymoon phase”. Importantly, when specific domains of HRQOL were examined, MCS patients were least satisfied with their health and functioning and most satisfied with significant others.⁵⁴ Health status, energy level, and independence were specific areas of more dissatisfaction.⁵⁴ When compared to MCS outpatients, the HRQOL of MCS inpatients was significantly worse.⁵³ This finding was supported in a small sample of MCS patients whose HRQOL improved from before to after discharge.⁶⁷ Small sample sizes, missing data, and use of first generation pulsatile devices limit the findings from these observational studies. HRQOL is collected as part of the INTERMACS registry at 3 months, 6 months, and at 6 month intervals through 2 years after implant and yearly thereafter.

Recommendations for Routine Assessment of HRQOL While Hospitalized Post MCS Implantation:

Class IIb:

1. Routine assessment of HRQOL while hospitalized after MCS implantation may be reasonable. Hospitalized patients are beginning to adjust to living with MCS, and as such require MCS team support as they recover from surgery and rehabilitate. Assessment of specific problems that are related to domains of HRQOL (e.g., depression, anxiety, or pain) based on symptoms should help guide an action plan for these patients.

Level of Evidence: B.

Discharge Preparations

The literature is limited on transitioning MCS patients from hospital to home. Discharging a MCS patient from the hospital requires a multi-disciplinary approach and good communication across settings to ensure that the patient and their caregiver are competent in device management in the community setting.⁶⁸

Prior to discharge, specific outpatient monitoring and management needs to be organized, including referrals for anticoagulation monitoring and dosing, with clear instructions for the patient and caregiver regarding anticoagulation management.⁴⁶ The patient and caregiver should be aware of the outpatient management plan, including MCS clinic appointments for medical follow-up (with labs and tests), physical therapy classes and ongoing education refresher sessions. Also, a source for dressing supplies needs to be identified. A clear algorithm for when and how to seek help, including contact numbers for MCS staff at the hospital, emergency services, and the general practitioner is essential for appropriate response to urgent and emergency situations. Transitioning to the outpatient environment is further discussed elsewhere in these guidelines.

Recommendations for Successfully Discharging a MCS Patient:

Class I:

1. Caregiver and community provider education with written discharge instructions, and preemptive home preparation regarding the safe management of the device and the MCS patient, is recommended.

Level of evidence: C.

Management of the MCS Inpatient During Subsequent Hospitalization

As the duration of support increases in the era of DT, patients with MCS will likely require re-hospitalization at some point. These hospitalizations may be for MCS related issues, but many times MCS patients are hospitalized at the implanting center, often on the cardiology or cardiac surgery service, for non-MCS related issues. This section of the guidelines discusses some of the more frequent issues requiring inpatient management faced by patients with MCS.

Gastrointestinal Bleeding

All devices require anticoagulation with warfarin, which is typically initially started after post-operative bleeding has resolved and often after a period of intravenous heparin. This anticoagulation, in addition to the initiation of antiplatelet therapy, can often result in bleeding from surgical sites and even result in late tamponade up to several weeks post-operatively as previously noted in this section. Regardless of

the source of post-operative bleeding, those who have bleeding episodes have worse short-term outcomes than those who do not.⁶⁹ The need for transfusions leads to an increased chance for Human Leukocyte Antigen (HLA) sensitization, which may make it more difficult to find a suitable donor organ.⁷⁰

While many patients have bleeding as a result of the type and intensity of anticoagulation, bleeding in those with continuous flow devices, particularly gastrointestinal bleeding, may be the result of an acquired von Willebrand syndrome. Large multimers of von Willebrand factor (vWF) become unfolded due to the shear forces from the impeller, which eventually leads to enzymatic breakdown of the multimers.⁷¹ This phenomenon has been most widely described with axial flow devices, but it also occurs with centrifugal flow devices. While the loss of large multimers of vWF is nearly universal with continuous flow pumps, bleeding is not. The bleeding propensity for a patient may be related to the level of vWF activity rather than loss of large multimers.⁷² Gastrointestinal bleeding is usually ascribed to gastrointestinal arteriovenous malformations, which may themselves be more likely to form in those with continuous flow devices due to reduced pulsatility or increased vasodilation.⁷² Rates of gastrointestinal bleeding in studies of continuous flow devices ranges from 19-22%.⁷³⁻⁷⁵ However, only about a third have been found to arise from arteriovenous malformations.⁷⁵

For patients who present with gastrointestinal bleeding, warfarin may be held or even reversed, depending on the severity of the bleeding and INR. Antiplatelet therapy is often discontinued as well. Anticoagulation and antiplatelet therapy typically continue to be withheld until the source of the bleeding has been addressed or, if a source has not been identified, until the bleeding subsides. Devices which require a higher INR and/or have mechanical valves are likely at the highest risk for potential thrombotic complications in these circumstances.

Recommendations for Management of Anticoagulation and Antiplatelet Therapy for Patients who Present with Gastrointestinal Bleeding:

Class I:

1. Anticoagulation and antiplatelet therapy should be held in the setting of clinically significant bleeding.
Level of Evidence: C.
2. Anticoagulation should be reversed in the setting of an elevated INR and clinically significant bleeding.
Level of Evidence: C.

3. Anticoagulation and antiplatelet therapy should continue to be held until clinically significant bleeding resolves in the absence of evidence of pump dysfunction.

Level of Evidence: C.

4. The patient, device parameters, and the pump housing (if applicable) should be carefully monitored while anticoagulation and antiplatelet therapy is being withheld or dose reduced.

Level of Evidence: C.

A source of the gastrointestinal bleeding should be sought after addressing the level of anticoagulation, supporting the patients with transfusions, and serially following blood counts. For the first episode of bleeding, all patients should have a comprehensive assessment for a bleeding source with a focus on gastrointestinal arteriovenous malformations for those with continuous flow devices. Consultation with the gastrointestinal consultation team is often critical to focus this evaluation. A colonoscopy and esophagogastroduodenoscopy (EGD) are often the first diagnostic tests and, if negative, can be followed by double balloon technique enteroscopy or capsule endoscopy to examine the small bowel. For patients who are actively bleeding without a source by endoscopy, then a tagged red blood cell scan or angiography may be useful. Anticoagulation and antiplatelet therapy can be restarted in patients who have a focal source that is able to be addressed, with a period of observation while an inpatient to assure stability, and a period of close outpatient follow-up once discharged. If no source is found or if nonbleeding arteriovenous malformations are identified, then anticoagulation can also be reintroduced with careful monitoring.

Recommendations for the Evaluation and Management of Patients who Present with a First Episode of Gastrointestinal Bleeding:

Class I:

1. Patients should be managed in consultation with gastroenterology.
Level of Evidence: C.
2. Patients should at least have a colonoscopy and/or upper endoscopic evaluation.
Level of Evidence: C.
3. If colonoscopy and/or upper endoscopic evaluation are negative, evaluation of the small bowel, particularly in those with continuous flow devices, should be considered.
Level of Evidence: C.

4. In the setting of persistent bleeding and a negative endoscopic evaluation, a tagged red blood scan or angiography should be considered.

Level of Evidence: C.

5. Once the gastrointestinal bleeding has resolved, anticoagulation and antiplatelet therapy can be reintroduced with careful monitoring.

Level of Evidence: C.

Recurrent gastrointestinal bleeding is addressed largely in the same way, although the invasiveness of subsequent evaluations may be less intense depending on the results of prior evaluations. If the source of bleeding remains unknown or is not amenable to endoscopic or surgical intervention, then alterations of the goal INR or the number, dosage, or even presence of antiplatelet agents may need to be considered. While patients with continuous flow pumps have been managed for long periods without warfarin in the setting of recurrent gastrointestinal bleeds, this approach must be weighed against the risk of thromboembolism or pump thrombosis for each patient, pump, and clinical setting. As previously noted, reduced pulsatility has been implicated in the development of arteriovenous malformations. Therefore, some have advocated decreasing pump speed to increase pulsatility as a mechanism to address bleeding from arteriovenous malformations. To date, the effectiveness of such a strategy or the target degree of pulsatility is not known. There are few data on strategies such as hormonal therapy, octreotide, or replacement of vWF.

Recommendations for the Evaluation and Management of Patients who Present with Recurrent Episodes of Gastrointestinal Bleeding:

Class I:

1. Repeated endoscopic evaluation should take place in conjunction with gastroenterology consultation.

Level of Evidence: C.

2. In the setting of recurrent gastrointestinal bleeding with no source or a source that is not amenable to therapy, the type and intensity or even the use of antiplatelet therapy should be reevaluated in the context of the bleeding severity and pump type.

Level of Evidence: C.

3. In the setting of recurrent gastrointestinal bleeding with no source or a source that is not amenable to therapy, the goal INR or even the continued use of warfarin should be reevaluated in the context of the bleeding severity and pump type.

Level of Evidence: C.

4. The patient and device parameters should be carefully monitored when anticoagulation and antiplatelet therapy have been reduced or discontinued due to recurrent gastrointestinal bleeding.

Level of Evidence: C.

Class IIb:

1. Reducing the pump speed for continuous flow pumps in the setting of recurrent gastrointestinal bleeding due to arteriovenous malformations may be considered.

Level of Evidence: C.

Neurological Events

Neurological events can present throughout the duration of MCS. Although their frequency tends to be higher in the first 30-60 days, they can occur throughout the duration of support.^{76,77} Events can differ in their etiology, relation to the device, permanence, and severity, but they remain one of the most common contributors to mortality.^{27,78,79} However, even a single event can result in profound and permanent functional consequences. Comparison of the rates of neurologic events in the literature must be tempered by the device(s) implanted, the definition of a neurologic event in each study, and the duration of support. Rates of stroke and transient ischemic events (TIA) are similar with the current generation of devices (Table 2). More recently, Interagency Registry for Mechanically Assisted Support (INTERMACS) definitions for adverse events are becoming widely accepted by clinicians, industry, and regulatory agencies. INTERMACS definitions of neurological dysfunction are as follows (<http://www.uab.edu/intermacs/appendices/appendix-a>):

1. **Neurological event:** Any new deficit, regardless of duration or focality that is determined by neurological assessment performed by a neurologist or other qualified physician with appropriate diagnostic tests.
2. **TIA:** Event that lasts less than 24 hours, is fully reversible, and is not accompanied by imaging proven infarction.
3. **Stroke:** Event that persists beyond 24 hours or lasts less than 24 hours and is accompanied by infarction on imaging. Strokes are subcategorized into hemorrhagic or embolic.

INTERMACS also mandates administration of the National Institutes of Health (NIH) stroke scale at 30 and 60 days following the event.

Pre and post-operative risk factors for the development of stroke have been described in series of patients with only or primarily pulsatile devices.^{81,82} In a recent, large series of 140 patients with HeartMate II and 167 patients with HeartMate XVE devices, no differences between devices were observed

in the rates of neurological complication between devices.⁸³ On multivariate analysis a history of stroke (odds ratio [OR] 2.37) and post-operative infection (OR 2.99) were associated with the development of neurological events. Furthermore, a combination of a history of stroke, pre and post-operative sodium and albumin, and post-operative hematocrit and infection are predictive of neurologic events.

Table 2 Rates of Neurologic Events with Continuous Flow MCSDs

Intention	Destination therapy				Bridge-to-Transplant			
	Device	HeartMateII ⁸⁰		HeartWare		HeartMateII ⁷⁷		
(n)		133		140		281		
Pt/yrs		211		87		181.8		
	%	Event/pt-yr	%	Event/pt-yr	%	Event/pt-yr	0-30 days	> 30 days
Ischemic	8	0.06	7.1	0.11	5	0.09	0.37	0.05
Hemorrhagic	11	0.07	2.9	0.05	3	0.05	0.18	0.03
TIA	--	--	5.0	0.08	2	0.04	0.14	0.02
Other neuro	22	0.17	--	--	5	0.09	0.18	0.08

The sources of embolic events are similar to that seen in the general population. The source can be intra-cardiac from the atria or ventricles that traverse the aortic valve when it opens. Vascular thrombi can arise from existing atherosclerotic disease of the aortic arch and great vessels. Routine screening for vascular disease is part of the assessment of candidacy for mechanical support, and it may help to focus the investigation of a source if an event occurs. Sources of embolism that may be specific to MCS include clot formed from stasis in the aortic root from an aortic valve that rarely opens, or if the outflow cannula is anastomosed to the descending aorta. Large clots ingested by continuous flow pumps become fragmented if they traverse impellers due to the small clearances in such devices. However, pump malfunction can cause heating or local flow disturbances, which may be a nidus for clot formation. Recent infection may alter the coagulation milieu and predispose to clot formation.⁸² Ingested clots can pass through pulsatile pumps and result in systemic embolization, or they may form on the valves or within the volume displacement chambers themselves. Given the use of anticoagulation, often in conjunction with antiplatelet therapy, hemorrhagic stroke or hemorrhagic conversion of an embolic stroke is also a risk while on MCS. Untreated hypertension may also result in the development of ischemic strokes. Altered mentation due to poor cardiac output may be observed in the setting of device malfunction or pump failure.

All patients who note the development of a new neurologic deficit should be quickly assessed by the MCS team in conjunction with neurologists or the acute stroke team

as soon as possible. In the intra-operative or early peri-operative period, delays in detecting neurologic events can result, as they may not be evident until sedation is weaned. Thus, it is critical to assess patients' mental status early after arrival in the intensive care unit and periodically thereafter until the patient is no longer sedated. The assessment should include appropriate imaging as directed by the neurological team, most often a computed tomography (CT) scan of the head. In the setting of an embolic event that is diagnosed shortly after the onset of presenting symptoms, angiography or vascular intervention may be possible. The safety of thrombolytic therapy has not been established in the MCS population, but it may be risk prohibitive in the peri-operative setting. An assessment of the current INR as well as recent INR should also be performed. For those with extracorporeal devices, the pump housing, the degree of emptying, and the cannula should be inspected for clot formation. For those with continuous flow pumps, the pump parameters should be reviewed for sign of pump malfunction or thrombus. Echocardiography, vascular ultrasound and other directed evaluation should be performed to determine exact pathophysiologic cause.

Recommendations for the Acute Management of Patients who Present with a New Neurological Deficit:

Class I:

1. Assessment of current INR and review of recent INR is recommended.

Level of Evidence: B.

2. Prompt neurological consultation is recommended.
Level of Evidence: B.
3. CT and angiography of the head and neck is recommended.
Level of Evidence: B.
4. Review of pump parameters for signs of device thrombosis or malfunction is recommended.
Level of Evidence: C.
5. Inspection of pump housing for clots in extracorporeal pumps is recommended.
Level of Evidence: C.
6. Discontinuation or reversal of anticoagulation in the setting of hemorrhagic stroke is recommended.
Level of Evidence: B.

Class IIa:

1. Assessing for source of thrombus in the setting of an embolic stroke should be considered.
Level of Evidence: B.

Class IIb:

1. Selective use of interventional radiologic approach to thrombotic strokes may be considered.
Level of Evidence: C.
2. Selective use of thrombolytics in the setting of thrombotic stroke without hemorrhage on head CT scanning may be considered.
Level of Evidence: C.

Class III:

1. Routine use of interventional radiologic approach to thrombotic strokes is not recommended.
Level of Evidence: C.
2. Routine use of thrombolytics in the setting of thrombotic stroke without hemorrhage on head CT scanning is not recommended.
Level of Evidence: C.

Recommendations for the Chronic Management of Patients after Presentation with a New Neurological Deficit:

Class I:

1. Formal stroke rehabilitation in consultation with neurology is recommended.
Level of Evidence: B.

2. Close monitoring of anticoagulation in the setting of an embolic event to assure adequate levels of anticoagulation is recommended.
Level of Evidence: C.
3. Long-term control of blood pressure is recommended.
Level of Evidence: B.
4. Administration of NIH stroke scale at day 30 and 60 days after a neurologic event is recommended.
Level of Evidence: C.
5. Resumption of anticoagulation in consultation with neurology or neurosurgery in the setting of hemorrhagic stroke is recommended.
Level of Evidence: C.

Neurocognitive Deficits

The development of and serial assessment for neurocognitive deficits have been described after coronary artery bypass surgery.^{84,85} Neurocognitive deficits can develop in the setting of advanced heart failure, and they may be exacerbated after MCS. In a study of 96 patients with a HeartMateII that were serially assessed at 1, 3, 6, 12 and 24 months after implant, there was stability or improvement in 6 domains of neurocognitive function, no differences in neurocognitive function compared to those who received a pulsatile device, and no domain of neurocognitive function had any significant decrement over time.⁸⁶ A separate study of 50 patients with a HeartWare device found similar results with no significant declines in neurocognitive function from baseline through 6 months, with some significant improvements in some domains.⁸⁷ Assessment of neurocognitive function after mechanical circulatory support is a part of many clinical trials, but it is also now a required measure for INTERMACS at 3, 6, 12, and 18 months post-implant.

Recommendations for Assessment of Neurocognitive Deficits:

Class I:

1. Routine neurocognitive assessment at 3, 6, 12, and 18 months post-implant is recommended.
Level of Evidence: C.

Infectious Issues

The classification of, investigations for, and definitions related to infection in patients with MCS were the subject of a detailed working formulation published from the Infectious Disease Council of the International Society of Heart and

Lung Transplantation in 2011.⁸⁸ A brief summary of their findings will be presented here as a reference.

Infections in the setting of MCS can be classified as MCSD-specific, MCSD-related, or non-MCSD infections. For MCSD-specific infections, the source can be related to the pump and/or cannula, the pump pocket, or the driveline. In contrast, MCSD-related infections consist of infective endocarditis, blood stream infections, and mediastinitis. Non-MCSD infections such as urinary tract infections will not be addressed in these guidelines. When approaching a patient on MCS with a suspected infection, the initial work-up should include a complete blood count, chest radiography, and blood cultures. For those with purulent drainage from a surgical site, cannula, or driveline, samples for Gram stain, KOH, and routine bacterial and fungal cultures should be obtained.

Recommendations for Evaluation of MCS Patients with a Suspected Infection:

Class I:

1. In all patients, a complete blood count, chest radiography, and blood cultures is recommended.

Level of Evidence: A.

2. At least three sets of blood cultures over 24 hours should be drawn, with at least one from any indwelling central venous catheters.

Level of Evidence: A.

3. For those with a suspected cannula or driveline infection, obtaining a sample for Gram stain, KOH, and routine bacterial and fungal cultures is recommended.

Level of Evidence: A.

4. When clinically indicated, aspirate from other potential sources as dictated by presenting symptoms and examination is recommended.

Level of Evidence: A.

5. Directed radiographic studies based on presenting symptoms and exam are recommended.

Level of Evidence: A.

Class IIa:

1. Erythrocyte sedimentation rate or serial C-reactive protein should be considered.

Level of Evidence: C.

Class III:

1. Routine CT of the chest, abdomen and pelvis is not recommended.

Level of Evidence: C.

Device-specific Infections:

It is often difficult to determine if a device has become infected, but there are a number of clinical and laboratory criteria by which such a determination can be made. The consensus statement notes several major and minor criteria that contribute to making the diagnosis of a device-specific infection.⁸⁸

Major criteria include:

- positive blood cultures with no other focus of infection
 - an indistinguishable organism (genus, species, and antimicrobial susceptibility pattern) recovered from 2 or more peripheral blood cultures taken >12 hours apart with no other focus of infection
 - All of 3 or a majority of ≥ 4 separate positive blood cultures (with the first and last sample drawn at least 1 hour apart) with no other focus of infection
- 2 or more positive blood cultures are taken from the central venous catheter (CVC) and peripherally at the same time
- echocardiogram positive for vegetation.

Minor clinical criteria include:

- fever ≥ 38 degrees Celsius
- vascular phenomena: major arterial emboli, septic pulmonary infarcts, mycotic aneurysm, intracerebral or visceral, conjunctival hemorrhage, and Janeway's lesions
- immunologic phenomena: glomerulonephritis, Osler's nodes, Roth spot
- blood cultures that do not meet the definition for major criteria.

The determination of a MCSD infection can be made using these criteria as shown in Table 3.

Recommendations for Determination of a MCSD-specific Infection:

Class I:

1. A proven MCSD-specific infection is defined as definitive microbiology, histologic confirmation at MCS explant, or two major clinical criteria.

Level of Evidence: B.

2. A probable MCSD-specific infection is defined as 1 major and 3 minor criteria, or 4 minor criteria.

Level of Evidence: B.

3. A possible MCSD-specific infection is defined as 1 major and 1 minor, or 3 minor criteria.

Level of Evidence: B.

Table 3 Determination of MCSD Infections

MCSD Specific Infections	
Proven	Definitive microbiology, or Histologic confirmation at explants, or 2 major clinical criteria
Probable	1 major and 3 minor criteria, or 4 minor criteria
Possible	1 major and 1 minor criteria, or 3 minor criteria
Unlikely	Presence of an alternative diagnosis, or Resolution after ≤ 4 days of antibiotics, or No pathologic evidence at surgery with antibiotics ≤ 4 days, or Not meeting established definitions
MCSD Pocket Infections	
Proven	Organisms cultured from fluid, or Abscess, or Other infection seen during surgical exploration, or 2 major criteria
Probable	1 major and 3 minor criteria, or 4 minor criteria
Possible	1 major and 1 minor criteria, or 3 minor criteria
Unlikely	Definitive alternative diagnosis, or Resolution with ≤ 4 days of antibiotics, or No pathological evidence at surgery after ≤ 4 days of antibiotics, or Negative cultures from fluid during surgery or aspiration

MCSD-Pocket Infection

As with MCSD-specific infections, there is not a single definitive method to determine if a pocket infection has developed with the exception of direct sampling of a collection around the pump. Major clinical criteria include microbiologic or evidence from drained or aspirated fluid, or radiographic detection of a new fluid collection. Minor criteria include fever in the absence of another source, new erythema over the pocket, pain and tenderness, induration or swelling, lymphangitis on radiography, or a new fluid collection without major criteria or diagnostic culture.

Recommendations for Determination of a MCSD Pocket Infection:**Class I:**

1. A proven MCSD pocket infection is defined as organisms cultured from fluid, abscess, or other infection seen during surgical exploration, or 2 major criteria.

Level of Evidence: B.

2. A probable MCSD pocket infection is defined as 1 major and 3 minor, or 4 minor criteria.

Level of Evidence: B.

3. A possible MCSD pocket infection is defined as 1 major and 1 minor, or 3 minor criteria.

Level of Evidence: B

Percutaneous Driveline Infections

One of the long-term risks with MCS is infection of the driveline or cannula, particularly for DT patients who do not have the option of transplantation if the infection becomes difficult to manage or cannot be eradicated with antibiotics and/or surgical revision. Driveline infections can be divided into superficial or deep infections that each have their own specific appearances, diagnostic criteria, and therapies. Each are divided into proven, probable, and possible with diagnostic criteria that consider the surgical/histology, microbiology, clinical presentation, and appearance of the wound. These criteria and definitions are shown in Table 4.

Management of Ventricular Arrhythmias

The incidence of ventricular arrhythmia post MCSD placement has been reported to range from 22% to 36%.⁸⁹⁻⁹² In one series, the incidence was as high as 52% in patients with the HeartMate II axial flow device, with the majority of cases occurring in the first post-operative month.⁹³ Early ventricular

tachycardia/ventricular fibrillation (VT/VF) was found to predict future ventricular arrhythmic events in this study. The non-usage of beta blockers post operatively may be associated with increased ventricular arrhythmic events, and they should be resumed along with conventional heart failure oral medications once inotropes and pressors have been weaned.⁹¹

Mechanisms of VT/VF in MCS patients may include reversible factors such as electrolyte abnormalities, the use QT interval prolonging drugs, and the presence of “suction events”.⁹⁰ Additionally, there may be irreversible factors including the presence of arrhythmogenic substrate in the cardiomyopathic heart, or formation of new arrhythmogenic foci resulting from surgical placement of the outflow cannula.

An episode of VT/VF may be well tolerated and resolved with anti-tachycardia pacing or defibrillation from an implantable cardioverter defibrillator (ICD). However, incessant ventricular arrhythmias may occur with repeated failure of the ICD to terminate the event. These events may produce hemodynamic compromise even in the MCS patient due to resultant RV dysfunction, as well as significant pain and emotional distress to the patient from repeated ICD discharges. In these cases, patients require prompt medical attention with expert involvement of an electrophysiologist. In situations when the arrhythmia cannot be managed medically, catheter ablation may need to be performed, sometimes urgently, by an electrophysiologist with the requisite knowledge and experience in treating these patients.⁹⁰

Recommendations for Inpatient Treatment of Ventricular Arrhythmias:

Class I:

1. MCS patients with incessant ventricular arrhythmias require prompt admission for further management as hemodynamic compromise may occur.

Level of Evidence: C.

2. Patients with ongoing ventricular tachycardia refractory to medical therapy may require catheter ablation, which should be performed by an electrophysiologist with the requisite knowledge and expertise in treating patients with MCS.

Level of Evidence: C.

Right Heart Failure

The relationship between perioperative RV function in the setting of left sided mechanical circulatory support has been discussed extensively elsewhere in these guidelines. However, after the initial perioperative period as patients are maintained on mechanical support over the long term, ongoing consideration should be given to ensuring optimal RV function. RV dysfunction can arise at some point distant to

the initial surgery, even in patients who have not manifested evidence of RV dysfunction in the perioperative period, or in patients in whom perioperative RV dysfunction has resolved.

There is an abundant literature on perioperative risk factors for RV failure after isolated LVAD placement. In contrast, there is a paucity of data on the incidence and predictors of RV failure in the later stages of LVAD support. RV dysfunction that does occur late after LVAD placement may be a manifestation of progression of the cardiomyopathic process, or due to chronic inadequate unloading of the left ventricle. Symptoms may include peripheral swelling, abdominal distention, and exertional shortness of breath. Changes in LVAD parameters such as a drop in flow and pulsatility may occur. On examination, elevated jugular venous pressure, hepatomegaly, and edema may be observed. Echocardiogram is used to assess RV function, concomitant valvular lesions, and position of the interventricular septum. Right heart catheterization demonstrates elevated right atrial pressure and depressed cardiac output. In isolated RV dysfunction, pulmonary capillary wedge pressure is normal or low. An elevated pulmonary capillary wedge pressure indicates ineffective unloading by the LVAD and warrants further evaluation. When RV dysfunction occurs, admission to the hospital for medical optimization including inotropic support may be required. In some cases, inotropic support cannot be weaned off and is continued in the outpatient setting.

Recommendations for Right Ventricular Function:

Class I:

1. Right ventricular dysfunction after LVAD placement may occur as a late manifestation with symptoms and signs of right heart failure and changes in LVAD parameters including a decrease in flows and pulsatility. Further evaluation should include echocardiogram.

Level of Evidence: C.

2. When evidence of RV dysfunction exists, MCS patients may need to be admitted to the hospital for optimization, which may include initiation of inotropic support.

Level of Evidence: C.

Table 4 Definitions of MCSD Specific Percutaneous Driveline Infection

	Surgical/histology	Microbiology	Clinical	General wound appearance
A. Superficial MCSD specific Percutaneous Driveline Infection				
Proven = Surgical/histology criteria ± other criteria	Involvement of tissues superficial to the fascia and muscle layers of the incision documented	Aseptic skin culture positive or not cultured	Local increase in temperature around the exit site	<ul style="list-style-type: none"> Purulent discharge from the incision but not involving fascia or muscle layers, or Erythema spreading around the exit site^a
Probable = No surgical/histology criteria with purulent discharge ± other criteria	<ul style="list-style-type: none"> Surgical debridement not performed No histology 	Aseptic skin culture positive or negative but patient already on antibiotic or had antiseptic used to clean wound	<ul style="list-style-type: none"> Local increase in temperature around the exit site and Treated as superficial infection with clinical response 	<ul style="list-style-type: none"> Purulent discharge from the incision but not involving fascia or muscle layers or Erythema spreading around the exit site^a
Possible = No surgical/histology or purulent discharge ± other criteria	<ul style="list-style-type: none"> Surgical debridement not performed No histology 	Aseptic skin culture positive or negative and patient not on antibiotics or had antiseptic used to clean wound	<ul style="list-style-type: none"> Local increase in temperature around the exit site and Treated as superficial infection with clinical response 	<ul style="list-style-type: none"> No discharge Erythema spreading around the exit site^a
B. Deep MCSD-specific Percutaneous Driveline Infection				
Proven = Surgical/histology criteria ± other criteria	<ul style="list-style-type: none"> Involves deep soft tissue (eg, fascial and muscle layers) on direct examination or on direct examination during re-operation An abscessis found on direct examination during re-operation 	Culture positive or histology puncture positive for infection	<ul style="list-style-type: none"> Temperature >38°C or Localized pain or tenderness 	<ul style="list-style-type: none"> A deep incision spontaneous dehiscence Abscess deep to the incision around the driveline
Probable = No surgical/histology criteria with spontaneous dehiscence ± other criteria	<ul style="list-style-type: none"> No surgical debridement No histology 	Culture negative but patients already on antibiotics or had antiseptic used on exit site	<ul style="list-style-type: none"> Temperature >38°C or Localized pain or tenderness and Treated as a deep infection 	An incision spontaneous dehiscence
Possible = No surgical/histology criteria with positive ultrasound ± other clinical criteria	<ul style="list-style-type: none"> No surgical debridement No histology 	Cultures not reserved	<ul style="list-style-type: none"> Localized pain or tenderness and Treated as a deep infection with clinical response 	Positive ultrasound

^aErythema excluding stitch abscess (minimal inflammation and discharge confined to the points of suture penetration).Reprinted with permission from Hannan MM et al. J Heart Lung Transplantation 2011;30:375-384.⁸⁸

Device Malfunction

A major limitation of first-generation pulsatile MCSs was durability. Failure rates for the HeartMate XVE were in the order of 31% to 35% largely due to internal bearing wear and degradation of the valved inflow cannula.^{94,95} With the advent of continuous flow MCS, incidence of device failure has decreased dramatically compared to pulsatile pumps. In a comparison of the continuous flow HeartMate II with the pulsatile HeartMate XVE in a DT cohort, the need for device repair or replacement strongly favored the continuous-flow device: 10% versus 36% (P=0.001) at 2 years.⁸⁰ Experience with HeartMate II BTT cohorts has demonstrated no or low instances, 0% to 1.2%, of primary mechanical pump failure.^{77,96,97}

Although incidence of pump failure requiring replacement is low, when this event occurs it can be catastrophic. The most common reasons for pump stoppage are thrombus formation in the rotor or mechanical failure. Unlike the pulsatile devices that could be actuated with a hand pump or pneumatic driver, there is no way to manually or externally actuate the continuous pump once it is stopped and cannot be restarted. If blood remains stagnant in the pump for a period of time, there is a risk of thrombus formation and embolization should the pump be restarted. For patients who are “pump dependent” with little residual cardiac function, sudden stoppage may result in death. In addition, there is backflow of blood through the valveless outflow cannula creating a situation comparable to free aortic insufficiency, adding a further volume load to the unsupported ventricle. In cases where there is residual cardiac function, the patient may survive if able to reach medical attention rapidly. In this scenario, the patient is treated for cardiogenic shock and may require inotropic and other supportive measures until they can be transported back to the implanting medical center. In cases where the patient cannot undergo surgery, the outflow cannula may be percutaneously occluded as a temporizing measure to stem the backflow through the outflow cannula.^{98,99} Ultimately, however, surgical pump exchange is the definitive therapy, as permitted by the clinical status of the patient and ability to survive re-operation. In less acute situations where the pump is functioning but there are pump alarms or changes in pump parameters that cannot be resolved as an outpatient, the patient may need to be admitted for observation and close monitoring.

Recommendations for Device Failure and Malfunction:

Class I:

1. Pump stoppage of a continuous flow MCS constitutes a medical emergency, and the patient should be rapidly transported back to the implanting or other expert MCS center for treatment.

Level of Evidence: C.

2. Definitive therapy for pump stoppage is surgical pump exchange if the patient is stable enough to undergo re-operation.

Level of Evidence: C.

3. Patients with a functioning pump, but with alarms or changes in parameters that cannot be resolved as an outpatient may need to be admitted to the hospital for observation and close monitoring.

Level of Evidence: C.

Class IIb:

1. For patients who are unable to undergo surgery, the outflow cannula may be occluded percutaneously to halt the backflow of blood through the valveless outflow cannula as a stabilizing maneuver.

Level of Evidence: B.

Non cardiac procedures

While on MCS, patients may face medical problems requiring surgical intervention. These interventions may be emergent or non-emergent, with varying degrees of risk to the patient and mortality outcomes. Several series have been published reporting outcomes in patient with MCS undergoing non-cardiac procedures (NCP) with 30 day mortality ranging from 9 to 25%.¹⁰⁰⁻¹⁰⁷ However, in one study, despite a 30 day mortality of 42% after emergent NCP and 18% after non-urgent NCP, *overall* mortality was no different for MCS patients who underwent NCP versus those who did not.¹⁰⁰ Procedures generally associated with worse outcomes included laparotomy, fasciotomy, and ventriculostomy when performed for emergent indications. In contrast, procedures such as open cholecystectomy, pericardiocentesis, urologic procedures, video assisted thoracoscopic surgery (VATS), and tunneled catheter placement were performed safely.¹⁰⁰

When a MCS patient presents for NCP, the two main perioperative challenges include appropriate hemodynamic monitoring and anticoagulation management. If possible, the patient should undergo their NCP at the implanting medical center or a center with infrastructure and personnel to support the MCS patient. Caring for the patient should be a joint effort

between the MCS team and the non-cardiac surgical team. Ideally, the physician performing the NCP should have some experience and knowledge of this patient population, which may be the case at an established MCS center. For an elective NCP, the physicians involved in the patient's care (including the MCS physicians) should decide whether antiplatelet and/or anticoagulation with warfarin should be stopped. Sometimes, it is possible to perform procedures with low bleeding risk without interruption of therapy. In cases when warfarin therapy needs to be stopped, patients may be bridged with low molecular weight heparin, intravenous heparin, or a heparin-alternative, with discontinuation prior to the elective procedure and resumption within a suitable time frame after the procedure. Alternatively, warfarin may be held for a few days without bridging if it is felt there is an increased bleeding risk with heparin or a heparin alternative. The patient should be made aware that anytime there is a discontinuation of warfarin and anti-platelet therapy there is always a risk of a thromboembolic event. Therefore, they should report any concerning symptoms promptly.

For emergent procedures, anticoagulation with warfarin may need to be reversed rapidly which can be done with administration of fresh frozen plasma (FFP) or prothrombin protein concentrate (PCC). Vitamin K may be administered either orally or intravenously, but the onset of action is slower. The degree of reversal and target INR must be determined by the clinical presentation of the patient and the risk of bleeding during the NCP. At that point in time, the risk of thromboembolic events may be far outweighed by the imminent risks of bleeding. Once the emergent procedure has been completed and the post-operative risk of bleeding has abated, bridging with heparin or a heparin-alternative may be considered.

Non-invasive blood pressure monitoring with Doppler may be appropriate for minor procedures. However, during any procedure where there is a risk of hypotension or non-invasive blood pressure cannot be reliably obtained, an arterial line should be placed. Placement of a central-venous catheter allows for monitoring of central-venous pressure and volume status during procedures that may result in fluid shifts, such as intra-abdominal operations. Central venous access also facilitates administration of vasoactive medications during hemodynamic instability. During any procedure, MCS parameters should be continuously monitored by expert personnel such as an MCS nurse or perfusionist. A cardiovascular surgeon should be in the operating room or immediately available in cases where the NCP may come in proximity to the MCS, such as during abdominal surgery.

Recommendations for Management of the MCS Patient during Non-Cardiac Procedures:

Class I:

1. The MCS team should be made aware when an MCS patient is undergoing a NCP so that collaboration between the MCS and surgical teams can take place.
Level of Evidence: C.
2. For non-emergent procedures, warfarin and antiplatelet therapy may be continued if the risk of bleeding associated with the procedure is low. If therapy needs to be stopped, warfarin and antiplatelet therapy should be held for an appropriate period of time as determined by the type of procedure being undertaken and risk of bleeding. Bridging with heparin or heparin-alternative while a patient is off warfarin may be considered.
Level of Evidence: C.
3. For emergent procedures, warfarin may need to be rapidly reversed with FFP or PCC. Vitamin K can be administered with caution but has slower onset of action.
Level of Evidence: B.
4. Post-procedure, warfarin and antiplatelet therapy may be resumed when risk of surgical bleeding is deemed acceptable. Patients may be bridged with heparin or heparin alternative while waiting for the INR to reach the target range.
Level of Evidence: B
5. During minor procedures, blood pressure monitoring with Doppler is appropriate.
Level of Evidence: C.
6. During procedures with risk of hemodynamic instability, an arterial line should be placed for blood pressure monitoring.
Level of Evidence: C.
7. A central venous catheter may be placed for monitoring of central venous pressure and to administer drugs in the case of hemodynamic instability during surgical procedures of moderate or high risk.
Level of Evidence: B.
8. During NCP, MCS parameters should be continuously monitored by expert personnel such as MCS nurses or perfusionists.
Level of Evidence: C.

9. A cardiovascular surgeon should be in the operating room or immediately available, especially in situations when the NCP is in close proximity to the MCSD itself.

Level of Evidence: C.

Class II:

1. Whenever possible, the surgeon performing the NCP should have experience in operating on patients with MCSD.

Level of Evidence: C.

ABBREVIATIONS

ACE = angiotensin converting enzyme
 ARB = angiotensin receptor blocker
 BAI = Beck Anxiety Index
 BDI = Beck Depression Inventory
 BiVAD = biventricular assist device
 BTT = bridge-to-transplant
 BUN = blood urea nitrogen
 CT = computed tomography
 CVC = central venous catheter
 CVP = central venous pressure
 CVVH = continuous veno-venous hemofiltration
 DT = destination therapy
 EGD = esophagogastroduodenoscopy
 FFP = fresh frozen plasma
 HEPA = high-efficiency particulate air
 HLA = Human Leukocyte Antigen
 HRQOL = health-related quality of life
 ICD = implantable cardioverter defibrillator
 ICU = intensive care unit
 INTERMACS = Interagency Registry for Mechanically Assisted Support
 INR = international normalized ratio
 JVP = jugular venous pressure
 LV = left ventricular
 LVAD = left ventricular assist device
 MAP = mean arterial pressure
 MCS = mechanical circulatory support
 MCSD = mechanical circulatory support device
 MRA = mineralocorticoid receptor antagonist
 MRSA = methicillin-resistant Staphylococcus aureus
 NCP = non-cardiac procedures
 NIH = National Institute of Health
 OR = odds ratio
 PCC = prothrombin protein concentrate
 PDE-5 = phosphodiesterase-5
 PVR = pulmonary vascular resistance
 REMATCH = Randomized Evaluation of Mechanical Assistance for the Treatment of Congestive Heart Failure
 RPM = revolutions per minute

RV = right ventricular

SADHART-CHF = Sertraline Against Depression and Heart Disease in Chronic Heart Failure

SVO₂ = mixed venous oxygen saturation

TIA = transient ischemic attack

VAD = ventricular assist device

VATS = video assisted thoracoscopic surgery

VF = ventricular fibrillation

VT = ventricular tachycardia

vWF = von Willebrand factor

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The 2013 International Society of Heart and Lung Transplantation Guidelines for Mechanical Circulatory Support

Task Force 5: Outpatient Management of the Mechanical Circulatory Support Device Recipient

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Topic 1: Transitioning the Mechanical Circulatory Support Device Patient to the Home or Community Environment

Introduction

The first step in maximizing long-term survival after initial mechanical circulatory support device (MCS) placement is ensuring a smooth transition from the hospital setting to the home environment. This time of transition can be fraught with fear and anxiety for the MCS patient and their family. The MCS program should mobilize a multidisciplinary team to maximize patients' rehabilitation, quality of life, and assimilation into the community while minimizing complications.

Evaluation for Safety of the Home Environment

Mechanical circulatory support (MCS) patients have unique requirements that mandate attention as they transition to home in order to provide an environment that is safe for device operation. A primary consideration is the need for continuous electrical supply. MCSs are dependent on electricity. Therefore, to prevent unintentional power interruption that may result in pump stoppage, outlets must be grounded, extension cords should not be used to power the external components, and outlets used for the left ventricular assist device (LVAD) and its components should not be controlled by a switch.

The local electric provider should be notified that the customer has a MCS and is dependent on electricity. Local companies may have online forms available to facilitate notifying the electric provider of the device's need for continuous electric supply. Additionally, the implanting center may need to write a letter to inform the company of the

device's electrical requirements. The notification must include the customer's account number as a reference. Patients must also develop a plan for managing their device if unanticipated electrical interruption to their home occurs for an extended period of time, such as during a natural disaster. Options may include staying with relatives who have electricity, going to a local emergency medical services (EMS) station temporarily, going to a hotel or hospital, or purchasing a generator.

Patients and families should consider the most appropriate placement for device equipment to minimize risk of falls, allow easy access to the bathroom and kitchen, and maximum opportunity to interact with family. Alarms should be easily audible to other household members throughout the home. The environment should be free of clutter and have adequate lighting to prevent falls. The bathroom should be safe for showering with placement of a shower chair. A seat lift should be installed on the toilet if recommended by physical therapy.

Patients must have a working telephone for emergency use and to facilitate communication with the implanting center. Patients should practice paging the on call MCS team when they arrive home to ensure they can reach the team quickly. This test should be done as soon as possible upon arriving home after discharge, so that patients have rehearsed the routine prior to needing to page if an actual emergency occurs. A discharge check list may be developed to facilitate communication regarding the specific home modifications that need to be made and to document progress in meeting these requirements prior to discharge.

Recommendations for Evaluation of Safety of the Home Environment:¹⁻⁴

Class I:

1. An uninterrupted supply of electricity to continuously power the MCS must be ensured. Outlets must be

grounded, and the use of electrical extension cords or outlets with a switch should be avoided. The local electrical company must be notified of the customer's need for electricity to power life sustaining equipment in the home. Patients are advised to develop an emergency plan in the event electricity becomes unavailable in the home.

Level of Evidence: C.

2. Patients should have a working telephone to allow outgoing calls in the event of an emergency and to allow the implanting center to contact the patient. The patient should familiarize themselves with paging the MCS team should an actual emergency arise.

Level of Evidence: C.

Class IIa:

1. Equipment at home should be placed in a configuration that minimizes the risk of falls, allows easy access to living and sleeping areas, and allows family members to hear alarms. Lighting should be adequate. The bathroom should be safe for showering with a shower chair, toilet seat, or any other necessary physical aids.

Level of Evidence: C.

2. A discharge check list may be developed to facilitate communication regarding the specific necessary home modifications and to document progress in meeting these requirements prior to discharge.

Level of Evidence: C.

Community Outreach by MCS Team

The MCS team should notify local EMS responders of the patient's home address and basic device design (i.e. non-pulsatile flow). A request should be made to make the patients' home a "location of interest" that will alert EMS providers that a patient has a MCSD. Patients and families are encouraged to visit EMS first responder stations to notify the EMS responders in person of the home address and basic device design.

Quick reference materials (Figure 1) assist EMS providers in identifying patients with MCSDs. The field guides provide step-by-step instructions for maneuvers such as controller changes. The field guides can be given to emergency departments, local hospitals, dialysis centers, long term care facilities, or any location caring for MCSD patients.

The MCS team should notify the local hospital, including the emergency room and referring physician, that MCSD patients will be living in the area and of their unique medical needs. The MCS team may offer to provide teaching materials, device manuals, or in-services based on the

resources the implanting facility can commit to outreach efforts. Field guides could be a tool given to remote hospitals as part of the education package provided by the implanting center.

Recommendations for Community Outreach by the MCS Team:²⁻⁶

Class I:

1. Community outreach should be performed by the implanting center's MCS team to inform the local health care providers including EMS personnel, emergency room staff, and referring physicians of the reintegration of the MCSD patient to his/her local environment. Education should be delivered so providers have knowledge of the concepts involving MCS and the associated physiologic changes.

Level of Evidence: C.

Class IIa:

1. Appropriate emergency maneuvers should be reviewed with local health care providers. Consideration may be given to developing a field guide for EMS personnel to aid in emergency responses.

Level of Evidence: C.

Assessment of Social Network

The MCS team designee must interview patients and family members regarding the strength and depth of their social support. Usually this interview is performed by a trained social worker or discharge planner. The social worker may involve family, friends, co-workers, and community organization members. The social support members must clearly state the nature of their involvement. They must commit to be trained in the proper daily and emergent management of the device. They must also commit to driving patients to follow up appointments. If it is determined that the social support network is weak or unreliable, the social worker may develop a "social contract" with specific duties that need to be performed in order to formalize the commitment. The social worker, along with other members of the team, must reassess the ability of family and friends to provide support as caregiver fatigue may cause a disintegration of the discharge plan.

To ensure successful outcome after MCSD placement, the primary designated caregiver(s) should receive adequate training and demonstrate competence with respect to MCSD functions and the appropriate response to alarms. A checklist may be helpful in assessing the ability of the caregiver to perform maneuvers related to the MCSD and troubleshoot emergency situations.

Figure 1 Sample Field Guide for the HeartMate II® Device Manufactured by Thoratec

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HeartMate II®

Can I do external CPR?
Only if absolutely necessary

If not, is there a “hand pump” or external device to use?
No.

If the device slows down (low flow state), what alarms will go off?
A red heart alarm light indicator and steady audio alarm will sound if less than 2.5 lpm.

How can I speed up the rate of the device?
Check for hypovolemia or right heart failure and treat

Do I need to heparinize the patient if it slows down?
Usually no, but you will need to check with implanting center

Can the patient be defibrillated while connected to the device?
Yes

If the patient can be defibrillated, is there anything I have to disconnect before defibrillating?
No.

Does the patient have a pulse with this device?
May have weak pulse or lack of palpable pulse.

What are acceptable vital sign parameters?
Normal mean arterial pressure of 10

Can this patient be externally paced?
Yes.

Adapted from Dweert, L. and WuJk, J., A. Mechanical Circulatory Devices in Transport in AITN: Patient Transport Principles and Practice, 4th ed., Miale,

FAQs

- May not be able to obtain cuff pressure (axial flow pump)
- Pump connected to electric line exiting patient’s abdominal area and is attached to computer which runs the pump.
- Pump does not affect EKG
- All ACLS drugs may be given.
- No hand pump is available.
- A set of batteries last approximately 3 hours
- Any emergency mode of transportation is ok. These patients are permitted to fly.

TROUBLE SHOOTING: HeartMate II®

When the Pump Has Stopped

- Check the connections between the controller and the pump and the power source
- Fix any loose connection (s) to restart the pump.
- If the pump does not restart and the patient is connected to batteries replace the current batteries with a new, fully-charged pair (see Changing batteries section below)
- If pump does not restart, change controllers (see changing controllers section below)

Alarms: Emergency Procedures

Yellow or Red Battery Alarm: Need to Change Batteries. See changing batteries section below.

Red Heart Flashing Alarm: This may indicate a Low Flow Hazard. Check patient—the flow may be too low. If patient is hypovolemic, give volume. If patient is in right heart failure—treat per protocol. If the pump has stopped check connections, batteries and controllers as instructed in the section above.




This guide does not supersede manufacturer instructions

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The Joint Commission requires patients and families to give feedback to the implanting center regarding their experience at home after the discharge process has occurred.⁷ A survey tool may be useful in evaluating the overall program, staff education, and support. It is recommended that the survey results be presented at a multidisciplinary quality meeting on a regular basis as a stimulus for program improvements.

Recommendations for Assessment of Social Network:⁴

Class I:

1. The primary designated caregiver should demonstrate competency in functioning of the MCS and the appropriate response to alarms.

Level of Evidence: C.

2. The MCS team designee must interview patients and family members regarding the strength and depth of their social support. The social worker or other MCS staff member may need to develop a formal “social contract” with the patient’s social network and/or caregiver(s) that outlines their commitment and responsibilities to ensure they are prepared to assist patients with device and/or driving needs until the patient is able.

Level of Evidence: C.

Class IIb:

1. A survey tool should be developed that allows patients to provide feedback to the MCS program on their preparedness for the transition to the home environment. Survey results should be reviewed by the multidisciplinary MCS team at regular intervals to help facilitate programmatic improvements.

Level of Evidence: C.

Driving a Motor Vehicle

Whether patients are permitted to drive after MCS implant is a center specific decision, in conjunction with local regulations. Basic criteria should be met if patients are allowed to drive. The patient’s sternum must be stable, which usually requires 6 - 8 weeks of post-operative recovery. Incisional pain must be managed without narcotics. Patients must reliably demonstrate their ability to manage MCS emergencies independently as dictated by the implanting center. The local jurisdiction paperwork must be completed as required (e.g. department of motor vehicle forms).

Recommendations for Driving a Motor Vehicle:⁴

Class IIb:

1. Clearance to drive a motor vehicle is a center specific decision and should be guided by local laws.

Level of Evidence: C.

Topic 2: Follow-up Care

Introduction

After implantation of the MCS and discharge from the index hospitalization, the clinician is faced with the challenge of caring for the MCS patient in the outpatient setting. This phase of care may last years, particularly for destination therapy (DT) patients. The clinical concerns faced by the patient and clinician may evolve considerably over time, and these changes must be reflected in the type of outpatient follow-up care delivered. For example, in the early post-MCS implantation period, there may be an emphasis on rehabilitation efforts. Over the later phase, the clinician must address longer term complications of MCS support such as acquired aortic insufficiency and RV (right ventricular) decline, as well as progression or development of other comorbid illnesses. These patients should receive ongoing follow-up in specialized MCS centers because of the nature of this developing field where recognition and description of longer term complications is evolving.

Multidisciplinary Approach to Follow-up Care

Successful mid- and long-term outcomes for patients with MCS are dependent on a multidisciplinary team approach to outpatient management. This approach is achieved by combining the expertise of cardiovascular surgeons, advanced heart failure cardiologists, specialized MCS coordinators and other health care providers.

Role of the Cardiologist

The cardiologist oversees optimization of heart failure therapy in the postoperative period. Once the patient has resumed standard heart failure therapy, ongoing surveillance is necessary to address device and non-device related issues that may limit long term survival. These issues may include right ventricular failure, evidence of device related infection, progression of known co-morbidities, and development of new medical issues.

Role of the Surgeon

The surgeon monitors the patient for appropriate post-surgical recovery including sternotomy and driveline healing. Driveline and pump pocket infections or device malfunctions may require surgical intervention in addition to antimicrobial therapy.

Role of the MCS Coordinator

The MCS coordinator has the critically important role of transitioning the patient back to their community and serving as the primary communication link between the patient and the MCS team over the patient's lifetime. The coordinator works with the team in troubleshooting device related problems including alarms and changes in device parameters.

Role of Other Disciplines

Patients with MCSs may develop complications requiring the expertise of other specialties, such as infectious disease, gastroenterology, psychiatry, or others. The MCS team should strive to establish collaborative relationships with health care providers from other specialties, who over time will become familiar with the unique issues affecting this patient population.

Role of the Referring Physician

The referring physician is encouraged to re-establish care with the MCS patient. Although most referring physicians will likely defer the bulk of patient management decisions to the MCS team, many may resume management of non-MCS related issues, such as diabetes, it is also useful to have a provider available in the patient's community to help facilitate assessment of the patient and transfer to the MCS center in case of emergency. In addition, transitioning the patient back to their referring physician helps increase awareness in the referring community of the potential benefits of MCS therapy, which is often underutilized in the treatment of advanced heart failure patients.

Recommendations for the Multidisciplinary Approach to Follow-up Care:

Class I:

1. Management of the patient with a MCS should be performed by a multidisciplinary team including cardiovascular surgeons, advanced heart failure cardiologists, and specialized MCS coordinators. Other health care providers may collaborate with the primary MCS team when additional expertise is required.

Level of Evidence: C.

Frequency of MCS Center Follow-up

In the early postoperative period, frequent outpatient visits ensure that patients appropriately convalesce, and it allows the medical team to continually assess the patient's and caregivers' competency with device management. During the early outpatient timeframe, it may be advisable for patients to stay within close travelling distance of the MCS center, to allow for rapid transfer to the hospital should emergencies arise. This may be especially relevant at centers that

encompass a large geographic referral area. One disease management model suggests that patients stay within 30 minutes driving distance for two weeks post hospital discharge, with a tapering schedule of clinic visits from twice per week down to a minimum of once monthly for the duration of time the patient is maintained on MCS support.⁸ These clinic visits should be coupled with a schedule of routine surveillance testing for patient and device related factors that may have unfavorable effects on MCS device function and patient survival, and to look for evidence of myocardial recovery. A disease management model may include monitoring phone calls placed from the MCS coordinator to the patient or caregiver to proactively identify issues that may have adverse effects on patient outcomes.

Recommendations for Frequency of Visits:⁸

Class I:

1. MCS patients should be seen in clinic regularly the frequency of which is dictated by their clinical stability.

Level of Evidence: B.

2. MCS patients should have a routine schedule of testing to survey for patient or device related issues that may adversely affect outcomes.

Level of Evidence: B.

Class IIa:

1. Between routinely scheduled visits, monitoring phone calls from the MCS coordinator to the patient or caregiver may help proactively identify issues that may adversely affect patient outcomes.

Level of Evidence: B.

Routine Testing Post MCS Placement

Role of Echocardiography

Transthoracic echocardiography is an important component of the pre and post-evaluation of MCS. Prior to implantation, patients with mild left ventricular dilatation (characterized as end diastolic dimension <60mm) have a higher incidence of recovery than those with moderate or severe dilatation.⁹ Parameters that indicate improved myocardial function post implantation include increase in left ventricular ejection fraction (LVEF) to 40-45%, normalization of fractional shortening, consistent aortic valve opening, and normalization of left ventricular dimensions.¹⁰⁻¹² Dobutamine stress echocardiography may be helpful in identifying patients with enough myocardial reserve to allow device explant.¹³ All MCS patients should be screened for evidence of myocardial recovery, particularly when there is a potentially reversible underlying etiology, such as myocarditis, there is a short

duration of history of heart failure, or the patient is of a young age (<45 years).

Echocardiography is helpful in the assessment of complications that may impact survival. Low MCS flow rates may be due to obstruction secondary to malposition of the cannula, intracardiac thrombus, or impingement by cardiac structures. The ventricle may appear distended with shift of the septum towards the unsupported ventricle.¹⁴ In the presence of kinking, there may be loss of Doppler flow signal within the ventricular assist device (VAD) cannula. Obstruction may be diagnosed by high spectral Doppler velocities (>2.3 m/s inflow and >2.1 m/s outflow for pulsatile pumps, and >2 m/s for axial flow pumps) obtained by continuous wave Doppler and color Doppler aliasing at the cannula orifice.^{15,16} Echocardiography may show underfilling resulting from dehydration, sepsis, or hemorrhage, which can result in obstruction of the inflow cannula by the septum or other cardiac structures.¹⁴ Bacteremia may lead to endocarditis of the native heart structures, prosthetic valves, or VAD components, which can be detected by echocardiography.¹⁷

Particular attention must be focused on the native aortic valve while on device support. Echocardiography is used to visualize the aortic valve opening, which is important to prevent thrombus formation in the aortic root and for optimal device function with some VAD types. Over time, hemodynamically significant aortic regurgitation may develop as a consequence of aortic root dilation.^{18,19} Commissural fusion and valve thickening have been noted as well, which may contribute to the development of aortic regurgitation.^{20,21}

Recommendations for the Use of Echocardiography:

Class I:

1. Echocardiography should be performed as part of the pre-operative assessment and routinely at regular intervals postoperatively to evaluate for signs of myocardial recovery and optimal MCS function. Echocardiography can be utilized for setting optimal pump parameters.

Level of evidence: B.

2. In addition to routine studies, echocardiography should be performed as part of the evaluation of suboptimal MCS function or in the presence of clinical signs of circulatory dysfunction including congestive or low output symptoms.

Level of Evidence B.

Role of Right Heart Catheterization

Assessment of Persistent HF Symptoms. Patients experiencing symptoms of recurrent heart failure after MCS placement require further assessment to elucidate the cause.

Cardiac catheterization can be used to define causes of MCS malfunction, as well as native heart causes of persistent heart failure. Hemodynamic measurement obtained by placement of a pulmonary artery (PA) catheter is crucial in determining if there is inadequate left ventricular (LV) unloading, manifested by elevated pulmonary capillary wedge pressure. Elevated left sided filling pressure may be due to low VAD pump speed, cannula malposition, obstruction or kinking. Native heart factors may include valvular heart disease. In particular, aortic regurgitation may develop post VAD placement and result in increased VAD flow rates, discrepancy between measured cardiac output by PA catheterization and displayed VAD flow, and elevated filling pressures.

Assessment of Right Ventricular Dysfunction. After MCS placement, right ventricular function may deteriorate over time with hemodynamic sequelae including drops in VAD flow and cardiac output, loss of pulsatility, and manifestations of right heart failure/cor pulmonale. Elevated central venous pressure (CVP) and low measured cardiac output in the absence of elevated left sided filling pressures as measured by PA catheterization may necessitate a trial of inotropic therapy for RV support, or other enhancement of medical therapy to help optimize RV function.

Assessment of Pulmonary Hypertension. Patients being bridged to cardiac transplantation with MCS therapy often have pulmonary hypertension that precludes immediate transplantation. After device placement, PA catheterization should be used at regular intervals to evaluate for improvement in pulmonary artery pressure, transpulmonary gradient (mean pulmonary artery pressure minus pulmonary artery wedge pressure), and/or pulmonary vascular resistance to values that would allow progression to cardiac transplantation.

Assessment of Myocardial Recovery. Right heart catheterization with hemodynamic measurement may be utilized to corroborate other evidence of myocardial recovery. A pulmonary artery catheter may be placed with step-wise lowering of pump speed to document acceptable hemodynamics with decreasing pump support and aid in the decision making for pump explantation.

Recommendations for the Use of Right Heart Catheterization:

Class I:

1. Right heart catheterization is useful in the assessment of persistent or recurrent heart failure symptoms after MCS placement and to evaluate for evidence of RV failure or device malfunction.

Level of Evidence: B.

- Right heart catheterization should be performed at regular intervals in patients being evaluated or listed for heart transplant to document pulmonary artery pressures, as irreversible pulmonary hypertension is associated with early allograft dysfunction/failure after heart transplantation.

Level of Evidence: A.

Class IIa:

- Right heart catheterization should be performed to help corroborate evidence of myocardial recovery. The pulmonary artery catheter may be left in place with serial lowering of pump speed to confirm acceptable hemodynamics with decreasing VAD support prior to pump explanation.

Level of Evidence: C.

Role of Computed Tomography Angiography

Computed tomography angiography (CTA) may be a helpful tool for assessing persistent or recurrent heart failure symptoms in patients with MCS. This technique allows visualization of inflow and outflow VAD cannulas including placement, angulation, kinking, or obstruction when other imaging modalities have not been revealing.²²⁻²⁴ The inflow cannula should be directed to the center of the left ventricular cavity with a neutral septum and without thrombus formation. The outflow cannula should be free of kinking with a patent aortic anastomosis. Caution should be used in administering intravenous contrast in patient with renal insufficiency.

Recommendations for Use of Computed Tomography Angiography:

Class I:

- CT angiography allows visualization of the native heart and MCS components and may be valuable when other imaging modalities have not been revealing.

Level of Evidence: B

Role of Functional Capacity Assessments

Routine assessment of exercise capacity is required for patients with mechanical circulatory support as part of the Joint Commission Certification for centers offering DT in the United States. In addition, objective measure of functional status is useful in prescribing activity in the early post-operative rehabilitation period, and it allows the clinician to follow the patient's progress over time.

Maximal oxygen consumption (peak VO_2) during cardiopulmonary stress testing (CPX) is the most objective and well-validated measure of exercise capacity in heart failure.²⁵ Post MCS placement, there are limited data on improvements in peak VO_2 , particularly in DT patients, due to

attrition of subjects over time and survivorship effect. Modest increases in peak VO_2 may be observed, usually within the first weeks to months after device placement.²⁶⁻³⁰

Six minute walk testing (6MWT) is easily performed in any clinic setting. It does not require specialized equipment, and it simply measures the distance covered by encouraged walking on a level hallway within 6 minutes. Unlike a maximal CPX, it does not provide specific information on the function of each of the different organs and systems involved in exercise or the mechanism of exercise limitation. However, correlation of the 6MWT to peak VO_2 is moderate to good, with 6MWT being between 83% and 91% accurate in predicting peak VO_2 in chronic heart failure patients if distance walked is less than 450 to 490 meters, respectively.³¹⁻³³ Data are lacking that examine outcomes in patients with mechanical circulatory support limited 6MWT distances. However, this submaximal exercise test may be helpful in assessing patients' capacity to perform activities of daily living.

Recommendations for Functional Capacity Testing:

Class I:

- Measurement of exercise capacity should be undertaken post MCS placement to allow for appropriate exercise prescription, which may be part of a formal cardiac rehabilitation program.

Level of Evidence: B.

Class IIa:

- Cardiopulmonary stress testing and/or six minute walk testing performed at regular intervals may be helpful in objectively assessing functional capacity in patients with MCS. Suggested intervals are 3 months, 6 months, and then at 6 month intervals through 2 years after implant, then yearly thereafter.

Level of Evidence: C.

Quality of Life Assessments

One of the primary goals of MCS therapy is to improve quality of life for patients with advanced heart failure. Therefore, it is important to measure health related quality of life (HRQOL) both at baseline (prior to implantation) and at regular intervals post operatively. Selection of reliable and valid HRQOL instrument(s) should be based on an understanding of the strengths and weaknesses of generic and disease-specific questionnaires, as well as the potential burden imposed on patients. In addition to overall HRQOL information, domains measured should include physical and occupational function, psychological state, social interaction, and somatic sensation (i.e., symptoms).³⁴ Meaningful assessments may include quality-adjusted survival that evaluates patient preferences for trade-offs between QOL and

survival outcomes, or calculating quality-adjusted life years to conduct a cost-utility analysis. It is also important to determine reasons for non-completion of functional and HRQOL assessments across time. Collection of data regarding caregiver burden and QOL might be considered. Table 1 summarizes available tools for measuring generic and heart failure specific HRQOL.

Recommendations for Health Related Quality of Life Assessments:

Class IIa:

1. HRQOL should be measured prior to MCS/D implantation and at regular intervals longitudinally for the duration of MCS/D support. Both generic and heart-failure specific measures can be utilized. Suggested intervals are 3 months, 6 months, and then at 6 month intervals through 2 years after implant, then yearly thereafter.

Level of Evidence: B.

Laboratory Studies

Serial laboratory studies should be obtained over the duration of MCS/D follow up. These should include general studies related to end-organ function, studies related to the device itself, and studies to diagnose or monitor the status of co-morbid conditions.

Assessment of End-Organ Function. Lab studies should be obtained on an ongoing basis to monitor end-organ function. These include, but are not limited to, creatinine and blood urea nitrogen to assess renal function and liver enzymes to assess liver integrity.

Assessment of MCS/D Related Issues. Continuous flow devices requiring anticoagulation and/or antiplatelet therapy require monitoring of therapy. Patients on warfarin should have regular international normalized ratio (INR) obtained, with the target range determined by the device manufacturer's recommendation and clinical status of the patient. Effectiveness of antiplatelet therapy may be monitored using platelet aggregation studies or thromboelastography (TEG). In order to monitor for evidence of hemolysis, complete blood count, lactate dehydrogenase and plasma free hemoglobin may be measured.

Diagnosis and Monitoring of Co-morbid Conditions. Blood work to diagnose new co-morbid conditions or to monitor the status of existing conditions should be obtained. Examples include lipid profile for patients with dyslipidemia, fasting glucose and hemoglobin A1C in patients with diabetes, and thyroid panel in patients taking amiodarone.

Recommendations for Laboratory Studies:

Class I:

1. Laboratory studies should be obtained at regular intervals to assess end-organ function, monitor device specific

issues, and diagnose or follow the status of co-morbid conditions.

Level of Evidence: C.

Assessment of the MCS/D

Driveline/Lead/Component Assessment. The driveline should be assessed at each patient visit to look for evidence of appropriate appearance and to exclude the presence of driveline infection. Ideally, there should be robust ingrowth of tissue into the driveline with good adherence. The driveline should be examined to exclude any breeches or defects in the casing as well as evidence of appropriate immobilization to minimize chances of tissue trauma at the exit site due to pulling. All connections should be examined to ensure they are intact. The console should be examined if present. Alarms should be reviewed and downloads performed at regular intervals. Battery status should be assessed, and the patient should be asked if they are carrying their backup equipment including extra batteries and controller. The appearance of the driveline, and other components should be noted in the medical record as part of the physical examination of the patient. A photographic record of the driveline exit site may also be helpful in assessing its appearance over time.

Adjustment of Pump Parameters for Optimal Device Function. The patient should bring a log of pump parameters to each clinic visit for review by the MCS team. Over time, adjustments in pump parameters may be needed which should be done according to the recommendations of the manufacturer. These changes may be guided by echocardiography and right heart catheterization.

Showering. The patient should be trained in the appropriate technique for showering once it is determined that satisfactory wound healing has taken place. Depending on when the patient is discharged relative to their implant, this education may be done in the outpatient setting.

Dressing Changes at the Driveline Site. The patient and caregiver should be trained in appropriate technique for dressing changes at the driveline site prior to hospital discharge, and independence in this skill should be demonstrated to the bedside nurse or VAD coordinator prior to discharge. Dressing protocols tend to be center specific. Ongoing reinforcement of proper technique should be provided at subsequent outpatient visits. Re-education may be necessary and especially important in the presence of driveline related infections or when surgical debridement has been performed.

Table 1 Selected Generic and Heart Failure Related Measures of QOL

Questionnaire	Number of items	Domains	Range of scores	Administration	Time required
General					
SF-36	36	<ul style="list-style-type: none"> Physical function Role-physical Pain Social functioning Role-emotional Mental health Vitality General Health 	0-100 Worst to best	Self	5-10 minutes
Sickness Impact Profile	136	<ul style="list-style-type: none"> Physical Psychosocial Independent 	0-100% Best to worst	Interview or self	20-30 minutes
EuroQoL	6	<ul style="list-style-type: none"> Mobility Self-care Usual activities Pain Depression 	1-3 for each question, can be converted into a weighted summary score + a visual analog scale	Self	90 seconds
Heart Failure Specific					
Minnesota Living with Heart Failure Questionnaire	21	<ul style="list-style-type: none"> Physical Emotional 	0-105 Best to worst	Self	
Chronic Heart Failure Questionnaire	16	<ul style="list-style-type: none"> Dyspnea Fatigue Emotional 	16-112 Worst to best	Interviewer	
Quality of Life Questionnaire for Severe Heart Failure	26	<ul style="list-style-type: none"> Psychological Physical activity Life-dissatisfaction Somatic Symptoms 	0-130 Best to worst	Self	
Kansas City Cardiomyopathy Questionnaire	23	<ul style="list-style-type: none"> Physical limitations Symptoms Self-efficacy Social limitation Quality of life 	0-100 Worst to best	Self	

Recommendations for Assessment of the MCS D:*Class I:*

1. The driveline, exit site, and MCS D components should be examined at each clinic visit to ensure their integrity. Alarm history and downloads should be obtained at regular intervals. Pump parameters should be reviewed regularly and adjusted accordingly to optimize pump functioning for the duration of time the patient is on support.

Level of Evidence: C.

2. The driveline should be assessed for proper position/use of binder or driveline immobilization at each clinic visit.

Level of Evidence: C.

3. The patient should be trained in proper self-care including showering technique and dressing changes prior to hospital discharge. These skills may need reinforcement over the patient's lifetime, depending on the clinical course.

Level of Evidence: C.

Health Maintenance

Patients with MCS Ds are advised to follow general health maintenance guidelines according to their age and gender. Vaccines should be administered according to Centers for Disease Control (CDC) recommendations. Appropriate dental care should be continued.

Recommendations for Health Maintenance:*Class I:*

1. Patients with MCS D therapy should continue to follow a general health maintenance schedule, including gender-related and age-specific recommendations, routine vaccinations, and dental care.

Level of Evidence: A.

Topic 3: Cardiac Rehabilitation and Exercise Guidelines

Cardiac rehabilitation has been demonstrated to reduce mortality in patients with coronary artery disease by 20 - 25%.^{35,36} Additionally, it has been shown to improve blood pressure and reduce recurrent myocardial infarctions and strokes, and improve quality of life.³⁷ Despite the improvements shown in patients with coronary artery disease, there were significant concerns about the risks and benefits of cardiac rehabilitation in heart failure patients until the publication of the Heart Failure: A Controlled Trial Investigating Outcomes of Exercise Training (HF-ACTION) trial.³⁸ In this trial, 2331 patients with New York Heart

Association (NYHA) Class II-IV heart failure symptoms were randomized to either exercise training or usual care. The patients who underwent exercise training had 36 supervised exercise sessions of aerobic activity followed by home based training. There was no difference in the primary endpoint of all-cause mortality or hospitalization between the two groups. However, after adjusting for prespecified high-risk covariates (exercise duration, LVEF, Beck Depression Inventory II score, and history of atrial fibrillation or flutter); patients who underwent exercise training had an 11% reduction in the primary endpoint (HR 0.89, 95% CI 0.81-0.99, P=0.03).³⁸

Exercise training was felt to be safe, a finding that is of perhaps more importance when considering cardiac rehabilitation in patients with a MCS D. During the exercise training period, 37 patients were hospitalized due to an event that occurred during or within 3 hours after exercise. A similar number of events was reported among patients in the usual care group. Based on the results of this trial, it is now generally accepted that exercise training in heart failure patients does not improve survival, but it is safe and is associated with an improvement in quality of life. The effects of cardiac rehabilitation in patients with a MCS D have not been well studied. It is clear that with both pulsatile and continuous flow LVADs, exercise is safe and exercise tolerance improves.³⁹⁻⁴¹

The two primary areas of focus for patient rehabilitation after MCS D implant include early strength training to reduce short-term post operative morbidity and post-discharge training to improve exercise capacity. Preoperatively, MCS D patients are often functionally limited due to both their heart failure and the need for chronic bed rest in patients with balloon pumps and right heart catheters. The resultant muscle wasting and weakness leads to a very debilitated patient who is at risk for prolonged ventilation, falls, fractures, and an increased risk of infection. Early mobilization of patients after surgery has been retrospectively associated with an improved ability to wean from the ventilator and shorter postoperative stays.^{42,43} These interventions included muscle strengthening and breathing exercises, bed mobility activities, transfers from bed to chair or commode, and gait training,⁴³ which are quite similar to the usual physical therapy activities for patients that have undergone cardiac surgery.

There are few data demonstrating the effects of cardiac rehabilitation in patients with MCS Ds.⁴⁴ Exercise training is considered safe, and it is associated with a reduction in norepinephrine and epinephrine levels.^{44,45} The data evaluating exercise in patients with a MCS D are limited, but extrapolating from the safety of cardiac rehabilitation in patients with heart failure or after cardiac surgery, it appears that cardiac rehabilitation in patients after MCS D implant is safe and improves exercise tolerance. A program similar to

that studied in the HF-ACTION trial should be used for patients with MCSD since it was shown to be safe in the chronic heart failure population. In HF-ACTION, patients exercised on either a treadmill or stationary cycle for 15 to 30 minutes at a workload corresponding to 60% of their heart rate reserve.³⁸ For patients with continuous flow devices, exercising to a Borg Rating of Perceived Exertion level of 12-14 could be used instead of the target heart rate, since it is difficult to obtain a pulse in those patients. Additionally, patients should participate in the other components of typical cardiac rehabilitation programs, including education about risk factors and psychosocial counseling.^{46,47} A few special considerations are warranted for MCSD patients undergoing cardiac rehabilitation. The facility and staff should receive basic training about MCSDs, and the meanings of the various alarms. Patients should be instructed to discuss the alarms with their trainers. Additionally, patients should be educated to stay well hydrated and to stop exercising if they experience dizziness, diaphoresis, severe dyspnea, or significant chest pain.⁴³ Finally, patients should stop exercising if their pump starts to alarm, and they should be advised against silencing the alarm and continuing to exercise.

Recommendations for Exercise and Cardiac Rehabilitation:

Class I:

- All patients who are able should be enrolled in cardiac rehabilitation after surgical placement of a MCSD.

Level of Evidence: C.

Topic 4: Medical Management of the MCSD Patient

Introduction

Patients are required to adhere to an often complex pharmacologic regimen including drugs specific to the functioning of the device (such as anticoagulation and antiplatelet agents), drugs specific to the underlying heart disease, and drugs to treat comorbid conditions. In addition to pharmacologic therapy, optimizing nutritional status and addressing substance use issues are important considerations in MCSD patients, especially in those bridging to cardiac transplantation.

Anti-Coagulation

Most devices, with the exception of the Heartmate XVE, which is no longer in use, require chronic anticoagulation with warfarin. Patients typically have achieved their goal INR prior to being discharged from their implant hospitalization. The goal INR ranges for Food and Drug Administration (FDA) approved devices are shown in Table 2. It is critical

that a reliable system is in place to track the INR in all patients on MCS, to maintain a record of their goal level of anticoagulation, to assure routine INR measurements, and to communicate any necessary changes in warfarin doses so that patients are maintained in their therapeutic range. Given the complexity of patients who receive MCS, the variety of potential devices, and patients' concomitant medical conditions, the MCS team often chooses to manage the anticoagulation, but an anticoagulation service may also be utilized. Although alternatives to warfarin have now been approved by the FDA (dabigatran, rivaroxaban), they have not been adequately studied in the MCSD population and are not recommended.

Table 2 Anticoagulation and Antiplatelet Therapy for Approved Mechanical Circulatory Support Devices

Device	INR range
AbioCor TAH	2.5 – 3.5
HeartMate II*	2.0 – 3.0
HeartWare HVAD	2.0 – 3.0
MicroMed DeBakey	2.5 – 3.5
Syncardia TAH	2.5 – 3.5
Thoratec IVAD	2.5 – 3.5
Thoratec PVAD	2.5 – 3.5

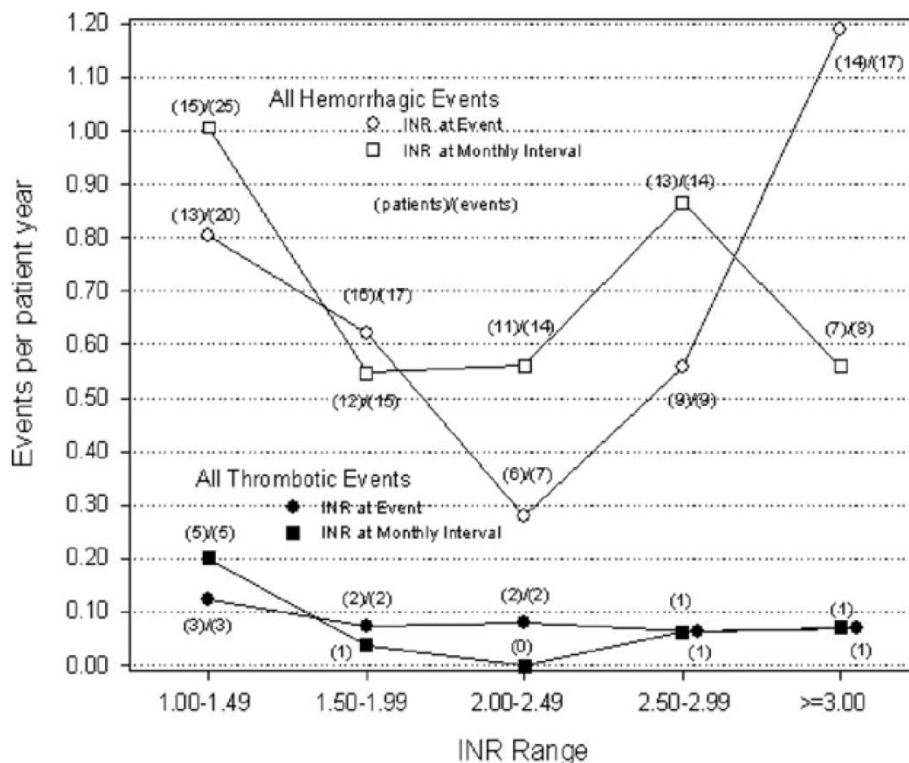
*goal from the clinical trials

Goal INR ranges attempt to strike a balance between the potential risks of thromboembolism or pump thrombosis and bleeding risks. Pulsatile devices with mechanical valves such as the Thoratec Paracorporeal Ventricular Assist Device (PVAD) require warfarin with an INR range similar to mechanical heart valves. In contrast to most devices, the HeartMate XVE does not have mechanical valves. It has a textured volume displacement chamber that becomes endothelialized and therefore does not require warfarin, only aspirin. However with smaller and more durable pumps available for bridge-to-transplant (BTT) and DT, utilization of the HeartMate XVE has declined substantially.⁴⁸ In the HeartMate II BTT trial, the goal INR was 2–3, and the rate of bleeding beyond 30 days which required ≥ 2 units of blood was 0.69 events per patient year. The rates of hemorrhagic and ischemic strokes were < 0.1 per patient-year, and the pump thrombosis rate was 0.02 per patient-year.⁴⁹ However, a review of 331 patients enrolled in the HeartMate II BTT trial that were supported for at least one month revealed that thrombotic event rates increased with an INR < 1.5 , and

hemorrhagic event rates increased with an INR >2.5. Hemorrhagic and thrombotic events occurred at similar rates with an INR range of 1.5 – 2 versus 2 – 2.5 as seen in Figure 2.⁵⁰ Thus, many centers have decreased their INR goals for the HeartMate II from 2.0-3.0 to 1.5–2.5. However, caution must be exercised in loosely applying this lower INR range, particularly if a patient maintains an INR lower than 1.5 for

extended periods before their warfarin dose is adjusted. The effects of more recent device design changes on thrombosis rates may mean INR targets derived from data utilizing previous pump designs may not reflect current thrombosis risk. Since recommendations regarding goal INR ranges are evolving, maintaining INRs at or above 2 may be most prudent.

Figure 2 Hemorrhagic and Thrombotic Adverse Events through Six Months in the HeartMate II Bridge to Transplant Trial



Reprinted with permission from Boyle AJ, Russell SD, Teuteberg JJ et al. Low thromboembolism and pump thrombosis with the HeartMate II left ventricular assist device: analysis of outpatient anti-coagulation. *J Heart Lung Transplant*. 2009;28(9):881-887.⁵⁰

There is no consensus on how frequently the INR should be monitored once the patient is discharged with a therapeutic INR. Monitoring of the INR may be weekly or even more frequent until a dose that achieves a stable INR is determined. Thereafter, the INR may be assessed monthly in the setting of clinical stability. The availability of home INR monitoring has not been established in a population on MCS, but it may allow for more frequent monitoring and more rigorous maintenance of INR in the therapeutic range. As in the setting of mechanical valves or atrial fibrillation, warfarin can be held for supratherapeutic INR values in the absence of bleeding. Acute reversal of anticoagulation in the absence of clinically significant bleeding has a high potential for harm, and there is no associated benefit to offset this risk. For devices with mechanical valves, an INR between 2-2.5 may only require a

simple dose adjustment of warfarin. Alternatively, patients with an INR substantially below the goal range could be treated with home administration of low molecular weight heparin, if feasible, or be hospitalized for heparin bridging. Patients frequently require invasive procedures for which they cannot be therapeutically anticoagulated with warfarin. Most patients are hospitalized and bridged with heparin, especially those with devices requiring the most intense anticoagulation. Patients with continuous flow devices that require a lower therapeutic INR range, such as the HeartMate II, may be able to have many invasive procedures at the lower end of their therapeutic INR.

In the setting of clinically significant blood loss, warfarin may be held or even reversed, with caution, if needed. Antiplatelet therapy can be continued in many cases, but it

may also need to be discontinued. Devices requiring higher INR ranges and those with mechanical valves are likely at the highest risk in these circumstances. Patients with extracorporeal pumps can have their pump housing inspected for clot if anticoagulation needs to be held, but clot may still be present that is not evident from visual inspection alone. The risk of bleeding must be balanced with the risk of thromboembolism or pump thrombosis for each patient, pump, and clinical setting.

Other concomitant medical conditions that may require anticoagulation at or above the level required for the MCS must be considered, such as atrial fibrillation, pulmonary embolism, or a mechanical valve. While some of these indications may be time limited, others may persist throughout the duration of MCS. Persistently low flows may also be another situation where anticoagulation may need to be intensified due to the risk of thrombus formation from stasis.

Recommendations for Anticoagulation:

Class I:

1. Patients with MCS should receive anticoagulation with warfarin to maintain an INR within a range as specified by each device manufacturer.

Level of Evidence: B.

Antiplatelet Therapy

Many devices recommend aspirin 81 or 325 mg daily in addition to the warfarin anticoagulation. However, the necessity of antiplatelet therapy, the particular antiplatelet drug or drugs, dosage, and frequency has not been established. Newer agents such as ticagrelor and prasugrel have not been studied in MCS patients and cannot be recommended.

In the early portion of the HeartMate II BTT trial the antiplatelet therapy was with aspirin in most patients, but about half also received dipyridamole. The prevalence of aspirin resistance varies widely in the literature from 5.5-60%, and it may be as high as 55% in a heart failure population.^{51,52} In a small study of Thoratec LVADs, aspirin resistance was observed in 26% of patients and persisted weeks after the surgery in some patients.⁵³ Studies have also demonstrated that markers of persistent platelet activation remain elevated for weeks after the implant surgery.⁵⁴ In small studies of patients with continuous flow devices, prolonged elevation of inflammatory markers and impaired platelet function has also been observed.^{55,56}

Higher rates of significant gastrointestinal bleeding have been reported in patients with axial continuous flow pumps as compared to patients with pulsatile pumps, however in these studies those with axial flow pumps were anticoagulated with warfarin, while those on pulsatile pumps did not require warfarin.⁵⁷ The high shear stress of such pumps has been

postulated to result in destruction of large multimers of von Willebrand factor (vWF), leading to decreased platelet aggregation and acquired von Willebrand disease.^{56,58,59} This process may be similar to the high shear stress and resultant high rates of bleeding associated with aortic stenosis.^{60,61} While many cases of gastrointestinal bleeding are associated with arteriovenous malformations (AVMs), it is unclear whether the decrease in platelet aggregation is responsible for more bleeding from occult AVMs, or if the lack of pulsatility itself may lead to the formation of AVMs.^{57,58,62,63} It is also unknown if patients with centrifugal continuous flow pumps develop a similar deficiency of vWF. Regardless, platelet aggregation and vWF activity normalize after cardiac transplantation.⁵⁹ The occurrence of impaired platelet function and the development of an acquired von Willebrand syndrome has led some experts to question the utility of routine antiplatelet therapy in patients with axial flow pumps.⁵⁹

Consensus is lacking with regard to appropriate dosing strategies for antiplatelet agents. Fixed dose antiplatelet therapy may be used, or the dose may be selected based on platelet function. For the latter, the optimal method of assessing platelet function is not known.⁵⁶ Physicians must also consider co-existing medical conditions that may require antiplatelet therapy, including as drug-eluting stents, prior stroke, or peripheral vascular disease. These requirements may be either time limited or permanent, and the required duration of antiplatelet therapy should be noted if different from the routine device specific therapies.

Recommendations for Antiplatelet Therapy:

Class I:

1. Chronic antiplatelet therapy with aspirin 81-325 mg daily may be used in addition to warfarin in patients with MCS.

Level of Evidence: C.

2. Antiplatelet therapy beyond aspirin may be added to warfarin as per the recommendations of specific device manufacturers.

Level of Evidence: C.

Class IIb:

1. Assessment of platelet function may be used to direct the dosing and number of antiplatelet drugs.

Level of Evidence: C.

Heart Failure Therapy

In patients who receive MCS as a possible bridge to recovery, many clinicians may add evidence-based heart failure therapy in an attempt to maximize the chance of

recovery. However, there is limited evidence to support the efficacy of this strategy. Myocardial recovery has been observed in some patients with nonischemic cardiomyopathy who were administered an aggressive heart failure based regimen (lisinopril, carvedilol, spironolactone, and losartan) and the beta₂ agonist clenbuterol with both pulsatile⁶⁴ and continuous flow devices.⁶⁵ However, clenbuterol is not commercially available outside of research protocols. In the setting of BTT and DT, there is no evidence that single or combination heart failure pharmacotherapy provides benefit in terms clinical outcomes or myocardial recovery.

MCS results in acute improvement to the heart failure state,⁶⁶ but volume overload typically persists until after discharge. It may become chronic if not aggressively treated in certain cases. Numerous conditions may contribute to venous congestion, including right ventricular dysfunction, renal insufficiency, hypoalbuminemia, or inadequate unloading of the left ventricle due to suboptimal VAD settings or mechanical obstruction to inflow or outflow. Most patients require diuretics at the time of discharge from their implant hospitalization. However, once euvolemia is achieved, the diuretic use may be decreased or even discontinued.

After the patient's heart failure status improves, hypertension present prior to the onset of advanced heart failure generally returns. In addition to typical adverse consequences of hypertension, increased afterload from hypertension can impact VAD performance and longevity. MCS pumps tend to produce less flow and provide less ventricular unloading in the setting of hypertension. Hypertension increases stress on the pneumatic or mechanical drivers in pulsatile pumps which, in turn, can increase mechanical wear. Flow in nonpulsatile pumps is afterload dependent, such that at a constant speed, there will be less forward flow with higher blood pressures. If the blood pressure becomes chronically elevated, the inadequate unloading of the left ventricle will be persistent due to the reduction in forward flow. Angiotensin converting enzyme (ACE)-inhibitors or angiotensin receptor blockers (ARBs) reduce afterload and are the first line drugs for post-MCS hypertension. In addition, there is widespread evidence that these agents are beneficial in patients with diabetes and vascular disease, which are common comorbidities in those undergoing MCS. ACE inhibitors are usually favored over ARBs in such circumstances primarily because of cost considerations. Renal insufficiency or hyperkalemia may limit the use or dosage of ACE-inhibitors and ARBs, especially in the early post-operative period prior to full renal recovery. Beta blockers, calcium channel blockers, and alpha blockers may be utilized to achieve additional blood pressure control as needed.

Beta-blockers are useful adjuncts to ACE-inhibitors or ARBs for blood pressure control, but caution should be exercised when initiating beta blockade in the setting of marginal RV function, especially in the face of persistent volume overload. Beta-blockade is also useful for rate control in the setting of atrial and ventricular tachyarrhythmias. There is no evidence base for the routine addition of aldosterone blockade after MCS implantation, but may be used to limit the need for potassium supplementation and for known anti-fibrotic effects. Many patients post-MCS still have some degree of renal insufficiency,⁶⁷ which increases the risk of hyperkalemia with aldosterone receptor antagonists, therefore potassium levels should be closely followed. Nitrates and hydralazine are useful for afterload reduction in patients who cannot tolerate an ACE-inhibitor or ARB due to renal insufficiency or hyperkalemia.

Recommendations for Heart Failure Therapy:

Class I:

1. Diuretics are useful for the management of volume overload during MCS.

Level of Evidence: C.

2. An ACE-inhibitor or ARB may be used for hypertension, or for risk reduction in patients with vascular disease and diabetes.

Level of Evidence: C.

3. Beta-blockers may be used for hypertension or for rate control in patients with tachyarrhythmias.

Level of Evidence: C

4. Mineralocorticoid receptor antagonists (MRAs, or aldosterone antagonists) may be used to limit the need for potassium repletion in patients with adequate renal function.

Level of Evidence: C.

Class II

1. Digoxin may be useful in the setting of atrial fibrillation with rapid ventricular response.

Level of Evidence: C.

Risk Factor Modification

Hypertension

Although blood pressure (BP) control is important as previously described, clinical trial evidence that identifies optimal target blood pressure is lacking in patients with MCS. The Interagency Registry for Mechanically Assisted Support (INTERMACS) definition of a hypertension adverse event is new onset systolic blood pressure (SBP) >140 mmHg

or diastolic blood pressure (DBP) >90 mmHg for pulsatile pumps and mean BP >110 mmHg for continuous flow pumps. The American Diabetes Association (ADA) blood pressure recommendations (SBP <130 mmHg and DBP <80 mmHg) are reasonable goals given the prevalence of vascular disease and diabetes in this population, as well as the mechanical consequences of persistently elevated blood pressure on pulsatile devices. As noted above, blood pressure control for patients with continuous flow pumps is essential to maximize pump output and ensure adequate decompression of the left ventricle. Outpatient assessment of blood pressure, especially at home, is difficult because patients may have very little pulsatility; thus, the BP can be very difficult to auscultate. Clinics that provide care for patients with continuous flow devices must be equipped with a Doppler probe to properly assess blood pressure. There is no evidence base for blood pressure targets with continuous flow pumps, but a mean blood pressure of ≤ 80 mmHg is a reasonable goal.

Recommendations for Hypertension Management:

Class IIb:

1. Patients with pulsatile MCSs should have a blood pressure goal of SBP <130 and DBP <85 mmHg.

Level of Evidence: C.

2. Patients with nonpulsatile MCSs should have a mean blood pressure goal of ≤ 80 mmHg

Level of evidence: C.

Diabetes

Patients should be screened for diabetes, and those with pre-implant diabetes should resume therapy post-operatively and continue their diabetes follow up after discharge. Patients should also reestablish or initiate follow up with their local primary care physicians and/or endocrinologists to assist in diabetes management. The MCS clinic should also assure patients with diabetes are obtaining routine screening by ophthalmology, nephrology, and podiatry as necessary. In one small series of patients with diabetes who were supported with MCS, their fasting glucose, glycosylated hemoglobin and daily insulin requirements were significantly improved after a mean of 4 months of mechanical support as compared to one month prior to implant.⁶⁸

Recommendations for Diabetes Management:

Class IIa:

1. Patients with diabetes should have continued therapy and close follow-up for their diabetes while on MCS.

Level of Evidence: C.

Renal Disease

Renal insufficiency is common prior to MCS from a combination of low output, high right atrial pressures, and an adverse neurohormonal milieu.^{69,70} Recovery of renal function is common after MCS implantation, and the majority of benefit from MCS on renal function is usually seen in the first 1-2 months.⁶⁷ Recovery of renal function can be maximized by assuring appropriate device output by adequate settings and aggressively treating hypertension, especially in those with continuous flow pumps. Renal function should also be monitored closely while treating residual volume overload with diuretics. Renal insufficiency in the setting of diabetes should prompt treatment with an ACE inhibitor or ARB, particularly in the setting of proteinuria. Recovery of renal function may also necessitate dose-adjusting renally cleared medications.

Recommendations for Treatment of Renal Disease:

Class IIb:

1. Renal function should be monitored on an ongoing basis after MCS placement.

Level of Evidence: C.

2. Persistent renal insufficiency after MCS should prompt further evaluation and management in collaboration with nephrology consultation.

Level of Evidence: C.

Hemolysis

Clinically significant hemolysis in patients with MCS is rare. It is potentially more common with continuous flow pumps, but the rate is still <5%.⁴⁹ Review of device parameters during clinic visits and examining longitudinal trends may help detect excessive pump speeds or other situations that may increase the risk for hemolysis. In the HeartMate II BTT trial, hemolysis was defined as two measurements of a plasma free hemoglobin >40 mg/dL or a lactate dehydrogenase (LDH) >1000 mg/dL within 24 hours.⁴⁹ INTERMACS defines hemolysis as a plasma free hemoglobin >40 mg/dL in association with clinical signs of hemolysis beyond 72 hours post implantation. Hemolysis not related to the device, e.g. from transfusions or liver disease, should also be considered in the differential.² Screening for hemolysis with LDH and plasma free hemoglobin should occur at least monthly in addition to assessment of the hematocrit and hemoglobin. In addition to elevations of LDH and plasma free hemoglobin, hemolysis may be associated with elevation of bilirubin, decrease in haptoglobin, anemia, hemoglobinuria and perturbations in pump parameters.

If hemolysis is suspected, it should be ensured that anticoagulation and anti-platelet therapy has been optimized.

If there is evidence that pump performance is being affected, usually manifested as either a sudden or gradual increased in pump power due to increased drag on the motor, the patient may require hospitalization for intravenous anticoagulation with heparin (or heparin-alternative) and platelet glycoprotein IIb/IIIa inhibitors such as eptifibatid or tirofiban.⁷¹ Thrombolytics have been used, but may be associated with significant hemorrhagic complications.⁷²⁻⁷⁴ Lowering pump speed may reduce power draw. Echocardiography should be performed to examine the ventricle for thrombus and to assess the inflow cannula. CTA may visualize cannula thrombus. The MCS surgeon should be consulted, as pump exchange may be required.

Recommendations for Evaluation and Management of Hemolysis:

Class I:

1. Screening for hemolysis should occur in the setting of an unexpected drop in the hemoglobin or hematocrit or with other clinical signs of hemolysis; e.g., hemoglobinuria.

Level of Evidence: C.

2. Hemolysis in the presence of altered pump function should prompt admission for optimization of anticoagulation and antiplatelet management and possible pump exchange

Level of Evidence: B.

Class IIa:

1. Routine screening for hemolysis with LDH and plasma free hemoglobin in addition to hemoglobin or hematocrit should occur periodically throughout the duration of MCS.

Level of Evidence: C.

Dietary Considerations: Obesity and Malnutrition

Malnutrition is a marker for poor outcomes post MCS implantation, with malnutrition defined as a pre-implant body mass index (BMI) <18.5 kg/m². In the outpatient setting, patients should have serial assessment of their weight and their adherence to the nutritional guidelines established as an inpatient. Nutritional recovery is best followed with pre-albumin rather than albumin because lack of improvement in pre-albumin has been linked to poor outcomes post-MCS.⁷⁵ Patients should be referred to a nutritionist as needed to assure nutritional goals are being met.

There are overlapping epidemics of obesity and heart failure. Although the impact of obesity on outcomes and adverse events has not been definitively established,⁷⁶ patients who are obese (BMI >30) or morbidly obese (BMI >40) may not be transplant eligible and certainly do not realize the same

improvement in functional capacity as the non-obese. Furthermore the obese are at risk for numerous other comorbidities including diabetes, hypertension, and persistent sleep apnea. Many patients may receive MCS as a bridge to weight loss, but there has been no evidence to demonstrate that such a strategy results in substantial weight loss. Weight gain can become more prevalent over time as cachexia resolves and patients revert to their prior poor eating habits. As with all obese patients, there is unlikely to be significant progress in the absence of patient motivation and a formal strategy to address weight loss. Exercise is an important component to weight loss in particular, and referral to cardiac rehabilitation is recommended and is addressed in Topic 3. Lastly, the combination of obesity surgery, either at the time of or after MCS implantation, has not been performed in sufficient numbers to determine the efficacy and safety of this strategy.

Recommendations for Dietary Management:

Class IIa:

1. Weight loss should be encouraged for all patients with a BMI >30.

Level of Evidence: C.

Smoking and Substance Abuse

Some patients may still be smoking at the time of implantation. Smoking cessation should be addressed during the immediate post-implantation hospitalization and should continue to be emphasized post-implantation at each follow up. Some patient's transplant candidacy may hinge on their cessation, but smoking cessation should be encouraged even in the absence of transplant eligibility. Both pharmacologic and psychiatric/psychological help may be offered. Routine screening for those whose transplant candidacy is dependent on their abstinence can be done in clinic with urine cotinine measurements.

Alcohol and substance abuse should be addressed in conjunction with social workers, psychiatrists, psychologists, and substance abuse specialists and programs. Often patients with a history of substance abuse enter into a contract with the implanting center which outlines the center's expectations in regards to a patient's particular goals and involves periodic screening for compliance with counseling and other outpatient support efforts.

Recommendations for Smoking and Substance Abuse:

Class I:

1. Smoking cessation should be encouraged in all patients on MCS who continue to use tobacco.

Level of Evidence: C.

Class IIa:

1. Alcohol and drug treatment programs should be required for patients with a history of substance abuse.

Level of Evidence: C.

Topic 5: Implantable Cardioverter Defibrillator and Arrhythmia Issues

Introduction

Patients with MCS still have substrate that places them at increased risk for development of arrhythmias. Those with an LVAD alone may be significantly adversely affected by the development of arrhythmias. In contrast, patients with biventricular support tolerate severe arrhythmias, including ventricular tachycardia (VT) or ventricular fibrillation (VF), often with little or no sequelae. In the DT population, patients are likely to be impacted by arrhythmias over the duration of their life with device; therefore, the clinician must have familiarity with these issues.

ICD and Pacemakers

Most patients who receive MCS in the current era will also have an implantable cardioverter defibrillator (ICD) alone or in combination with cardiac resynchronization therapy (CRT). In the recent HeartMate II BTT trial, 76% of patients had an ICD and in the HeartMate II DT trial 82% had an ICD.^{66,77} In the absence of persistent ventricular dysrhythmias, the defibrillator function of an ICD should be turned back on post-operatively and this should be confirmed prior to discharge from the implant hospitalization. Permanent inactivation of the ICD should routinely be considered in patients who have biventricular support and are in persistent VT or VF. Pacemaker or ICD functions such as back-up pacing for bradycardia, biventricular pacing, anti-tachycardiac pacing, and defibrillation will not adversely affect most current generation pumps or their controlling systems. Rarely, some ICDs and pacemakers may need programming changes due to electromagnetic interference from the assist device or repositioning of the RV lead. Device manufacturers often have a list of such pump-ICD interactions on their websites.

Patients who do not have an ICD prior to MCS are typically those who receive MCS after presenting with acute myopathies or post-cardiotomy failure. ICD placement is warranted prior to discharge as appropriate shocks occur in 21% of MCS patients and ICD is associated with improved survival in MCS-supported heart failure patients.⁷⁸

After discharge, patients should re-establish contact with their electrophysiologist and/or resume home monitoring of their ICD or pacemakers. Often these clinic visits are scheduled to coincide with outpatient visits to the mechanical

support clinic. Routine interrogation of devices allows for assessment of ventricular dysrhythmias as well as the occurrence or recurrence of atrial fibrillation.

Recommendations for ICD Placement:

Class I:

1. For patients who have an ICD prior to MCS, the ICD should be reactivated in the post-operative setting.

Level of Evidence: A.

Class IIa:

1. Routine placement of an ICD should be considered for patients who did not have an ICD prior to MCS.

Level of Evidence: B.

2. Inactivation of the ICD should be considered in patients with biventricular assist devices (BiVADs) who are in persistent VT/VF or who have frequent sustained runs of VT despite optimal antiarrhythmic therapy.

Level of Evidence: C.

Atrial Fibrillation or Atrial Flutter

Both atrial fibrillation (AF) and atrial flutter are common pre-implantation, often persist post implantation, and may even occur peri-operatively. Rate control and adequate anticoagulation are the primary goals of therapy. Atrial dysrhythmias may be more likely to occur or recur post-operatively in the setting of volume overload, inadequate decompression of the left and/or right ventricles, or in the setting of RV failure. Poor rate control may cause RV failure in the setting of marginal RV function and thus poor LVAD filling. For patients with long-standing AF prior to implantation, relief of the heart failure state may decrease atrial stretch enough to warrant an attempt at restoration of sinus rhythm. However, many of these patients have substantial adverse atrial remodeling, and they are unlikely to maintain sinus rhythm even with normalization of their hemodynamics. Once patients are rate controlled, the major impact of paroxysmal or persistent atrial arrhythmias is to increase the goal INR to 2-3 for devices that have target INRs <2.

For patients with new onset AF, it is reasonable to attempt cardioversion, either electrically or pharmaceutically once inotropic support is discontinued and volume status has normalized. For patients who have been cardioverted with an antiarrhythmic drug, it is reasonable to continue the antiarrhythmic with appropriate follow up, especially in the case of amiodarone. There is no known long-term advantage to an aggressive pursuit of sinus rhythm in patients with controlled ventricular rates, except to minimize anticoagulation requirements. However, in the setting of atrial

dysrhythmias with poorly controlled ventricular rates, antiarrhythmics, cardioversion and even atrioventricular (AV) nodal ablation with permanent pacing (if an ICD or pacemaker is already in place) are all potential options.⁷⁹

Recommendations for Management of Atrial Fibrillation and Flutter:

Class I:

1. Cardioversion of atrial fibrillation is recommended in patients with rapid ventricular rates that compromise device performance.

Level of Evidence: C.

Class IIa:

1. When atrial fibrillation is present and does not interfere with device functioning, management following the most recent American College of Cardiology/American Heart Association (ACC/AHA) atrial fibrillation guidelines (2011)⁸⁰ is recommended.

Level of Evidence: C.

Ventricular Arrhythmias

In the immediate post-operative period, ventricular dysrhythmias are also reasonably common. These either persist from the pre-implantation period, or they are exacerbated by the post-operative state. In the Heart Mate II BTT trial, 56% of patients had a history of ventricular arrhythmia. Post-operatively, 42% had a ventricular arrhythmia, most of which occurred in the first 30 days.⁴⁹ Beyond the first month post-implant, sustained ventricular dysrhythmias are much less common. Occurrence of sustained VT or VF in the outpatient setting can be discovered as the result of palpitations, light headedness, an appropriate ICD shock, or upon routine interrogation of the device. The effect of persistent ventricular arrhythmias on LVAD function is primarily the result of the tachycardia on right ventricular function. The more marginal the right ventricular function and the faster the ventricular rhythm, the more likely patients will experience RV dysfunction. The RV dysfunction usually results in underfilling of the left ventricle and thus the LVAD. Patients may experience hypotension and low flow alarms or, in those with continuous flow pumps, an increased likelihood of suction event. Lastly, in contrast to LVADs, patients who have BiVADs can usually hemodynamically tolerate persistent VT or even VF. However, such patients may still have compromised right ventricular assist device (RVAD) filling, have a slightly higher long-term risk of thromboembolism, and have no back up native heart function if support becomes interrupted through device failure or user error.

The approach to the occurrence of sustained ventricular arrhythmias is much the same as in those without MCS.

Searches for reversible causes such as electrolyte abnormalities, drugs which may prolong the QT interval, or more uncommonly, ischemia are reasonable first steps. There are causes of ventricular arrhythmias specific to MCS that should be recognized. With the widespread adoption of continuous flow devices, clinicians have to be aware of the possibility of a suction event, or over decompression of the left ventricle, as a source for ventricular arrhythmias. Many of the ventricular arrhythmias that occur with a suction event are recurrent episodes of premature ventricular contractions (PVCs) or short runs of VT, but the arrhythmias may become prolonged or even potentially sustained. A suction event can occur in a number of settings: after increasing the speed of the device; with volume loss in the setting of over diuresis, bleeding, tamponade, or dehydration from emesis, diarrhea, or insensible losses; or sudden decreases in afterload such as with aggressive treatment of hypertension. In the setting of a suction event, patient and device parameters should be reviewed. Lastly, patients may experience new onset VT as a result of reentry around the apical ventricular cannula.

Treatments for VT not caused by a suction event are similar to those recommended for patients without MCS, including beta-blockade, antiarrhythmics, and/or cardioversion.⁸¹ Reprogramming of the ICD may sometimes be necessary to avoid unnecessary or inappropriate shocks. Patients may even require mapping and ablation if the rhythms are difficult to control pharmacologically.

Recommendations for Management of Ventricular Arrhythmias:

Class I:

1. Cardioversion is recommended for VT that results in poor device flows and/or hemodynamic compromise.

Level of Evidence: C.

2. The occurrence of VT on MCS should prompt a search for reversible causes, such as electrolyte abnormalities or drug toxicities.

Level of Evidence: C.

Class IIa:

1. Amiodarone is a reasonable chronic outpatient treatment to prevent recurrence of VT in patients with MCS.

Level of Evidence: C.

2. Beta-blockade may be a useful in the setting of recurrent VT.

Level of Evidence: C.

3. Recurrent VT in the setting of a continuous flow pump should prompt consideration of a suction event.

Level of Evidence: C.

Class IIb:

1. In patients with biventricular support with VF who are refractory to therapy, but have stable flows, the patient may be left in VF with the defibrillator function of the ICD turned off.

Level of Evidence: C.

Topic 6: Psychological and Psychiatric Issues

Compared to palliative treatment strategies,^{82,83} MCS is an alternative, but costly treatment option for advanced heart disease. The presence of premorbid psychiatric disorders, the use of psychotropic drugs, and previous neurologic events must be taken into account during MCS evaluation as psychiatric burden influences compliance and overall outcome.^{84,85} After discharge, caregivers of a MCS patient are additionally placed under significant pressure which changes over the span of the MCS experience. Different coping mechanisms are used to deal with the initial shock and significant burden.⁸⁶ For patients undergoing heart transplant, partner support seems to be one of the most significant psychosocial variables that can influence clinical success.⁸⁷ Similarly, the following psychosocial predictors of clinical success from one study of heart transplant patients might also be applicable to MCS candidates: empathy, partner support (affective involvement), few demands for emotional communication (affective expression), self-control, stress resistance, emotional stability, high frustration tolerance, low aggression level, and younger age.⁸⁷

Bridge-to-Transplant

Even as implantation of MCS as DT receives more and more ubiquitous acceptance, the major indication still remains BTT. A European study prospectively comparing health related quality of life between MCS and heart transplant patients showed HRQOL improved significantly in heart transplant patients in the SF-36 physical ($P = 0.02$), but not in the psychosocial ($P = 0.27$) component score during follow-up. In the MCS group, HRQOL showed improvements for both the SF-36 physical and psychosocial component scores (both $P = 0.04$).⁸⁸ Interestingly, the BTT strategy does not lead to post-traumatic stress disorder (PTSD) in patients, but it may result in this condition in their spouses over the long term.^{89,90}

Destination Therapy

For patients with advanced heart failure and contraindications to cardiac transplantation, MCS have evolved as a permanent alternative, or DT.⁹¹ Moreover, as technology progresses in the context of limited organ donor supplies, MCSs may replace cardiac transplantation in the future. Success with MCS depends on adherence to a complicated mechanical regimen combined with

anticoagulation and care for the driveline.⁹² Even with successful outcomes, life is still far from normal. During the duration of support, which may be years, psychiatric and psychosocial issues may either progress or newly emerge. This highlights the importance of ongoing surveillance by the MCS team for these types of issues.

Adherence

Adherent behavior is not only a prerequisite for a successful BTT strategy,⁹³ but also for transplantation. A large number of studies have shown that preoperative factors exist which may predict post-transplant compliance,⁹⁴ and these may also be relevant to the MCS patient. These include: demographic variables, psychological variables, psychiatric disorders, poor social support, pretransplant non-adherence, obesity, and substance abuse.

Evaluation of Mental State

A rising proportion of cardiac transplant candidates are equipped with MCS. This patient cohort is burdened with characteristic psychiatric and psychosocial problems (Figure 3).⁹⁵ To illustrate this issue, one small study showed six (out of the notably small cohort of fourteen) heart transplant candidates with an MCS had more than one DSM-IV diagnosis.⁹⁵ The drugs used in nine patients included antipsychotics, antidepressants and anti-anxiety drugs. Only five (36%) candidates remained without psychiatric interventions. Patients identified with psychiatric issues should be formally evaluated by a psychiatrist, ideally one familiar with mental illness in the context of chronic medical illness. Appropriate pharmacologic treatment and psychological therapy should be initiated. Counseling may need to be extended to family members as well.

Figure 3 Time Course of Heart Transplantation and Neuropsychiatric Problems

Reprinted with permission from Baba A, Hirata G, Yokoyama F, et al. Psychiatric problems of heart transplant candidates with left ventricular assist devices. *J Artif Organs*. 2006;9:203-208.⁹⁵

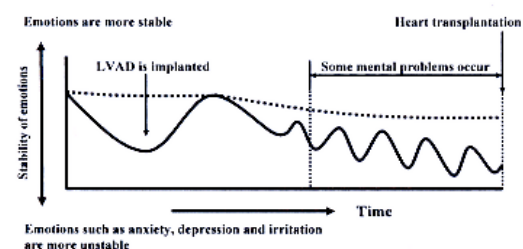


Fig. 3. The time course of heart transplantation and mental problems. In candidates who waited for several months or more in the hospital for transplantation, some emotional reactions occurred. The y axis represents the instability of the patients' emotions, with instability increasing in the downward direction. *Solid line*, most candidates; *dotted line*, some candidates; *LVAD*, left ventricular assist device

Suicide after MCS Implantation

Depression and anxiety are well documented in patients with end-stage heart failure. This state correlates with a higher risk of suicide. Cases of suicide in MCS patients by disconnecting at the driveline or batteries have been reported.⁹⁶ Pre-implant psychological screening and long-term psychological support should be provided to this vulnerable patient population.

Neurocognitive Assessment during Follow-Up

Although physical rehabilitation and emotional adjustment to heart transplant is similar in MCS-and non-MCS-bridged patients, MCS patients retain greater levels of cognitive impairment and return to correspondingly lower levels of social functioning post-transplant.⁹⁷ In a single-arm, non-randomized prospective study, the cognitive performance of advanced heart failure patients remained stable or showed slight improvements from month “one” to month “six” under continuous-blood-flow support with the HeartMate II.⁹⁸

Age Related Considerations

As the incidence of advanced heart failure affecting the elderly increases, new elements for psychosocial assessment needs to be considered.⁹⁹ Screening for pre-senile dementia and Alzheimer disease must be included in the evaluation, as these conditions may limit the patient’s long term survival.

Recommendations for Psychological and Psychiatric Issues:

Class I:

1. Patients being considered for MCS should have a detailed psychosocial evaluation.

Level of Evidence: C.

2. A formal consultation with a psychiatrist should be obtained for those with concerns for psychiatric illness. Appropriate pharmacologic and psychological therapy should be initiated as needed. Counseling may need to be extended to include family members as well.

Level of Evidence: C.

Topic 7: Emergency Procedures for Device Malfunction or Failure

Introduction

As MCS technology has improved, the incidence of MCS mechanical failure has rapidly decreased. However, the risk of device malfunction or frank device failure has not been totally eliminated. With continuous flow devices, it is impossible to manually actuate the device in the event of pump stoppage. Therefore, it is critically important to train

patients and caregivers in emergency procedures and to establish an algorithm to transport the patient emergently to the implanting center where pump exchange can be performed.

Before Discharge Home

The training of patients, family, and other designated caregivers should be performed in the implanting hospital by the MCS team. The training should include recognition of the different device alarms, the proper response to them, and appropriate means of resolving emergency situations. The training should be based on theoretical knowledge supported by a written manual provided by the company for the specific system and on practical exercises demonstrated by MCS team. There should be a final test (oral, written or both) to show that the individual and caregivers have understood and retained the information.

After Discharge Home

Patients, relatives, and caregivers should receive regular refresher courses during outpatient visits in the skills needed to resolve emergency situations.

Establishing an On-Call Notification Tree

Each MCS center should establish an on-call system that patients and their caregivers are familiar with and have practiced contacting. The “first-call” provider should be expert in trouble-shooting MCS related malfunctions.

Establishing a Transport System

In the event a patient has a medical emergency including pump malfunction, a transport system should exist to expedite returning the patient to the implanting center. For centers that encompass a large geographic referral area, this may include transportation by medical jet. A critical care transport team familiar with management of MCS patients should be dispatched for the transfer.

Recommendations for Emergency Procedures with Device Malfunction or Failures:

Class I:

1. The patient and their caregivers should be trained to recognize MCS alarms and troubleshoot emergencies prior to hospital discharge. This training should be delivered using both written materials and visual demonstrations and emergency response skills should be tested prior to the patient and caregiver leaving the hospital.

Level of Evidence: C.

- Ongoing refreshers should be provided to patients and caregivers at outpatient visits to ensure they remain competent in emergency procedures.

Level of Evidence: C.

- An emergency on-call algorithm should be established that patients and caregivers are familiar with, so they may quickly contact the implanting center in the event of emergencies.

Level of Evidence: C.

- An emergency transport system should be established to expedite transfer back to the implanting center in the case of emergency.

Level of Evidence: C.

Topic 8: End of Life Issues

General End of Life Issues

The mean age of patients reported to the INTERMACS registry for the (primary) implantation of a MCS is approximately 52 years (range 4.5 to 79.9).¹⁰⁰ Especially in an older population ethical questions such as “should MCSs be implanted in patients of advanced aged?” or “are there guidelines for turning-off the pump?” are becoming more and more important, especially in the context of limited societal financial resources.¹⁰¹ Patients being considered for MCS therapy must be fully informed of the risks and benefits of therapy with autonomous decision making. Advanced care planning should be undertaken including designation of a surrogate decision maker and exploration of the patient’s values and treatment preferences in the event that they are unable to express their wishes.^{102,103} This can be facilitated by preparation of a living will. Collaboration with a palliative care team may help the primary MCS team introduce these issues and concepts to patients being evaluated for MCS.

Deactivating the MCS

Similar to the considerations faced when deactivating an ICD, there are many issues to weigh when considering turning off a MCS. The patient’s wishes, either directly expressed or relayed through a living will or surrogate decision maker, are of paramount importance. A consensus by the treating medical team that the chance of meaningful recovery is negligible would further corroborate the futility of ongoing MCS support. A hospital ethicist may aid in making decisions about deactivating the MCS when consensus does not exist, especially when family members are at odds with the patient directly or with the medical team.

Palliation and MCSs

Recently published data in metastatic cancer patients demonstrated that early referral to palliative care lead to improvements in both quality of life and mood, with less aggressive care at the end of life, but longer survival compared to a group assigned to standard care.¹⁰⁴ In a small series of MCS patients, consultation with palliative medicine was obtained around the time of device implantation. Of the 19 patients studied, 13 (68%) completed advanced directives.¹⁰⁵ This proactive approach to involving palliative medicine may help optimize symptom management and facilitate referral to hospice at the juncture when survival on the MCS is determined to be limited due to device or non-device related issues.

Recommendations for End-of Life Issues:

Class I:

- Consultation with palliative medicine should be considered prior to MCS implantation to facilitate discussion of end-of-life issues and establish an advance directive or living will, particularly when implanted as DT.

Level of Evidence: C.

- In situations when there is no consensus about discontinuing MCS support, consideration may be given to consulting with the hospital ethicist or ethics board.

Level of Evidence: C.

ABBREVIATIONS

6MWT = 6-minute walk testing

ACC/AHA = American College of Cardiology/American Heart Association

ACE = angiotensin converting enzyme

ADA = American Diabetes Association

AF = atrial fibrillation

ARB = angiotensin receptor blocker

AV = atrioventricular

AVM = arteriovenous malformations

BiVAD = biventricular assist device

BMI = body mass index

BP = blood pressure

BTT = bridge-to-transplant

CDC = Centers for Disease Control

CRT = cardiac resynchronization therapy

CTA = computed tomography angiography

CPX = cardiopulmonary stress test

CVP = central venous pressure

DBP = diastolic blood pressure

DT = destination therapy

EMS = emergency medical services

FDA = Food and Drug Administration
 HF-ACTION = Heart Failure: A Controlled Trial Investigating Outcomes of Exercise Training
 HRQOL = health related quality of life
 ICD = implantable cardioverter defibrillator
 INR = international normalized ratio
 INTERMACS = Interagency Registry for Mechanically Assisted Support
 LDH = lactate dehydrogenase
 LV = left ventricular
 LVAD = left ventricular assist device
 LVEF = left ventricular ejection fraction
 MCS = mechanical circulatory support
 MCSD = mechanical circulatory support device
 MRA = mineralocorticoid receptor antagonist
 NYHA = New York Heart Association
 PA = pulmonary artery
 PTSD = post-traumatic stress disorder
 PVAD = Paracorporeal Ventricular Assist Device
 PVC = premature ventricular contraction
 RV = right ventricular
 RVAD = right ventricular assist device
 SBP = systolic blood pressure
 TEG = thromboelastography
 VAD = ventricular assist device
 VF = ventricular fibrillation
 VT = ventricular tachycardia
 vWF = von Willebrand factor

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