CHEST

Mechanical Circulatory Support Devices in the ICU

Keyur B. Shah, MD; Melissa C. Smallfield, MD; Daniel G. Tang, MD; Rajiv Malhotra, MD; Richard H. Cooke, MD; and Vigneshwar Kasirajan, MD, FCCP

The medical community has used implantable mechanical circulatory support devices at increasing rates for patients dying from heart failure and cardiogenic shock. Newer-generation devices offer a more durable and compact option when compared with bulky early-generation devices. This article is a succinct introduction and overview of the hemodynamic principles and complications after device implantation for ICU clinicians. We review the concepts of device physiology, clinical pearls for perioperative management, and common medical complications after device implantation. CHEST 2014; 146(3):848-857

ABBREVIATIONS: AUC = area under the curve; CF = continuous flow; CVP = central venous pressure; ΔP = pressure differential; HQ = hydrodynamic performance; LV = left ventricular; LVAD = left ventricular assist device; MCS = mechanical circulatory support; RV = right ventricular; RVAD = right ventricular assist device; RVF = right ventricular failure; SVR = systemic vascular resistance; TAH = total artificial heart; TTE = transthoracic echocardiography; vWF = von Willebrand factor

The medical community has used implantable mechanical circulatory support (MCS) devices at increasing rates for patients dying from heart failure and cardiogenic shock.[1] Traditionally, these devices were used with the intention to bridge patients to recovery or to heart transplantation. With the development of more reliable continuous flow (CF) left ventricular assist devices (LVADs), there has been a rise in implantation of devices as the definitive therapy for end-stage cardiomyopathy without the intention for heart transplantation (destination therapy). Newer-generation LVADs offer a more compact and durable option when compared with bulky, early-generation devices.[2]

With increasing device usage, physicians have admitted a greater number of patients with MCS to the ICU. From perioperative management to hospital readmissions for complications, the patient with a CF LVAD presents a distinct cardiovascular physiology and unique set of complications. Furthermore, additional devices, including right ventricular assist devices (RVADs) and the total artificial heart (TAH), are used in patients with biventricular dysfunction or anatomic contraindications to an LVAD.

For reference, an early iteration of society-sanctioned guidelines for care of patients with MCS have been previously published, albeit primarily with level C evidence (expert opinion), which highlights the absence of comparative, prospective studies in this field.[3] This article is a succinct introduction and overview of the hemodynamic

Manuscript received November 7, 2013; revision accepted December 26, 2013.

AFFILIATIONS: From the Division of Cardiology (Drs Shah, Smallfield, and Cooke), the Division of Cardiothoracic Surgery (Drs Tang and Kasirajan), and the Division of Pulmonary and Critical Care Medicine (Dr Malhotra), Virginia Commonwealth University, Richmond, VA.

CORRESPONDENCE TO: Keyur B. Shah, MD, Heart Failure/Transplantation, Division of Cardiology, Virginia Commonwealth University, MCV Campus, PO Box 980204, Richmond, VA 23298-0204; e-mail: kshah@mcvh-vcu.edu

DOI: 10.1378/chest.13-2645

principles and complications after MCS implantation for ICU clinicians. For CF LVADs, we review the concepts of device physiology, clinical pearls for perioperative management, and the common medical complications after device implantation. Additionally, we provide a brief overview of the general perioperative and postoperative management of individuals with the TAH.

The general purpose of an LVAD is to use a mechanical pump to draw blood from the left side of the heart and eject it into the aorta. The typical implantable LVAD has an inflow cannula that draws blood from the apex of the left ventricular (LV) cavity and ejects it into the proximal aorta through an outflow cannula (Fig 1). The end result is a parallel circuit to the systemic cardiac outflow that mechanically reduces the LV filling pressure and augments cardiac output. Early-generation assist devices were bulky and cumbersome pumps with poor long-term durability and a high frequency of mechanical failure. These displacement pumps have been replaced with CF technologies, which allow for a smaller and more durable design. CF pumps consist of a rapidly rotating, electromagnetically driven impeller that pumps blood in either an axial (linear; ie, HeartMate II; Thoratec Corporation) or centrifugal (tangential; ie, HVAD; HeartWare Inc) direction (Fig 2).

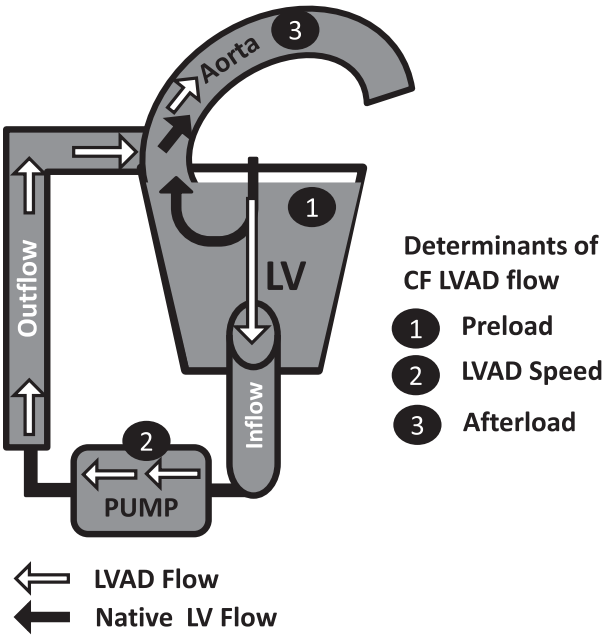

Figure 1 – *The diagram depicts the general configuration and determinants of blood flow for a CF LVAD. The LVAD flow is parallel to the native circulation and is determined by the preload, afterload, and LVAD speed. CF = continuous flow; LV = left ventricle/ventricular; LVAD = left ventricular assist device.*

Flow through a CF LVAD is dependent on the rotational speed of the impeller (set by the user) and the pressure differential (ΔP) from the inlet cannula (preload) to the outlet cannula (afterload). As the ΔP increases, the flow or work performed at a given speed decreases. In other words, pump flow increases by decreasing systemic vascular resistance (SVR) and optimizing blood volume availability in the LV cavity. Since the ΔP changes through the cardiac cycle, flow through a CF LVAD is not completely continuous but also changes throughout the cardiac cycle (Fig 3) with augmentation of flow during systole.

Each LVAD has its own unique hydrodynamic performance (HQ) curve, which describes the relationship of ΔP and flow at various pump speeds. Generally speaking, the HQ curve for centrifugal flow LVADs tends to be more flat, where a small change in the ΔP results in a wide change in flow. Conversely, the HQ curve for axial flow devices tends to be steeper, where a change in the ΔP results in a small change in flow. Because of these operating characteristics, centrifugal-flow LVADs tend to be more sensitive to high SVR states than axial-flow LVADs. Centrifugal flow pumps may exhibit low pump output and inadequate LV unloading when afterload (ie, BP) is increased. Alternatively, centrifugal-flow LVADs are less likely to over-decompress the left ventricle if there is an abrupt drop in preload. If the ventricle becomes too decompressed, the myocardium may crowd the inflow cannula, leading to obstruction of blood flow, colloquially described as a "suction event." A suction event may cause symptoms from disruption of flow or may be a subclinical event and detected only by algorithms programmed in the controller of the LVAD. A comprehensive review has been published by Moazami et al[4] comparing the mechanics and physiology of these two device platforms.

Perioperative Management

In the postoperative period, one may frequently observe unstable hemodynamics and fluctuations in LVAD flow, which may be due to a number of causes (Tables 1, 2). A systematic approach is necessary to diagnose these problems and implement appropriate treatment. Many of these patients are critically ill prior to LVAD implantation with existing or impending end-organ dysfunction. Patients may have pulmonary edema from cardiogenic shock, profound disturbances in coagulation, and unrecognized sepsis from central IV catheters or temporary mechanical support. Early postoperative problems that may lead to hemodynamic instability (discussed in more detail later) include right ventricular (RV) failure,