JOURNAL OF THE AMERICAN COLLEGE OF CARDIOLOGY

PUBLISHED BY ELSEVIER INC.

VOL. 64, NO. 12, 2014
ISSN 0735-1097/$36.00
http://dx.doi.org/10.1016/j.jacc.2014.06.1188

Echocardiographic Evaluation of Hemodynamics in Patients With Systolic Heart Failure Supported by a Continuous-Flow LVAD

Jerry D. Estep, MD,* Rey P. Vivo, MD,*† Selim R. Krim, MD,‡ Andrea M. Cordero-Reyes, MD,* Barbara Elias, RN,* Matthias Loebe, MD, PhD,* Brian A. Bruckner, MD,* Arvind Bhimaraj, MD,* Barry H. Trachtenberg, MD,* Guha Ashrith, MD,* Guillermo Torre-Amione, MD, PhD,*§ Sherif F. Nagueh, MD*

ABSTRACT

BACKGROUND Hemodynamics assessment is important for detecting and treating post-implant residual heart failure, but its accuracy is unverified in patients with continuous-flow left ventricular assist devices (CF-LVADs).

OBJECTIVES We determined whether Doppler and 2-dimensional transthoracic echocardiography reliably assess hemodynamics in patients supported with CF-LVADs.

METHODS Simultaneous echocardiography and right heart catheterization were prospectively performed in 50 consecutive patients supported by using the HeartMate II CF-LVAD at baseline pump speeds. The first 40 patients were assessed to determine the accuracy of Doppler and 2-dimensional echocardiography parameters to estimate hemodynamics and to derive a diagnostic algorithm for discrimination between mean pulmonary capillary wedge pressure ≤15 versus >15 mm Hg. Ten patients served as a validation cohort.

RESULTS Doppler echocardiographic and invasive measures of mean right atrial pressure (RAP) ($r = 0.863$; $p < 0.0001$), systolic pulmonary artery pressure (sPAP) ($r = 0.880$; $p < 0.0001$), right ventricular outflow tract stroke volume ($r = 0.660$; $p < 0.0001$), and pulmonary vascular resistance ($r = 0.643$; $p = 0.001$) correlated significantly. Several parameters, including mitral ratio of the early to late ventricular filling velocities >2, RAP >10 mm Hg, sPAP >40 mm Hg, left atrial volume index >33 ml/m^2, ratio of mitral inflow early diastolic filling peak velocity to early diastolic mitral annular velocity >14, and pulmonary vascular resistance >2.5 Wood units, accurately identified patients with pulmonary capillary wedge pressure >15 mm Hg (area under the curve: 0.73 to 0.98). An algorithm integrating mitral inflow velocities, RAP, sPAP, and left atrial volume index was 90% accurate in distinguishing normal from elevated left ventricular filling pressures.

CONCLUSIONS Doppler echocardiography accurately estimated intracardiac hemodynamics in these patients supported with CF-LVAD. Our algorithm reliably distinguished normal from elevated left ventricular filling pressures. (J Am Coll Cardiol 2014;64:1231–41) © 2014 by the American College of Cardiology Foundation.

Over the last 6 years, ~6,000 patients with advanced heart failure have received continuous-flow left ventricular assist devices (CF-LVADs), which constitute >95% of all long-term mechanical circulatory support implantations (1). With 1- and 2-year survival estimated at ~82% and 74%, respectively, increasing use of these devices is expected (1,2). When evaluating patients

From the *Houston Methodist DeBakey Heart & Vascular Center, Houston Methodist Hospital, Houston, Texas; †Mechanical Circulatory Support and Heart Transplantation Program, UCLA Ahmanson Cardiomyopathy Center, Los Angeles, California; ‡John Ochsner Heart and Vascular Institute, Ochsner Clinic Foundation, New Orleans, Louisiana; and the §Catedra de Cardiologia y Medicina Vascular, Tecnológico de Monterrey, Nuevo León, Mexico. Dr. Estep has received consulting fees from Thoratec Corp. All authors have reported that they have no relationships relevant to the contents of this paper to disclose.
Listen to this manuscript's audio summary by *JACC* Editor-in-Chief Dr. Valentin Fuster.
You can also listen to this issue's audio summary by *JACC* Editor-in-Chief Dr. Valentin Fuster.

Manuscript received March 20, 2014; revised manuscript received May 16, 2014, accepted June 3, 2014.

ABBREVIATIONS AND ACRONYMS

A = mitral inflow late diastolic filling peak velocity

CF-LVAD = continuous-flow left ventricular assist device

E = mitral inflow early diastolic filling peak velocity

e′ = early diastolic mitral annular velocity

LAP = left atrial pressure

LAVi = left atrial volume index

LV = left ventricular

LVAD = left ventricular assist device

NYHA = New York Heart Association

PCWP = pulmonary capillary wedge pressure

PVR = pulmonary vascular resistance

RAP = right atrial pressure

rpm = revolutions per minute

RV = right ventricular

RVOT = right ventricular outflow tract

sPAP = systolic pulmonary artery pressure

with left ventricular assist devices (LVADs) for ventricular size and function, valvular function, and potential device complications, echocardiography remains the imaging modality of choice (3). Although echocardiography can reliably measure right ventricular (RV) and left ventricular (LV) hemodynamics in patients with decompensated heart failure (4), its utility and accuracy measured against invasively derived hemodynamics in the CF-LVAD population have not been fully examined.

SEE PAGE 1242

Unplanned readmissions attributed to left-sided and/or right-sided heart failure after CF-LVAD accounts for significant patient morbidity (5,6). Current practice guidelines support the use of right heart catheterization in patients on CF-LVADs with persistent or recurrent heart failure (7). However, invasive testing is not always readily available and carries intrinsic risks in this patient group given their need for chronic anticoagulation. We therefore performed a prospective study to examine the application of Doppler echocardiography for the hemodynamic assessment of patients with CF-LVADs. In addition, we aimed to develop a practical echocardiographic algorithm to detect elevated LV filling pressures due to partial LV unloading in this patient population.

METHODS

PATIENT POPULATION. Between July 2009 and December 2013, a total of 55 consecutive patients supported with a CF-LVAD at the Houston Methodist Hospital and with a clinical indication for invasive hemodynamic assessment (e.g., persistent residual heart failure, pre-heart transplant pulmonary pressure assessment, or as part of a screening protocol to evaluate for myocardial recovery) were prospectively enrolled under an institutional review board-approved protocol. Patients with a mitral valve annuloplasty ring ($n = 2$), significant mitral annular calcification ($n = 1$), and those with suboptimal images due to poor acoustic windows ($n = 2$) were excluded.

All 50 patients received the HeartMate II CF-LVAD (Thoratec Corporation, Pleasanton, California). Simultaneous echocardiography and right heart catheterization were performed in the catheterization laboratory on all patients at baseline pump speed, typically 9,000 revolutions per minute (rpm). Clinical heart failure on CF-LVAD support was defined as the presence of shortness of breath (i.e., New York Heart Association [NYHA] functional class III or IV symptoms) with an elevated pulmonary capillary wedge pressure (PCWP) >15 mm Hg defined by using the right heart catheterization at baseline LVAD pump speed. Right-sided heart failure was attributed to residual left-sided heart failure while on CF-LVAD support; this assumption was made on the basis of right heart catheterization if the mean right atrial pressure (RAP) was >10 mm Hg in the presence of an elevated PCWP and pulmonary hypertension.

ECHOCARDIOGRAPHIC IMAGING AND ANALYSIS. Complete transthoracic echocardiographic studies were performed in standard fashion in accordance with current American Society of Echocardiography guidelines and were reviewed by an independent reader blinded to the invasive hemodynamic measurements. From the parasternal window, LV end-diastolic diameter, pulmonary annulus diameter, and right ventricular outflow tract (RVOT) velocity were measured per guidelines (8,9). RVOT stroke volume was derived as the RVOT cross-sectional area × RVOT time-velocity integral flow according to pulsed-wave Doppler (9). Right-sided cardiac output (the sum of LVAD flow and native LV outflow tract) was calculated as the product of RV stroke volume and heart rate, and indexed to body surface area to calculate cardiac index. In addition, 2-dimensional echocardiography and M-mode were used from the parasternal window to record aortic valve function per institutional guidelines in patients on CF-LVAD support with classification as follows: aortic valve opening after every cardiac cycle, intermittent aortic valve opening, or complete aortic valve closure (10).

From the apical window, left atrial volume was measured by using the biplane method of disks from the apical 4-chamber and apical 2-chamber views at ventricular end-systole, then indexed to body surface area to yield the left atrial volume index (LAVi) (8). Pulsed-wave Doppler was used to record mitral inflow for 3 to 5 cardiac cycles at the mitral valve leaflet tips. Doppler signals were analyzed for mitral valve peak early (E) and late (A) diastolic velocities, E/A ratio, and deceleration time of mitral E velocity (11). Tissue Doppler was applied to measure mitral annular early (e') velocities at the lateral and septal annulus. The resulting annular velocities according to pulsed-wave Doppler were recorded for 3 to 5 cardiac cycles at a sweep speed of 100 mm/s. E/e′ ratios were computed by using the average of the lateral and septal e′. Mitral deceleration index was derived as mitral deceleration time divided by peak E-wave velocity (12). Using at least 3 cardiac cycles, the estimated left atrial