Preoperative Three-Dimensional Echocardiography to Assess Risk of Right Ventricular Failure After Left Ventricular Assist Device Surgery

MICHAEL S. KIERNAN, MD, MS,[1] AMY L. FRENCH, MD,[1] DAVID DENOFRIO, MD,[1] YUVRAJSINH J. PARMAR, MD,[2] DUC THINH PHAM, MD,[1] NAVIN K. KAPUR, MD,[1] NATESA G. PANDIAN, MD,[2] AND AYAN R. PATEL, MD[1,2]

Boston, Massachusetts

ABSTRACT

Background: Right ventricular failure (RVF) is associated with significant morbidity after left ventricular assist device (LVAD) surgery. Hemodynamic, clinical, and 2-dimensional echocardiographic variables poorly discriminate patients at risk of RVF. We examined the utility of 3-dimensional echocardiography (3DE) right ventricular (RV) volumetric assessment to identify patients at risk for RVF.

Methods and Results: RVF was defined as the need for inotropic infusion for >14 days after LVAD surgery or the need for biventricular assist device support. Preoperative RV volumes and ejection fraction (EF) were measured, blinded to clinical data, from transthoracic 3DE full volume data sets in 26 patients. Baseline variables and 3DE RV indices were compared between patients with and without RVF. Twenty-four patients received continuous-flow LVADs, and 2 required biventricular support devices. Ten patients required prolonged inotropes after LVAD placement. Baseline characteristics associated with RVF included higher right atrial pressure, higher right atrial pressure to pulmonary capillary wedge pressure ratio, and lower cardiac index and RV stroke work index (RVSWI). Echocardiographic indices associated with RVF included 3DE indexed RV end-diastolic and end-systolic volumes (RVEDVI and RVESVI) and RV ejection fraction (RVEF). The relationship between 3DE quantification of RV volumes and the development of RVF was independent from RVSWI: RVEDVI: odds ratio (OR) 1.16, 95% confidence interval (CI) 1.00−1.33 (P = .04); RVESVI: OR 1.14, 95% CI 1.01−1.28 (P = .03).

Conclusions: Quantitative 3DE is a promising method for pre-LVAD RV assessment. RV volumes assessed by 3DE are predictive of RVF in LVAD recipients independently from hemodynamic correlates of RV function. (*J Cardiac Fail 2015;21:189−197*)

Key Words: Right ventricular failure, left ventricular assist device, preoperative risk assessment, three-dimensional echocardiography.

Despite improvements in technology and perioperative care, postoperative right ventricular failure (RVF) remains a major cause of morbidity and mortality after left ventricular assist device (LVAD) surgery.[1,2] Early planned institution of mechanical right ventricular (RV) support is associated with improved outcomes[3,4]; however, there is no consensus on how to best define a target population for univentricular left-sided support. Enhanced preoperative identification of patients at higher risk of postoperative RVF may alter perioperative management strategies leading to improved clinical outcomes and resource utilization.

Standard 2-dimensional transthoracic echocardiographic (2DE) assessment of the right ventricle (RV) has a number of limitations. The complex 3-dimensional structure of the RV makes 2DE quantitative assessment difficult, and qualitative evaluation of function may be inconsistent between operators.[5] Two-dimensional quantitative parameters provide only a limited assessment of RV function owing to their inability to fully visualize and quantitate the RV. Consistently with these drawbacks, standard 2DE preoperative assessment of RV function has not been identified as a consistent predictor of RVF after LVAD surgery.[6−12] In

From the [1]Heart Failure and Cardiac Transplant Center, Tufts Medical Center, Boston, Massachusetts and [2]Cardiovascular Imaging and Hemodynamic Laboratory, Tufts Medical Center, Boston, Massachusetts.

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Reprint requests: Michael S. Kiernan, MD, MS, Tufts Medical Center, 800 Washington Street, Boston, MA 02111. Tel: 617-636-8068; Fax: 617-636-6030. E-mail: mkiernan@tuftsmedicalcenter.org

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contrast, compared with conventional 2-dimensional imaging, real-time 3-dimensional transthoracic echocardiography (3DE) assessment of RV function improves accuracy and decreases interobserver variability.[13] Among patients with RV dysfunction due to pulmonary arterial hypertension or RV myocardial infarction, 3DE demonstrated improved discrimination of RV volumes and ejection fraction (RVEF) compared with 2DE and has been observed to correlate well with cardiac magnetic resonance imaging (CMRI).[5,14] However, the role of quantitative 3DE in the preoperative assessment of RV function of patients undergoing LVAD surgery has not yet been explored. The aim of the present investigation was to explore the association between RV volumes and ejection fraction, as quantified by 3DE, and postoperative RVF among LVAD recipients.

Materials and Methods

Study Design

All patients undergoing long-term ventricular assist device implantation (LVAD or biventricular assist device) at a single institution from January 1, 2008, to December 31, 2011, were retrospectively screened for inclusion in the study. Patients were excluded if they did not have adequate quality preoperative 2DE and 3DE imaging of the RV at our institution before LVAD implantation or if image quality precluded accurate RV assessment. Postoperative RVF was defined as the need for prolonged inotropes (≥14 d) after LVAD insertion or the need for biventricular mechanical support.[6,8,9,15] The study was approved by the Institutional Review Board at Tufts Medical Center.

Hemodynamic and Laboratory Assessments

Hemodynamic measurements before LVAD surgery were obtained as part of routine perioperative care. Transpulmonary gradient (mm Hg) was calculated as mean pulmonary arterial pressure − pulmonary capillary wedge pressure. Pulmonary vascular resistance (Woods units) was calculated as transpulmonary gradient/cardiac output. RV stroke work index (RVSWI; g m^{-2} $beat^{-1}$) was calculated as (mean pulmonary artery pressure − right atrial pressure) × stroke volume index. Baseline laboratory values were obtained from all patients before surgery.

Echocardiography

Standard 2-dimensional and Doppler echocardiography was performed before LVAD implantation. The 2DE and 3DE measurements were performed by a single observer. Left- and right-side chamber dimensions and functional parameters were measured according to established guidelines.[16,17] Measurement of left ventricular (LV) end-diastolic diameter (LVEDD) was made from 2D images acquired from the parasternal long-axis view. LV internal dimensions were measured along the LV minor axis at the level of the mitral chordae. End-diastole was defined as the frame just after mitral valve closure or as the largest chamber size. End-systole was defined as the frame just preceding mitral valve opening, or the smallest chamber size. RV linear dimension and area measurements were obtained from the apical 4-chamber view. RV basal diameter was measured as the end-diastolic short-axis dimension in the basal one-third of the RV, near the level of the tricuspid annulus. The RV/LV diameter ratio was calculated as end-diastolic RV basal diameter/LVEDD.[18] The RV end-diastolic and end-systolic areas were measured by means of endocardial border tracing of the RV in the apical 4-chamber view. RV trabeculations and the moderator band were considered to be part of the RV cavity and excluded from the border tracing. Fractional area change (RVFAC) was defined as ([end-diastolic area − end-systolic area]/end-diastolic area) × 100. Tricuspid annular plane systolic excursion was measured according to accepted guidelines.[17] RV function according to 2DE was also qualitatively graded as normal (0), mildly reduced (1), mildly to moderately reduced (1.5), moderately reduced (2), moderately to severely reduced (2.5), or severely reduced (3). 2DE RV function was then dichotomized as group 1 (normal, mildly reduced, mildly to moderately reduced, moderately reduced) or group 2 (moderately to severely reduced, severely reduced).

Three-Dimensional Echocardiography. Transthoracic 3DE full-volume data sets focused on the RV were obtained from a modified apical 4-chamber view (iE-33 system/X3-1 transducer; Philips Healthcare, Andover, Massachusetts) and analyzed on an offline workstation (Tomtec Imaging, Munich, Germany) to quantify RV end-diastolic volume and RV end-systolic volume.[17,19] Echocardiographic analysis was performed by a single operator blinded to the clinical data. From the 3DE dataset, RV image alignment was optimized in a multiplanar view demonstrating 3 orthogonal planes. The end-diastolic and end-systolic endocardial borders were traced in 16 equiangular apical rotational cut-planes to obtain volume measurements. The RV endocardial border tracing included the RV outflow tract up to the plane of the pulmonic valve. The RV trabeculations were considered to be part of the RV cavity and excluded from the endocardial border tracing. Endocardial boundaries were displayed in 3 multiplanar views to verify accurate border tracing (Fig. 1). The time required for 3D RV analysis was 8 ± 2 minutes. RVEF was calculated as ([RV end-diastolic volume − RV end-systolic volume]/RV end-diastolic volume) × 100. RV end-diastolic and end-systolic volumes were indexed for body surface area (RVEDVI and RVESVI). Right ventricular end-diastolic volume, RV end-systolic volume, and RVEF were remeasured in 10 randomly selected subjects to assess interobserver variability with 2 independent observers and for intra-observer variability with a single observer at 2 different time points.

Statistical Analysis

LVAD recipients with RVF and biventricular assist device recipients were pooled together for comparison with the LVAD without RVF group. Continuous variables are presented as mean ± SD and were compared with the use of the Student unpaired *t* test; variables that were not normally distributed were described as median and interquartile range (IQR), and differences were analyzed with the use of the Wilcoxon rank sum test. Normality was evaluated for each variable with the use of the Shapiro-Wilk test. Equality of variances was assessed with the use of the folded F method to determine pooled versus Satterthwaite *t* test procedure. Categoric variables are presented as percentage and were compared by means of the Fisher exact test. Binary logistic regression models were constructed to assess the relationship of preoperative RV size (RVEDVI, RVESVI) and function (RVEF) according to 3DE with postoperative RVF independently from RVSWI. Given that the number of events in this study was small (n = 12), the regression model was limited to 2 variables and therefore could not include other variables associated with RVF in earlier investigations. These statistical analyses were performed with the use of SAS version 9.4 (SAS Institute, Cary, North Carolina).