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Original Article

Intraoperative Transesophageal Echocardiography and Right Ventricular Failure After Left Ventricular Assist Device Implantation

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Objective: To determine whether intraoperative measures of right ventricular (RV) function using transesophageal echocardiography are associated with subsequent RV failure after left ventricular assist device (LVAD) implantation.
Design: Retrospective, nonrandomized, observational study.
Setting: Single tertiary-level, university-affiliated hospital.
Participants: The study comprised 100 patients with systolic heart failure undergoing elective LVAD implantation.
Interventions: Transesophageal echocardiographic images before and after cardiopulmonary bypass were analyzed to quantify RV function using tricuspid annular plane systolic excursion (TAPSE), tricuspid annular systolic velocity (S'), fractional area change (FAC), RV global longitudinal strain, and RV free wall strain. A chart review was performed to determine which patients subsequently developed RV failure (right ventricular assist device placement or prolonged inotrope requirement ≥ 14 days).
Measurements and Main Results: Nineteen patients (19%) subsequently developed RV failure. Postbypass FAC was the only measure of RV function that distinguished between the RV failure and non-RV failure groups (21.2% *v* 26.5%; $p = 0.04$). The sensitivity, specificity, and area under the curve of an abnormal RV FAC ($< 35\%$) for RV failure after LVAD implantation were 84%, 20%, and 0.52, respectively. No other intraoperative measure of RV function was associated with subsequent RV failure. RV failure increased ventilator time, intensive care unit and hospital length of stay, and mortality.
Conclusion: Intraoperative measures of RV function such as tricuspid annular plane systolic excursion, tricuspid annular systolic velocity, and RV strain were not associated with RV failure after LVAD implantation. Decreased postbypass FAC was significantly associated with RV failure but showed poor discrimination.

Key Words: transesophageal echocardiography; left ventricular assist device; right ventricular failure; right ventricular strain

HEART FAILURE IS a disease that affects 6.5 million Americans, with almost 1 million new cases annually.[1] Although heart transplantation is the treatment of choice for end-stage heart failure, the clinical need far exceeds the number of transplantations available each year.[2] As a result, durable left ventricular assist devices (LVADs) increasingly are being used as a bridge to transplantation, a bridge to recovery, and now for destination therapy. The number of LVAD implantations has continued to grow in North America and now exceeds the number of heart transplantations.[3,4]

One limitation of LVADs is that the device only supports the left ventricle, and right ventricular (RV) failure occurs in up to 30% to 40% of patients after LVAD implantation.[5–8] RV

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failure after LVAD implantation is associated with increased morbidity,[5,9] decreased survival to transplantation,[5,6] and decreased survival after transplantation.[10]

Methods for predicting RV failure after LVAD implantation are an important clinical target because they may help to direct therapy. There is evidence to suggest that patients with planned biventricular assist device (BIVAD) placement have higher survival to discharge than those with subsequent right ventricular assist device (RVAD) placement after isolated LVAD implantation.[11] Preoperative clinical risk factors for RV failure after LVAD implantation may include elevated liver enzymes, elevated creatinine, the need for vasopressor support or intra-aortic balloon counterpulsation, increased pulmonary vascular resistance, and LVAD placement as destination therapy.[6,12,13] Several clinical risk scores have been developed to predict RV failure after LVAD implantation.[12,13] These scores combine laboratory values, right heart catheterization data, and clinical risk factors but often do not include echocardiographic data. More recently, however, Grant et al. found that the echocardiographic evaluation of RV function using strain analysis was able to predict RV failure after LVAD implantation.[7] Subsequently, Kato et al. found that a combination of reduced RV global longitudinal strain (GLS), tricuspid annular systolic velocity (S'), and RV filling pressures (as measured by E/e') discriminated patients who developed RV failure after LVAD placement with a predictive accuracy of 76%.[8] These studies, however, were performed using transthoracic echocardiography (TTE), often several days before or after LVAD implantation.

The echocardiographic evaluation of RV function is complicated by the 3-dimensional shape of the right ventricle and hence the inability to accurately apply simple 2-dimensional models of ejection fraction as is common practice for the left ventricle. As a result, RV function generally is assessed either with surrogate measures of function such as tricuspid annular plane systolic excursion (TAPSE), S', fractional area change (FAC), or simply by subjective "eyeballing." The quantification of RV function with transesophageal echocardiography (TEE) is even more challenging than with TTE because TAPSE and S' are angle dependent and may not be accurate when applied to TEE using standard technology.[14]

The purpose of this study was to determine whether intraoperative measures of RV function using TEE could be used to predict RV failure after LVAD implantation. The authors hypothesized that RV strain analysis using TEE would be a better predictor of RV failure after LVAD than more traditional measures of RV function, such as TAPSE, S', or FAC.

Methods

Study Design

This was a retrospective, observational study in which intraoperative TEE images of the right ventricle acquired before and after cardiopulmonary bypass (CPB) were analyzed and compared with clinical outcomes after LVAD implantation. The authors' institution has maintained a database of all intraoperative TEE procedures since 2010. After approval by the authors' institutional review board with a waiver of consent, this database was screened and all cases of LVAD implantation were identified. Images from these studies then were reviewed, and those with adequate images of the right ventricle in a midesophageal 4-chamber view both before and after CPB were included in the study. Right ventricle images then were analyzed to quantify RV function using RV-specific speckle-tracking strain software (EchoInsight; Epsilon Imaging, Ann Arbor, MI) that also allowed for the calculation of TAPSE, S', and FAC. These results then were compared with patient outcomes. The 2 investigators who analyzed the images of the right ventricle (N.S. and C.M.) were blinded to the outcome data, which were obtained by a third investigator (R.P.).

Study Population

Included in the study were patients at the authors' institution who underwent TEE imaging during their LVAD implantation between April 2010 and December 2016. Preoperative demographic data were obtained using the Interagency Registry for Mechanically Assisted Circulatory Support database.

Patients were excluded if they did not have adequate images of the right ventricle immediately before and after CPB. Adequate images of the right ventricle were defined as a modified midesophageal 4-chamber view that included the entire tricuspid valve annulus both in systole and diastole (Fig 1). Patients were excluded if there was a planned BIVAD or if the patient came to the operating room with an LVAD, RVAD, or extracorporeal membrane oxygenator already in place. Due to the possible effect on the measurement of TAPSE, S', and RV strain, patients also were excluded if they either had a history of tricuspid valve repair or if concomitant tricuspid valve repair was performed during their LVAD implantation.

Image Acquisition

Images were acquired intraoperatively using either a Phillips IE33 or Epiq system and an X7-2t (Philips, Andover, MA) TEE probe. Images were stored electronically using a Syngo PACs system (Siemens Medical Systems, Malvern, PA) and then uploaded into the EchoInsight right ventricle analysis software program.

Quantification of Right Ventricular Function

EchoInsight is a speckle-tracking RV analysis software designed for RV strain measurements. The software calculates both RV free wall strain (FWS) and RV GLS. RV FWS is the average strain of the basal, mid, and apical segments of the lateral wall of the right ventricle. RV GLS includes both the lateral wall of the right ventricle and the interventricular septum and is, therefore, the average strain of 6 segments. The software also uses speckle tracking to calculate other measures of RV function such TAPSE, S', and FAC. These

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