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CLINICAL RESEARCH

Serial Echocardiography Using Tissue Doppler and Speckle Tracking Imaging to Monitor Right Ventricular Failure Before and After Left Ventricular Assist Device Surgery

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Objectives This study aimed to investigate the utility of serial tissue Doppler imaging (TDI) and speckle tracking echocardiography (STE) for monitoring right ventricular failure (RVF) after left ventricular assist device (LVAD) surgery.

Background RVF post-LVAD is a devastating adverse event.

Methods The authors prospectively studied 68 patients undergoing elective LVAD surgery. Echocardiograms were performed within 72 h before and 72 h after surgery. RVF was pre-specified as: 1) the need for salvage right ventricular assist device (RVAD); or 2) persistent need for inotrope and/or pulmonary vasodilator therapy 14 days after surgery. Patients were classified as Group RVF or Group Non-RVF.

Results A total of 24 patients (35.3%) met criteria for RVF. Preoperative TDI-derived S' was lower and RV E/E' ratio was higher (3.7 ± 0.6 cm/s vs. 4.7 ± 0.9 cm/s, 12.0 ± 2.3 vs. 10.0 ± 2.5, both $p < 0.001$, respectively), and the absolute value of RV longitudinal strain (RV-strain) obtained from STE was lower (−12.6 ± 3.3% vs. −16.2 ± 4.3%, $p < 0.001$) in Group RVF vs. Group Non-RVF. Echo parameters within 72 h after surgery showed higher RV-E/E', (13.9 ± 4.6 vs. 10.1 ± 3.0, $p < 0.001$) and lower RV-strain (−11.8 ± 3.5% vs. −16.7 ± 4.4%, $p < 0.001$) in Group RVF vs. Group Non-RVF. Preoperative S'<4.4 cm/s, RV-E/E'>10 and RV-strain < −14% discriminated patients who developed RVF at day 14 with a predictive accuracy of 76.5%. When we included postoperative RV-E/E' and RV-strain, the predictive accuracy increased to 80.9%, with a sensitivity of 66.7% and a specificity of 88.7%.

Conclusions Serial echocardiograms using TDI and STE before and soon after LVAD surgery may aid in identifying need to initiate targeted RVF specific therapy in this population. (J Am Coll Cardiol HF 2013;1:216–22) © 2013 by the American College of Cardiology Foundation

Despite significant advances in device technology and perioperative care, right ventricular failure (RVF) remains a major cause of morbidity and mortality following left ventricular assist device (LVAD) surgery (1–3). Under LVAD support, right ventricular (RV) preload increases as a result of increased circulatory volume, whereas RV afterload is expected to decrease secondary to improvement in pulmonary vascular resistance (4). Septal wall shift induced by LVAD alters RV structure, which may worsen RV contractile and relaxation abnormalities (5). Therefore, consideration of RV systolic and diastolic reserve before and also after surgery is important to identify which patients may need RV-specific mechanical and medical support post-LVAD.

Previously described RVF risk assessment strategies contain several limitations with regard to their general applicability. Most of these studies either included a combination of pulsatile and nonpulsatile devices, or did not exclude patients in cardiogenic shock undergoing planned biventricular support surgery (2,3,6–8). RVF risk assessment using

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conventional echocardiography has also been reported, which suggest that tricuspid annular motion and right-to-left ventricular diameter ratios may predict RVF (9,10). Left-sided conventional echo parameters reflecting restrictive physiology have also been associated with RVF post-LVAD (11). Recently, Grant et al. (12) used 2-dimensional (2D) speckle tracking echocardiography (STE) and reported that reduced RV free wall peak longitudinal strain was associated with an increased risk for RVF in LVAD recipients. Tissue Doppler imaging (TDI) and STE allow quantitative assessment of both systolic and diastolic ventricular function (13–15). These parameters are relatively insensitive to changes in preload (15). In addition, angle-independency of STE (16) is a major advance toward improving accurate and reproducible measurements.

This is a preliminary study, which investigated the utility of serial TDI and STE assessment in continuous-flow LVAD recipients who were optimized for surgery and where biventricular support was not planned. The purpose of serial echocardiography was to identify specific parameters of systolic and diastolic RV function, which might identify patients who would require specific RV mechanical support and/or medical support therapy through postoperative day 14.

Methods

Study design. This was a prospective, observational study based on a total of 68 patients (89.7% male), undergoing LVAD-only implantation from August 2010 through February 2012 in a single institution. All enrolled patients underwent transthoracic echocardiography (TTE) with additional TDI and STE measurements, invasive hemodynamics and laboratory tests within 72 h prior to surgery. Patients then underwent TTE within 72 h after surgery. During the study period, our institution performed 128 mechanical support surgeries; however, patients who were in profound RVF where right ventricular assist device (RVAD) implantation was planned (n = 41, 32.0%), those with poor RV echo images (n = 10, 7.8%) and those in whom consent could not be obtained (n = 9, 7.0%) were excluded from the study. This resulted in our enrollment rate of 53.1% of all VAD recipients. Patients supported with an intra-aortic balloon pump (IABP) prior to LVAD surgery were not excluded, as our practice has been to use IABP to optimize hemodynamics in certain patients with the key goal of avoiding RVAD implantation.

In the present study, RVF after LVAD was defined as 1) need for RVAD; 2) inotropic support at 14 days after surgery; or 3) inhaled or oral pulmonary vasodilators (iloprost, inhaled nitric oxide, or sildenafil) at 14 days after surgery. According to our definition, patients were classified into Group RVF vs. Group Non-RVF. Patients who initially were weaned from inotrope/pulmonary vasodilator drugs in the early postoperative period, but required readministration of these therapies through day 14 were considered as Group RVF. The study was approved by the Institutional Review Board of Columbia University.

Abbreviations and Acronyms

LV = left ventricular/ventricle
LVAD = left ventricular assist device
RV = right ventricular/ventricle
RVAD = right ventricular assist device
RVF = right ventricular failure
STE = speckle tracking echocardiography
TDI = tissue Doppler imaging
TTE = transthoracic echocardiography

Echocardiograms. Standard echocardiography and TDI/STE were performed with the Vivid I digital ultrasound system (GE Medical Systems, Horten, Norway). All measurements obtained were in accordance with recommendations of the American Society of Echocardiography (17,18). LV ejection fraction was calculated by the modified Simpson's method. Tricuspid annular plane systolic excursion (TAPSE) was measured, and RV fractional area change (FAC) was obtained by tracing the RV endocardium in systole and diastole. Peak early (E) trans-tricuspid filling velocities, peak systolic (S') and early diastolic velocity (E') of the RV free wall at the tricuspid annulus were obtained using TDI. The RV-E/E' ratio was calculated and used as an index of ventricular filling pressures (19,20). Upon completion of the standard echocardiographic measurements, global RV longitudinal strain, derived from 2D-STE, was measured by off-line analysis using ECHOPAC (GE Medical Systems, Horten, Norway). All echo parameters were averaged for three consecutive beats. Two examiners who were blinded to the clinical status of the patient interpreted the echocardiograms. Reproducibility was analyzed in 10 randomly selected patients. Intraobserver reproducibility was assessed with a single reader (T.S.K.) on two separate occasions. Interobserver reproducibility was assessed with two independent readers (S.K. and T.S.K.).

Hemodynamic and laboratory assessments. Hemodynamic measurements before and after LVAD surgery were obtained, as part of routine peri-operative care. Trans-pulmonary gradient was calculated as: TPG (mm Hg) = [mean pulmonary artery pressure (mean PA) − pulmonary capillary wedge pressure (PCWP)]. Pulmonary vascular resistance (PVR) was calculated as: PVR (Wood units) = TPG/ cardiac output. RV stroke work index (RVSWI) was calculated as: RVSWI (g/m^2/beat) = [mean PA − mean right atrial pressure (RA)]·stroke volume index·0.0136.

Laboratory values before and after LVAD were obtained from all patients. The Model for End-Stage Liver Disease-eXcluding international normalized ratio (INR) (MELD-XI) was calculated as a measure of liver dysfunction (21) as MELD-XI = 5.11 × Ln (Bili) + 11.76 × Ln (Cr) + 9.44 (22). Any variable with a value less than 1 was assigned a value of 1 to avoid negative scores.

Statistical analysis. Data are presented as mean ± SD. Normality was evaluated for each variable from normal distribution plots and histograms. Variables were compared between the groups with Student's unpaired two-tailed t-test.

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Table 1 Clinical Characteristics

Characteristic	Group RVF (n = 24)	Group Non-RVF (n = 44)	p Value
Age (yrs)	62.8 ± 10.6	62.5 ± 12.4	0.91
No. of males (% of total)	22 (91.7%)	39 (88.6%)	0.69
BSA (m^2)	1.86 ± 0.16	1.91 ± 0.21	0.26
Mean no. of prior sternotomies	1.26 ± 0.66	1.31 ± 0.91	0.81
Cause of heart failure: no. of pts. with ischemic cardiomyopathy (%)	8 (34.8%)	22 (50.0%)	0.23
Ethnicity distribution (% of total)			0.79
White	16 (66.7%)	32 (72.7%)	
African American	5 (20.8%)	5 (11.4%)	
Other	3 (12.5%)	7 (15.9%)	
No. of pts. undergoing treatment prior to LVAD (%)			
Inotrope	21 (85.5%)	35 (79.6%)	0.41
Vasopressors (norepinephrine/ vasopressin)	2 (8.3%)	6 (13.6%)	0.55
Pulmonary vasodilators (iloprost, iNO, sildenafil)	1 (4.2%)	1 (2.3%)	0.67
IABP	7 (29.2%)	13 (29.5%)	0.94
Aquapheresis	1 (4.2%)	0 (0.0%)	0.14

Values are mean ± SD or n (%).
BSA = body surface area; IABP = intra-aortic balloon pump; iNO = inhaled nitric oxide; LVAD = left ventricular assist device; pts = patients; RVF = right ventricular failure.

Categorical variables were compared using the chi-square test. Values before and after surgery for each group of patients were assessed with Student's paired *t* test. Univariate logistic analysis was performed to find RV-related echo parameters associated with RVF at day 14 after LVAD surgery. The cutoff value associated with RVF at day 14 was determined using a receiver operating characteristic (ROC) curve. Sensitivity, specificity and predictive accuracy were determined and expressed as percentages. All data were analyzed using the Statistical Analysis Systems software JMP 7.0 (SAS Institute Inc., Cary, North Carolina).

Results

Baseline characteristics. Clinical characteristics of patients at the time of LVAD surgery are summarized in Table 1. The 2 vasopressors used pre-operatively were norepinephrine and vasopressin. Among 68 patients, 24 (35.3%) were classified as Group RVF. The 24 patients in Group RVF consisted of 4 patients who required RVAD (5.9%), 10 patients who required inotropic support (14.7%), and 19 patients who required inhaled or oral pulmonary vasodilator support (27.9%) 14 days after LVAD surgery, including patients receiving concomitant use of RVAD, inotropes and pulmonary vasodilators. Percutaneous RVAD was not used in our cohort. Five patients classified as Group RVF were initially off inotrope or pulmonary vasodilators at 3 days post-LVAD, but required resumption of these therapies out of clinical concern for hemodynamically significant RVF. Preoperative optimization therapies were not different between the groups (Table 1).

Hemodynamic and laboratory examinations. Hemodynamic and laboratory variables before and after LVAD are summarized in Table 2. Within 72 h after surgery, 31 patients (45.6%) were still on inotrope and/or pulmonary vasodilators, 12 of whom were successfully weaned from these therapy by postoperative day 14. Prior to LVAD surgery, the PVR and

Table 2 Hemodynamic and Laboratory Variables Before and Soon After LVAD Surgery

	Within 72 h Before Surgery			Within 72 h After Surgery		
Variable	Group RVF (n = 24)	Group Non-RVF (n = 44)	p Value	Group RVF (n = 24)	Group Non-RVF (n = 44)	p Value
Hemodynamic variables						
Mean RA (mm Hg)	10.1 ± 6.4	9.5 ± 4.7	0.646	11.9 ± 3.8 (n = 22)	10.8 ± 2.8 (n = 38)	0.237
Mean PA (mm Hg)	35.4 ± 10.7	32.5 ± 8.9	0.080	29.0 ± 6.9 (n = 22)†	25.5 ± 6.9 (n = 34)†	0.060
PCWP (mm Hg)	22.0 ± 7.8	22.1 ± 7.9	0.960	NA	NA	—
RA/PCWP	0.43 ± 0.2	0.43 ± 0.2	0.714	NA	NA	—
TPG (mm Hg)	**13.4 ± 6.5**	**10.4 ± 4.6**	**0.030**	NA	NA	—
CI (l/min/m^2)	1.7 ± 0.4	1.7 ± 0.5	0.874	3.4 ± 1.5 (n = 23)*	3.9 ± 1.6 (n = 35)*	0.298
PVR (wood)	**4.4 ± 2.8**	**2.8 ± 1.9**	**0.009**	NA	NA	—
RVSWI (g m^2/beat)	7.3 ± 4.0	7.3 ± 3.2	0.990	8.5 ± 6.5 (n = 22)†	8.2 ± 4.8 (n = 31)	0.830
Laboratory variables						
Hct (%)	31.6 ± 7.5	34.2 ± 6.9	0.671	34.1 ± 7.0	35.2 ± 8.9	0.571
Plat (×103 /μl)	200 ± 58	211 ± 57	0.622	200 ± 58	211 ± 57	0.622
Na (mEq/l)	134.5 ± 9.2	135.3 ± 8.6	0.849	136.3 ± 5.2	137.3 ± 4.5	0.755
Crea (mg/dl)	1.7 ± 0.5	1.4 ± 0.4	0.058	1.7 ± 0.4	1.4 ± 0.4	0.020
Alb (mg/dl)	3.8 ± 0.5	3.7 ± 0.5	0.442	3.9 ± 0.4	3.9 ± 0.4†	0.884
T-Bil (mg/dl)	1.5 ± 0.8	1.5 ± 1.2	0.835	1.5 ± 1.3	1.3 ± 1.3	0.913
MELD-XI	**16.5 ± 3.2**	**14.5 ± 4.0**	**0.040**	**17.1 ± 4.0**	**14.9 ± 4.1**	**0.024**

Values are mean ± SD. Values in **bold** are significantly different between the groups by Student unpaired *t* test. *p < 0.001. †p < 0.05 versus. the preoperative value, derived by Student paired *t* test.
Alb = albumin; CI = cardiac index; Crea = creatinine; Hct = hematocrit; MELD-XI = Model for End-Stage Liver Disease-eXcluding international normalized ratio; Na = sodium; NA = not accessed; PA = pulmonary artery; PCWP = pulmonary capillary wedge pressure; Plat = platelet count; PVR = Pulmonary vascular resistance; RA = right atrial (pressure); RVF = right ventricular failure; RVSWI = RV stroke work index; T-Bil = total bilirubin; TPG = transpulmonary gradient.

TPG were higher in Group RVF versus. Group Non-RVF. Preoperative MELD-XI was higher in Group RVF than Group Non-RVF, driven by differences in creatinine.

None of the hemodynamic variables obtained within 72 h after surgery were different between the groups. Cardiac index increased and mean PA pressure decreased in both groups after surgery. The increase in RVSWI after LVAD implantation was significant only in Group RVF. Because postoperative pulmonary capillary wedge pressures were missing for many patients, post-operative PVR and TPG differences could not be determined.

Comparison of postoperative laboratory variables between the groups revealed that serum creatinine concentration and MELD-XI were higher in Group RVF than Group Non-RVF.

Echocardiographic data. Echocardiographic parameters of patients between the groups are compared in Table 3. Twelve and 7 patients had atrial fibrillation before and after LVAD surgery, respectively; but all of them had analyzable echo images. Prior to LVAD surgery, left atrial diameter (LAD) was larger and TAPSE was lower in Group RVF than Group Non-RVF. Both S' and E' at RV free wall were lower, RV-E/E' was higher, and the absolute value of global RV longitudinal strain was lower in Group RVF than Group Non-RVF prior to surgery. Representative RV strain and TDI images obtained from both groups of patients are shown in Figure 1.

Post-operative echoes obtained within 72 h after surgery revealed that TAPSE, RV E/E' and the absolute value of global RV longitudinal strain remained lower in Group RVF than Group Non-RVF.

The LVEF, %LVFS and RV FAC decreased and the RV-E/E' increased only in Group RVF after surgery compared to the preoperative values (Online Fig. 1).

Intraobserver and interobserver reproducibility for TDI and STE parameters was sufficient, with the interclass correlation coefficient (ICC) being 0.88 and 0.90 (intra-), 0.90 and 0.89 (inter-) for RV E/E' and RV strain, respectively.

RV echo parameters associated with persistent RVF at 14 days post-LVAD. Univariate analysis for RV echo parameters revealed that lower TAPSE, lower S' and E', higher RV-E/E', and lower absolute value of RV global strain obtained before surgery were associated with RVF at day 14. Among the variables obtained within 72 h after surgery, lower RV FAC, lower TAPSE and E', higher RV-E/E' and lower absolute value of RV global strain was associated with RVF at day 14 (Table 4). Study size limited our ability to perform a valid multivariable analysis.

RV-echo parameters to risk-stratify patients with RVF at day 14 post-LVAD. ROC curve analysis identified the optimal cutoff values for RV echo-parameters associated with RVF 14 days post-LVAD (Online Table 1). Using the ROC-derived cutoff values as a reference, clinically relevant values for each variable were used to calculate the number of echo-derived risk factors for RVF. Pre-operative S'<4.4 cm/s, RV-E/E' >10 and absolute RV longitudinal strain <|14|% were used for our RVF prediction model (Online Fig. 2A). ROC curve analysis revealed that if patients met criteria for two preoperative echo risk parameters, RVF post-LVAD could be predicted with a sensitivity of 87.5%, specificity of

Table 3 Echocardiograms 72 h Before and 72 h After LVAD Surgery

	Within 72 h Before Surgery			Within 72 h After Surgery		
Parameter	Group RVF (n = 24)	Group Non-RVF (n = 44)	p Value	Group RVF (n = 24)	Group Non-RVF (n = 44)	p Value
LV parameter based on conventional echo						
LVEDD (mm)	69.1 ± 11.0	69.6 ± 12.8	0.865	61.4 ± 10.6†	59.3 ± 9.6*	0.404
LVESD (mm)	62.3 ± 12.4	64.4 ± 13.4	0.520	56.9 ± 10.8†	54.2 ± 9.2*	0.289
LVEF (%)	20.7 ± 8.7	17.2 ± 9.7	0.140	15.3 ± 8.2†	16.9 ± 8.0	0.422
% LVFS	10.8 ± 5.1	8.5 ± 5.5	0.094	8.6 ± 5.2†	8.5 ± 5.0	0.969
LAD (mm)	**51.7 ± 6.0**	**47.3 ± 6.9**	**0.031**	45.4 ± 6.2†	42.7 ± 6.1*	0.090
LAD/LVEDD	0.76 ± 0.13	0.71 ± 0.12	0.078	0.75 ± 0.09	0.73 ± 0.11	0.415
RV parameter based on conventional echo						
RVEDD (mm)	41.5 ± 3.0	40.7 ± 4.3	0.451	40.0 ± 4.4†	38.6 ± 4.4†	0.228
TAD (mm)	37.6 ± 3.0	37.2 ± 2.9	0.581	36.5 ± 3.4	36.3 ± 3.5	0.560
RV FAC (%)	24.8 ± 8.7	28.9 ± 8.1	0.062	**17.8 ± 7.0**†	**24.5 ± 9.7**	**0.004**
TAPSE (cm)	**1.5 ± 0.5**	**1.8 ± 0.5**	**0.030**	**1.5 ± 0.6**	**1.8 ± 0.5**	**0.012**
TTF E velocity (cm/s)	44.1 ± 8.1	45.4 ± 11.0	0.621	51.9 ± 18.1	44.0 ± 13.6	0.051
TDI or STE derived RV echo parameters						
S' (cm/s)	**3.7 ± 0.6**	**4.7 ± 0.9**	**<0.001**	4.1 ± 1.0	4.3 ± 0.8	0.271
E' (cm/s)	**−3.7 ± 0.5**	**−4.4 ± 0.8**	**<0.001**	**−3.9 ± 1.0**	**−4.4 ± 0.8**	**0.020**
RV E/E'	**12.0 ± 2.3**	**10.0 ± 2.5**	**0.003**	**13.9 ± 4.6**†	**10.1 ± 3.0**	**<0.001**
Global strain (%)	**−12.6 ± 3.3**	**−16.2 ± 4.3**	**<0.001**	**−12.5 ± 3.6**	**−16.7 ± 4.4**	**<0.001**

Values are mean ± SD. Values in **bold** are significantly different between the groups by Student unpaired *t* test. *p < 0.001 †p < 0.05 versus the preoperative value derived by Student paired *t* test.
E = trans-tricuspid filling velocity; E' = early diastolic velocity; E/E' = trans-tricuspid filling velocity/early diastolic velocity ratio; FAC = fractional area change; Global strain = global RV longitudinal strain; LAD = left anterior descending; LVEDD = left ventricular end-diastolic diameter; LVEF = left ventricular ejection fraction; LVESD = left ventricular end-systolic diameter; LVFS = left ventricular fractional shortening; RV = right ventricular; RVEDD = right ventricular end-diastolic diameter; RV FAC = right ventricular fractional area change; STE = speckle tracking echocardiography; TAD = transverse abdominal diameter; TAPSE = tricuspid annular plane systolic excursion; TDI = tissue Doplpler imaging; TTF = time-to-treament failure.

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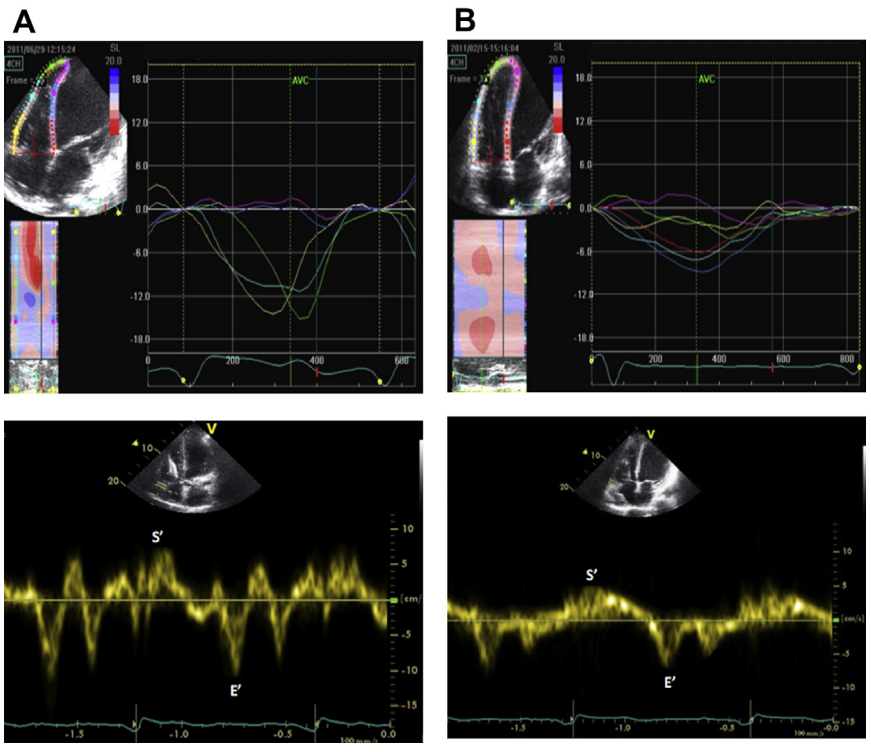

Figure 1 **Representative Global RV Longitudinal Strain and TDI Obtained Before Surgery From a Patient Without RVF After LVAD and From a Patient With RVF After LVAD**

(A) The right ventricular (RV) global longitudinal strain, tissue Doppler images (TDI)-derived S' and E' for patient A was –14.3%, 7.8 cm/s and –10.8 cm/s, respectively. **(B)** These parameters were –6.2%, 4.6 cm/s and –5.3 cm/s, respectively. LVAD = left ventricular assist device; RVF = right ventricular failure.

70.4%, and a predictive accuracy of 76.5% (Online Fig. 2B). When we included both pre- and post-operative echo parameters, predictive accuracy increased to 80.9% (Online Figs. 2C and 2D). In this analysis, prediction means that based on preoperative and early postoperative echo data, we could anticipate the clinical state of the patient at day 14, a time-point where discharge from the hospital would have been the target goal.

Discussion

RVF in the context of patient selection for LVAD surgery has been studied for more than a decade (2,3,6–11). RVF after LVAD occurs in approximately 30% of patients, with a range of 10 to 50% depending on the definition (2,3,6–11). The definition of RVF has been standardized by the Interagency Registry for Mechanically Assisted Circulatory Support (INTERMACS) as symptoms and signs of persistent RVF requiring RVAD implantation; or requiring inhaled nitric oxide (iNO) or inotropic therapy for more than 1 week at any time after LVAD implantation. More recently, Kormos et al. (23) evaluated RVF predictors in nonpulsatile devices and did not include the iNO in their definition of RVF. In a recent randomized clinical trial, use of iNO at 40 ppm perioperatively did not decrease the incidence of RVF after LVAD (24). In our study, we pre-specified that extended use of inhaled or oral pulmonary vasodilators at 14 days after surgery is considered RVF. We included this specification because extended post-operative pulmonary vasodilator therapy may improve the clinical condition of the patient by decreasing RV afterload, thus facilitating RV contractility. While oral pulmonary vasodilator therapy is reasonably low risk, it is currently uncertain which patients might benefit. Information regarding RV function, based on TDI and STE measurements, associated with the clinical impression of RVF, may allow a more rational clinical decision making process with regard to specific RV supportive therapeutic regimens.

Echocardiography is an ideal modality to monitor patients peri-operatively. It is noninvasive, can be performed at the patient's bedside, and the advanced imaging techniques of TDI and STE are easily to obtain and highly reproducible. The angle-independency of STE may overcome the difficulties of positioning patients in an appropriate posture for Doppler angles. In addition, 2D-STE and TDI parameters reflect both systolic and diastolic ventricular function (11–13). The author previously reported that LV strain correlates well with LV relaxation abnormalities and ventricular stiffness (15). Both LV myocardial relaxation abnormalities and

Table 4 RV Echocardiographic Parameters Associated With RVF at 14 Days After LVAD Surgery

	Univariate Analysis	
Parameter	**OR (95% CI)**	**p Value**
Pre-operative echo (within 72 h before surgery)		
RVEDD (mm)	1.053 (0.925–1.215)	0.436
RV FAC (%)	0.942 (0.880–1.000)	0.532
TAPSE (cm)	**0.317 (0.103–0.874)**	**0.026**
E velocity (cm/s)	0.987 (0.937–1.038)	0.614
S' (cm/s)	**0.220 (0.090–0.456)**	**<0.001**
E' (cm/s)	**0.113 (0.031–0.313)**	**<0.001**
RV E/E'	**1.340 (1.120–1.809)**	**0.002**
Global strain (%)	**1.257 (1.097–1.475)**	**<0.001**
Post-operative echo (within 72 h after surgery)		
RVEDD (mm)	1.075 (0.959–1.218)	0.217
RV FAC (%)	**0.905 (0.834–0.968)**	**0.002**
TAPSE (cm)	**0.299 (0.106–0.771)**	**0.012**
E velocity (cm/s)	1.034 (1.000–1.074)	0.050
S' (cm/s)	0.723 (0.394–1.286)	0.272
E' (cm/s)	**0.461 (0.231–0.858)**	**0.014**
RV E/E'	**1.317 (1.131–1.593)**	**<0.001**
Global strain (%)	**1.335 (1.162–1.584)**	**<0.001**

Values in **bold** are significant.
CI = confidence interval; OR = odds ratio. Other abbreviations as in Table 3.

stiffness are key factors of LV functional reserve (15). We speculate that RV myocardial relaxation abnormalities and stiffness reflected by abnormal RV strain and TDI parameters would also reflect RV functional reserve. The challenge is to incorporate advanced imaging into routine clinical echo assessments, to gain experience with serial use of these parameters, to correlate these findings with clinical impression and hemodynamic scenarios.

Although this is a preliminary study with a small cohort of patients, we have shown that: 1) despite enrolling only patients who were not anticipated to require biventricular support, 33% of patients developed RVF requiring specific RV supportive therapies; 2) TDI and STE-derived RV systolic and the diastolic parameters before surgery were associated with post-LVAD RVF; and 3) serial post-operative echo assessment further increased the predictive accuracy of the clinical status of the patient at day 14 where discharge from hospital was the goal.

Grant et al. has reported that RV strain is a useful preoperative predictor of RVF in patients undergoing LVAD (12), showing its superiority over conventional echocardiographic parameters (10,11), although their endpoint of RVF did not include need for ongoing pulmonary vasodilators. They suggested an incremental role of RV strain analysis to previously described RVF risk stratification models (7,8), resulting in the increase of AUC to 0.70 to 0.77; however, these earlier models were created in the era where many patients received pulsatile-flow devices and included patients who were anticipated to require RVAD support.

Study limitations. This is a preliminary study of a small cohort of patients; therefore, the echo parameters we presented require external validation to further assess the accuracy of our findings. The results we present here may be used in conjunction with previously described RVF risk models (6–8) to further stratify patients at risk for RVF under LVAD support. Importantly, the value of RV strain can be different depending on different software (25). The software we used in the present study calculates strain at the endocardial borders (26), therefore we include RV-sided septal wall for global RV longitudinal strain analysis, whereas Grant et al. excluded the septal wall, which may have impacted on the difference in RV strain values between the studies.

Conclusions

RV stiffness as reflected by TDI-derived E/E', and decreased RV contractility as reflected by TDI-derived S' and RV longitudinal strain, before and soon after LVAD surgery, may be useful parameters to include in the peri-operative management of LVAD patients.

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Key Words: echocardiogram ■ heart failure ■ left ventricular assist device ■ prediction ■ right ventricular failure.

APPENDIX

For a supplemental table and figures please see the online version of this article.