Original Article / Özgün Makale

Prognostic value of TAPSE/PASP ratio in right ventricular failure after left ventricular assist device implantation: Experience from a tertiary center

Sol ventrikül destek cihaz implantasyonu sonrasında sağ kalp yetmezliğinde TAPSE/PASP oranının prognostik değeri

Sena Sert[1] , **Nehir Selçuk[2]** , **Özlem Yıldırımtürk[1]** , **Gökçen Orhan[2]**

[1]Department of Cardiology, Dr. Siyami Ersek Thoracic and Cardiovascular Surgery Training and Research Hospital, Istanbul, Türkiye
[2]Department of Cardiovascular Surgery, Dr. Siyami Ersek Thoracic and Cardiovascular Surgery Training and Research Hospital, Istanbul, Türkiye

ABSTRACT

Background: In this study, we aimed to investigate the prognostic value of the tricuspid annular plane systolic excursion (TAPSE)/pulmonary arterial systolic pressure (PASP) ratio in right ventricular failure patients undergoing left ventricular assist device implantation.

Methods: Between February 2013 and February 2020, a total of 75 heart failure patients (65 males, 10 females; median age: 54 years; range, 21 to 66 years) were retrospectively analyzed. The prognostic value of TAPSE/PASP ratio was assessed using the multivariate Cox regression models and confirmed using the Kaplan-Meier analyses.

Results: Forty-one (55.4%) patients had an ischemic heart failure etiology. The indication for assist device implantation was bridge to transplant in 64 (85.3%) patients. The overall survival rates at one, three, and five years following left ventricular assist device implantation were 82.7%, 68%, and 49.3%, respectively. Right ventricular failure was observed in 24 (32%) patients during follow-up. In the multivariate analysis, TAPSE/PASP was found to be independently associated with postoperative right ventricular failure (HR: 1.63; 95% CI: 1.49-2.23). A TAPSE/PASP of 0.34 mm/mmHg was found to be the most accurate predictor value, with lower ratios correlating with right ventricular failure. The Kaplan-Meier analysis showed a better overall survival using a TAPSE/PASP ≥ of 0.34 mm/mmHg (p<0.001).

Conclusion: A lower TAPSE/PASP ratio, particularly lower values than 0.34 mm/mmHg, strongly predicts right ventricular failure after left ventricular assist device implantation in patients with advanced heart failure.

Keywords: Left ventricle assist device, pulmonary artery systolic pressure, right heart failure, tricuspid annular plane systolic excursion.

ÖZ

Amaç: Bu çalışmada sol ventrikül destek cihazı takılan sağ kalp yetmezlikli hastalarda triküspit annular plan sistolik ekskürsiyon (TAPSE)/pulmoner arter sistolik basıncı (PASP) oranının prognostik değeri araştırıldı.

Çalışma planı: Şubat 2013 - Şubat 2020 tarihleri arasında kalp yetmezliği olan toplam 75 hasta (65 erkek, 10 kadın; medyan yaş: 54 yıl; dağılım, 21-66 yıl) retrospektif olarak incelendi. Çok değişkenli Cox regresyon modelleri ile TAPSE/PASP oranının prognostik değeri araştırıldı ve Kaplan-Meier analizleri ile doğrulandı.

Bulgular: Kırk bir (%55.4) hastada etyoloji iskemik kalp yetmezliği idi. Altmış dört (%85.3) hastada destek cihazının takılma endikasyonu nakile köprüleşme idi. Sol ventrikül destek cihazı takıldıktan sonra bir, üç ve beşinci yılda genel sağkalım oranları sırasıyla %82.7, %68 ve %49.3 idi. Takip sırasında 24 (%32) hastada sağ kalp yetmezliği gözlendi. Çok değişkenli analizde TAPSE/PASP oranı ameliyat sonrası sağ kalp yetmezliği ile bağımsız olarak ilişkili bulundu (HR: 1.63; %95 GA: 1.49-2.23). 0.34 mm/mmHg'lik TAPSE/PASP oranı en doğru öngördürücü değer olup, daha düşük oranlar sağ kalp yetmezliği ile ilişkili idi. Kaplan-Meier analizinde TAPSE/PASP ≥0.34 mm/mmHg ile daha iyi sağkalım olduğu gösterildi (p<0.001).

Sonuç: Özellikle <0.34 mm/mmHg olmak üzere, düşük TAPSE/PASP oranı, ileri evre kalp yetmezliği olan hastalarda sol ventriküler destek cihaz implantasyonundan sonra sağ kalp yetmezliğinin güçlü bir öngördürücüsüdür.

Anahtar sözcükler: Sol ventrikül destek cihazı, pulmoner arter sistolik basıncı, sağ kalp yetmezliği, triküspit annular plan sistolik ekskürsiyon.

Although heart transplantation is the gold-standard treatment for end-stage heart failure (HF) patients, in the absence of sufficient donor supply, continuous-flow left ventricular assist devices (LVADs) have a pivotal role as a bridge to transplantation or as destination therapy.[1-4] These devices provide isolated left ventricle (LV) support that could be adequate for a reasonable number of patients. However, right ventricular failure (RVF) due to both leftward shift of the interventricular septum, which results in a more spherical shape of the right ventricle and reduced contractile properties, and hemodynamic changes owing to changing flow generated by the device can cause an increased risk of mortality and morbidity after LVAD implantation.[5,6] Unfortunately, the dominant cause of hemodynamic vulnerability in patients with LVAD is RVF, and it is necessary to understand and identify the predictors of RVF.

In the present study, we, therefore, evaluated the prognostic value of the ratio of echocardiography-derived tricuspid annular plane systolic excursion (TAPSE) and pulmonary arterial systolic pressure (PASP) in patients with LVAD. The aim of this study was to investigate the preoperative TAPSE/PASP ratio as a postoperative RVF predictor in LVAD patients.

PATIENTS AND METHODS

This single-center, retrospective study was conducted at, Dr. Siyami Ersek Thoracic and Cardiovascular Surgery Training and Research Hospital, Department of Cardiology and Cardiovascular Surgery between February 2013 and February 2020. A total of 75 HF patients (65 males, 10 females; median age: 54 years; range, 21 to 66 years) with reduced ejection fraction (EF) who were referred for LVAD implantation were included. All patients had right heart catheterization (RHC) before LVAD implantation and were followed until December 2020. Patients' preoperative background characteristics including age, sex, body mass index, Interagency Registry for Mechanically Assisted Circulatory Support (INTERMACS) class, etiology for HF, indication for LVADs and device type, patients' echocardiographic parameters (right ventricular diameter [RVD] and TAPSE, left ventricular end-diastolic and systolic diameters, left ventricular EF, estimated PASP, right ventricular systolic Doppler velocity [RVS], right ventricle basal diameter), and RHC data (right atrial pressure [RAP], mean pulmonary arterial pressure [MPAP], pulmonary capillary wedge pressure [PCWP], cardiac index [CI], cardiac output [CO], transpulmonary gradient [TPG], pulmonary artery pulsatility index [PAPI], and right ventricular stroke work index

[RVSWI]) were recorded. Hemodynamic parameters were calculated as follows: (TPG, mmHg)= (mPAP, mmHg) - (PCWP, mmHg); pulmonary vascular resistance (PVR, Wood Units)=(mPAP-PCWP)/(CO, L/min); (PAPI)=(systolic PAP [sPAP, mmHg]-diastolic PAP [dPAP, mmHg])/RAP; (RVSWI, g/m^2/beat)=(mPAP-RAP)×stroke volume (SV) index (mL/m^2) * 0.0136.

Follow-up was ceased at death, heart transplantation, or pump exchange. The primary outcome measure was post-LVAD RVF. The definition of RVF was the failure to wean pulmonary vasodilators or intravenous inotropes within 14 days and right ventricular assist device placement after LVAD.

Statistical analysis

Statistical analysis was performed using the IBM SPSS version 22.0 software (IBM Corp., Armonk, NY, USA). The variables were investigated using visual (histograms, probability plots) and analytical methods (Kolmogorov-Smirnov/Shapiro-Wilk test) to determine whether they were normally distributed. Descriptive data were presented in mean ± standard deviation (SD) for normally distributed variables and median and interquartile range (IQR) for non-normally distributed variables. Categorical variables were compared using the chi-square (χ^2) test and presented in number and frequency. The Wilcoxon test was used to compare categorical data and data that failed to meet the normality assumption (Shapiro-Wilk test) or the equal variance tests. Univariate logistic regression analyses were used to identify predictors of outcome. The prognostic relevance of TAPSE/PASP was assessed with multivariate Cox regression models and confirmed using Kaplan-Meier analyses. The time-independent association between the TAPSE/PASP variable and the outcome was assessed using receiver operating characteristic (ROC) curve analysis. When a significant cut-off value was observed, the sensitivity, specificity, positive, and negative predictive values were calculated. A *p* value of <0.05 was considered statistically significant.

RESULTS

Patients' demographics and echocardiographic parameters before LVAD implantation are shown in Table 1. Forty-one (55.4%) patients had an ischemic HF etiology. The indication for LVAD was bridge to transplant in 64 (85.3%) patients. The overall survival rates at one, three, and five years following LVAD implantation were 82.7%, 68%, and 49.3%,

Table 1. Demographic and clinical characteristics of patients prior to LVAD implantation (n=75)

	n	%	Mean±SD	Median	Min-Max
Demographic parameters					
Age (year)				54	21-66
Sex					
Male	65	86.7			
BMI (kg/m²)			27.3±4.4		
Ischemic etiology	41	54.7			
Bridge to transplant (indication)	64	85.3			
Device type					
Centrifugal type	25	33.3			
Axial type	50	66.7			
INTERMACS Class					
2	5.3	4			
3	21.3	16			
4	45.3	34			
5	28.1	21			
Comorbidities					
Diabetes	36	27			
Hypertension	45.3	35			
Chronic renal failure	17.3	13			
Median duration of follow-up (year)			3.95±1.7		
NT pro-BNP (pg/mL)				430	200-660
Echocardiographic parameters					
Left ventricular end-diastolic diameter (cm)			6.8±7.3		
Left ventricular end-systolic diameter (cm)			6.1±7.2		
Left ventricular ejection fraction (%)				20	18-20.2
Estimated systolic pulmonary artery pressure (mmHg)				49	42.6-51.3
Tricuspid annular plane systolic excursion (mm)			15±4.1		
Right ventricular systolic Doppler velocity (cm/sec)				10	9.3-10.6
Right ventricle basal diameter (cm)				4.0	3.0-5.1
TAPSE/PASP (mm/mmHg)				0.35	0.3-0.48
Hemodynamic parameters					
mPAP (mmHg)			37±10.6		
PVR, Wood Units				3.2	3-3.8
PAPI				2.4	2.3-3.2
PCWP (mmHg)				28	24.6-28.6
Cardiac output (L/min)			3.4±0.8		
Cardiac index (L/min/m²)			1.78±0.4		
RVSWI (g/m²/beat)			6.3±2.6		
RAP (mmHg)			13±4.6		
MAP (mmHg)			85.3±11.8		
TPG (mmHg)			10.4±4.8		

LVADs: Left ventricular assist devices; SD: Standard deviation; BMI: Body mass index; INTERMACS: Interagency Registry for Mechanically Assisted Circulatory Support; NT-Pro-BNP: N terminal Pro-Brain natriuretic peptide; TAPSE: Tricuspid annular plane systolic excursion; PASP: Systolic pulmonary artery pressure; mPAP: Mean pulmonary arterial pressure; PVR: Pulmonary vascular resistance; PAPI: Pulmonary artery pulsatility index; PCWP: Pulmonary capillary wedge pressure; RVSWI: Right ventricular stroke work index; RAP: Right atrial pressure; MAP: Mean arterial pressure; TPG: Transpulmonary gradient.

respectively. During follow-up, RVF was observed in 24 (32%) patients.

Multivariate Cox regression analyses for baseline clinical variables and indices of RV failure are presented in Table 2. Cox regression revealed a significant relationship between RVF and TAPSE/PASP, TAPSE, RVSWI, and age. In all multivariate models, TAPSE/PASP remained independently associated with a primary endpoint that was determined as post-LVAD RVF (hazard ratio [HR]: 1.63; 95% confidence interval [CI]: 1.49-2.23).

We evaluated TAPSE/PASP to determine a cut-off value as an independent prognostic factor of RVF post-LVAD by ROC analysis, a TAPSE/PASP of 0.34 mm/mmHg was found to be the most accurate

predictor value for with a lower ratio correlating with RVF (Figure 1). The ROC area was 0.937 (95% CI: 0.886-0.988, p<0.001). The sensitivity was calculated as 96.2%, while specificity was 75%. Positive and negative predictive values were reported in 67.6% and 97.3%, respectively.

Kaplan-Meier analyses showed better overall survival with TAPSE/PASP ≥0.34 mm/mmHg (p<0.001) (Figure 2). The patients were dichotomized into two groups using the value of 0.34 mm/mmHg of TAPSE/ PASP that was appointed in the ROC curve analysis. Patients with lower TAPSE/PASP ratios, N terminal Pro-Brain natriuretic peptide (NT Pro-BNP), left ventricular end-diastolic diameter (LVEDD), PASP, RVD, and PCWP were higher,

Table 2. Cox regression analyses for baseline clinical variables and indices of RV failure

	HR	95% CI	*p*
Age (year)	0.75	0.64-0.87	**0.020***
Sex			
Male	1.44	0.14-1.53	1.090
BMI (kg/m²)	1.01	0.84-1.22	0.860
Ischemic etiology	1.44	0.36-5.6	0.600
NT pro-BNP (pg/mL)	1.06	1.02-1.1	**0.002***
Left ventricular end-diastolic diameter (cm)	1.03	0.98-1.09	0.220
Left ventricular ejection fraction (%)	1.05	0.9-1.2	0.490
TAPSE/PASP (mm/mmHg)	1.63	1.49-2.23	**<0.001***
Tricuspid annular plane systolic excursion (mm)	0.77	0.67-0.89	**<0.001***
Right ventricular systolic Doppler velocity (cm/sec)	1.3	0.94-2.05	0.090
Right ventricle basal diameter (cm)	1.05	0.91-1.25	0.060
Hemodynamic parameters			
mPAP (mmHg)	0.99	0.9-1.09	0.880
PVR, Wood Units	1.8	0.9-1.91	0.060
PAPI	1.15	0.47-2.7	0.750
PCWP (mmHg)	0.98	0.88-1.08	0.700
Cardiac output (L/min)	0.78	0.13-4.4	0.710
Cardiac index (L/min/m²)	0.18	0.06-5.9	0.340
RVSWI (g·m/m²/beat)	0.8	0.74-0.89	**0.003**
RAP (mmHg)	1.18	0.98-1.41	0.070
MAP (mmHg)	1.03	0.97-1.1	0.230
TPG (mmHg)	1.01	0.84-1.22	0.090

RV: Right ventricular; HR: Hazard ratio; CI: Confidence interval; BMI: Body mass index: NT-Pro-BNP: N terminal Pro-Brain natriuretic peptide; TAPSE: Tricuspid annular plane systolic excursion; PASP: Systolic pulmonary artery pressure; mPAP: Mean pulmonary arterial pressure; PVR: Pulmonary vascular resistance; PAPI: Pulmonary artery pulsatility index; PCWP: Pulmonary capillary wedge pressure; RVSWI: Right ventricular stroke work index; RAP: Right atrial pressure; MAP: Mean arterial pressure; TPG: Transpulmonary gradient.
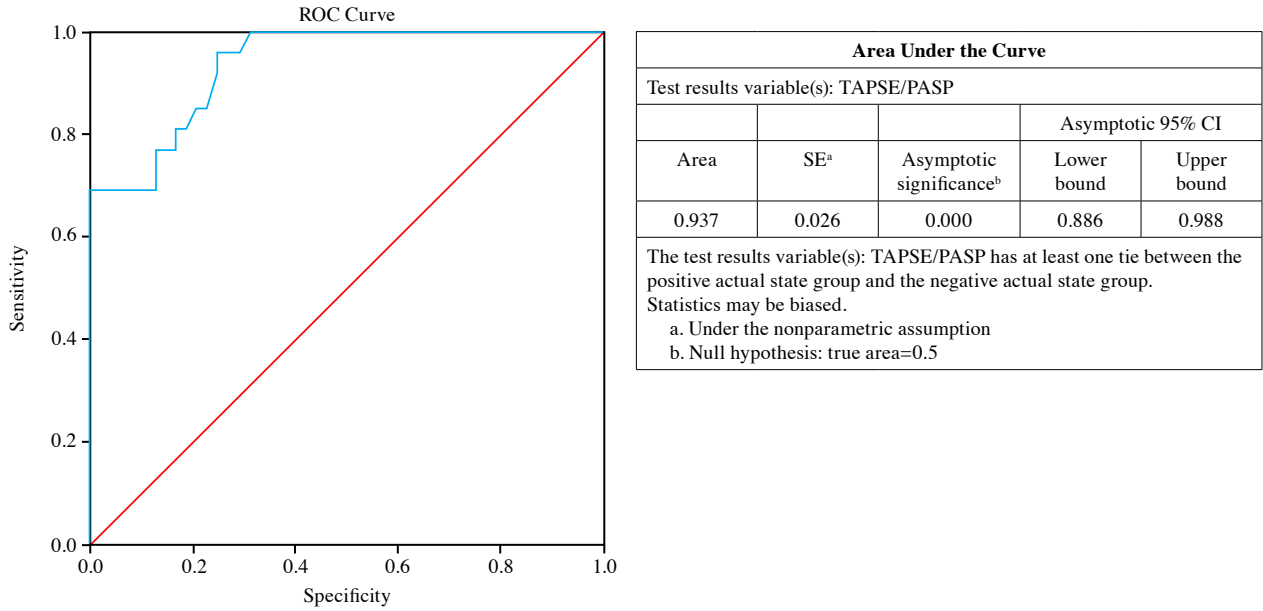
Figure 1. ROC curve of CI at T0 as a predictor of subsequent RVF diagnosis.

ROC: Receiver operator characteristic; TAPSE: Tricuspid annular plane systolic excursion; PASP: Systolic pulmonary artery pressure; CI: Confidence interval; RVF: Right ventricular failure.
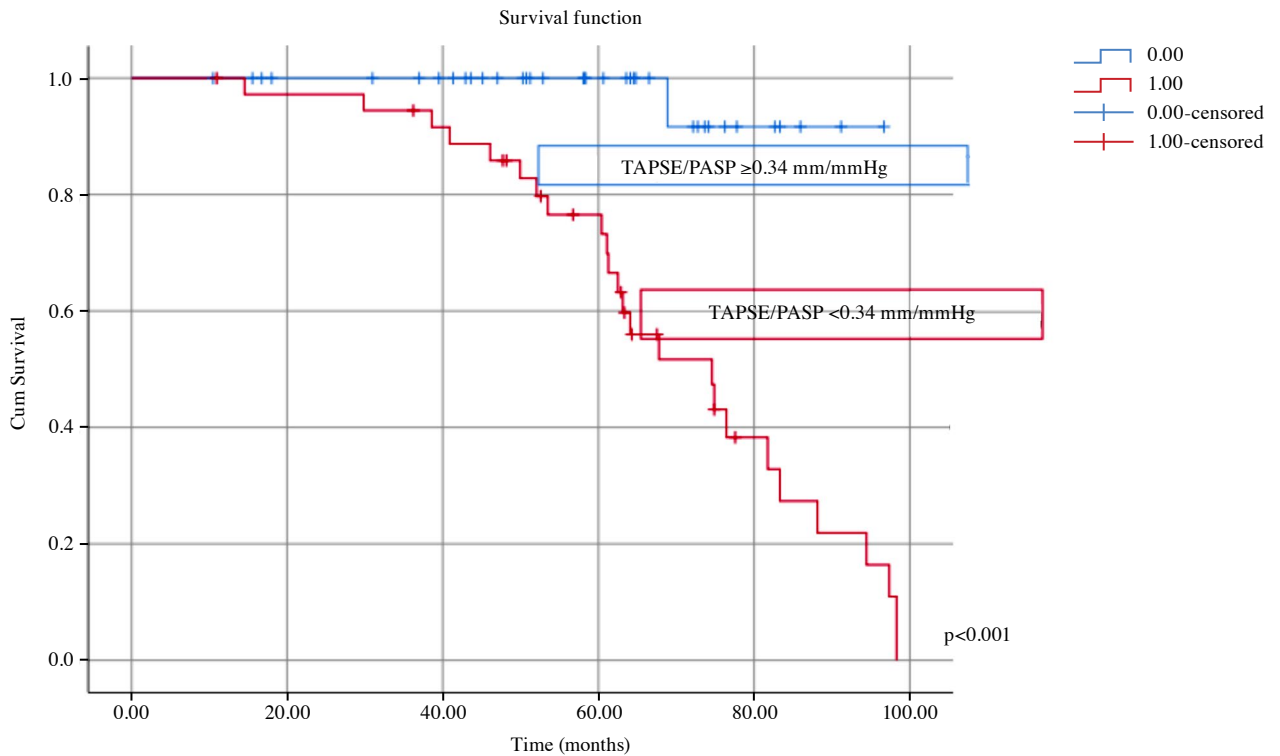
The table within the figure reads:

Area Under the Curve				
Test results variable(s): TAPSE/PASP				
			Asymptotic 95% CI	
Area	SE[a]	Asymptotic significance[b]	Lower bound	Upper bound
0.937	0.026	0.000	0.886	0.988

The test results variable(s): TAPSE/PASP has at least one tie between the positive actual state group and the negative actual state group. Statistics may be biased.
  a. Under the nonparametric assumption
  b. Null hypothesis: true area=0.5

Figure 2. Kaplan-Meier analyses for right ventricular failure when comparing TAPSE/PASP ≥ 0.34 mm/mmHg with TAPSE/PASP <0.34 mm/mmHg.

TAPSE: Tricuspid annular plane systolic excursion; PASP: Systolic pulmonary artery pressure;

Table 3. Comparison of demographic parameters and clinical characteristics of patients with high and low tricuspid annular plane systolic excursion/pulmonary arterial systolic pressure (TAPSE/PASP) ratios

	TAPSE/PASP ≥0.34 (n=45)					TAPSE/PASP <0.34 (n=30)					p
	n	%	Mean±SD	Median	Min-Max	n	%	Mean±SD	Median	Min-Max	
Age (year)				52	26-66				55	21-66	0.230
Sex											
Male	37	82.2				28	93.3				0.960
BMI (kg/m²)			27±4.8					27±4.1			0.770
INTERMACS groups											0.160
INTERMACS 2	1	2.2				3	10				
INTERMACS 3	5	11.1				11	36.7				
INTERMACS 4	23	51.1				11	36.7				
INTERMACS 5	16	35.6				5	16.6				
Ischemic etiology	21	46.7				20	66.6				0.810
NT pro-BNP (pg/mL)				220	200-240				540	500-590	**0.040***
Left ventricular end-diastolic diameter (cm)			66.8±6.5.3					72.5±11.1			**0.030***
Left ventricular ejection fraction (%)				20	18.9-21.8				19	17-19.9	0.080
Estimated systolic pulmonary artery pressure (mmHg)				34	30.8-39				60	56-64	**<0.001***
Tricuspid annular plane systolic excursion (mm)			19±3.7					15±3.4			**<0.001***
Right ventricular systolic Doppler velocity (cm/sec)				12	9.5-11.9				9	8.2-9.7	**0.030***
Right ventricle basal diameter (cm)				4.0	3.0-5.1				4.4	3.4-5.8	**0.030***
Hemodynamic parameters											
mPAP (mmHg)			33.2±8.6					41.8±11			**0.020***
PVR, Wood Units			3.2±1.3					3.6±1.8			0.370
PAPI				2.6	2.3-3.1				1.9	2.1-3.6	**0.030***
PCWP (mmHg)				25	21.7-27.2				30	26.5-31.8	**0.010***
Cardiac output (L/min)			3.4±0.9					3.3±0.6			0.710
Cardiac index (L/min/m²)			1.79±0.4					1.78±0.4			0.750
RVSWI (g/m²/beat)			7.2±2.9					5.6±2.9			**0.040***
RAP (mmHg)			11.2±4.6					12.8±4.4			0.240
MAP (mmHg)			86.2±11.8					84.4±11.9			0.380
TPG (mmHg)			9.4±3.8					11.7±5.6			0.090

TAPSE: Tricuspid annular plane systolic excursion; PASP: Systolic pulmonary artery pressure; SD: Standard deviation; BMI: Body mass index; INTERMACS: Interagency Registry for Mechanically Assisted Circulatory Support; NT-Pro-BNP: N terminal Pro-Brain natriuretic peptide; mPAP: Mean pulmonary arterial pressure; PVR: Pulmonary vascular resistance; PAPI: Pulmonary artery pulsatility index; PCWP: Pulmonary capillary wedge pressure; RVSWI: Right ventricular stroke work index; RAP: Right atrial pressure; MAP: Mean arterial pressure; TPG: Transpulmonary gradient.

Table 4. The number of the patients in each INTERMACS class according to TAPSE/PASP ratio in comparison with right ventricular failure

| | TAPSE/PASP <0.34 | | TAPSE/PASP ≥0.34 | | |
	n	%	n	%	p
INTERMACS 2 (n=4)					
RVF (+)	2	50	0	0	
RVF (-)	1	25	1	25	0.250
INTERMACS 3 (n=16)					
RVF (+)	8	50	0	0	
RVF (-)	3	18.7	5	31.3	**0.026**
INTERMACS 4 (n=34)					
RVF (+)	4	11.8	2	5.9	
RVF (-)	7	20.6	21	61.7	**0.025**
INTERMACS 5 (n=21)					
RVF (+)	4	19	4	19	
RVF (-)	1	4.8	12	57.2	**0.024**

INTERMACS: Interagency Registry for Mechanically Assisted Circulatory Support; TAPSE: Tricuspid annular plane systolic excursion; PASP: Systolic pulmonary artery pressure; RVF: Right ventricular failure.

while TAPSE, RVS, PAPI, and RVSWI were lower (Table 3). The mean values of TAPSE/PASP ratio comparison in each dichotomized groups using the value of 0.34 mm/mmHg of TAPSE/PASP among INTERMACS groups are demonstrated in Table 3. The distributions of INTERMACS classes according to TAPSE/PASP ratios in comparison with RVF are shown in Table 4 and found a significant relationship between TAPSE/PASP ratio and RVF in INTERMACS 3, 4 and 5.

DISCUSSION

In the present study, we investigated the preoperative TAPSE/PASP ratio as a postoperative RVF predictor in LVAD patients. The results of this study indicate that lower TAPSE/PASP ratios could predict worsening RV function over time following LVAD implantation.

Right ventricular failure remains a leading cause of morbidity and mortality after LVAD implantation even in the contemporary continuous flow era.[7,8] Particularly for the patients receiving LVAD as destination therapy in whom there is no opportunity for bailout with heart transplantation, RVF has a significant role on post-LVAD mortality and morbidity. Our patients received LVAD therapy as bridge to transplant but in the absence of sufficient donor supply, most of them turn into destination therapy

eventually. So find out and/ or predict RVF before and after LVAD implantation become crucial to avoid morbidity and mortality due to RVF. Post-LVAD RVF has been reported between 4 and 50%, while we observed 32% of RVF after LVAD transplantation.[9-13] Kormos et al.[14] demonstrated significantly worse outcomes with RVF after LVAD transplantation that the six-month mortality was associated with RVF in 29% of the patients. Until now, several theories have been set forth to explain the mechanism of RVF after LVAD implantation; one of the theories is a triggering role of LVADs' booster effect on CO by increasing the workload of RV that may cause RVF. The other one is that the procedure during LVAD surgery may precipitate transient trauma due to RV ischemia, blood product use, and inflammation. The final one is consequence of LVAD suction, LV volume decreases, and interventricular septum shifts to leftward. This configuration causes RV remodeling, impairment in tricuspid valve coaptation, progressive tricuspid regurgitation and eventually RV dysfunction.[15] According to developing RV dysfunction, it is predicted to observe a decrease at TAPSE with higher PASP values due to increased RV preload with both provided by LVAD and tricuspid regurgitation itself.

Guazzi et al.[16] introduced TAPSE/PASP ratio as a RV-arterial coupling marker that reflects RV contractile

function in HF with preserved EF. They confirmed the validation of TAPSE/PASP ratio as a non-invasive assessment tool against invasively recognized gold standard hemodynamic measurements. They found that patients' functional class and TAPSE/PASP ratios were inversely correlated. In another study, also, they examined the TAPSE/PASP ratio as a predictor of adverse outcomes in HF with reduced EF patients and demonstrated that non-survivors were more frequently presenting with higher PASP and lower TAPSE.[17] Studies investigating the predictors of RVF after LVAD implantation have demonstrated that high RAP, low RVSWI, an enlarged right ventricle with concomitant low RV free wall longitudinal strain can predict patients at higher risk for RVF after LVAD implantation.[18-23] Compared to these results, we introduced TAPSE/PASP ratio as another predictor along with RVSWI in LVAD patients. The RV-arterial coupling as a clinical index of the length-force relationship determines by the relationship between longitudinal RV fiber shortening (TAPSE) and PASP. The RV-arterial uncoupling is a strong and independent predictor of mortality in HF patients.[16] In the setting of maladaptive phase, an inverse relationship between TAPSE and PASP is expected. The link between lower values of TAPSE/PASP ratio and higher risk for RVF after LVAD implantation can be explained by this inverse relationship. The TAPSE/PASP emerged as an independent predictor of RVF (HR: 1.49), with a $</\geq 0.34$ mmHg/mm threshold as the best identified cut-off for post-LVAD RVF. When we dichotomized the patients' characteristics according to this threshold, patients with lower TAPSE/PASP ratios significantly tended to have higher NT Pro-BNP, LVEDD, PASP, RVD, and PCWP values with lower TAPSE, RVS, PAPI, and RVSWI. The Kaplan-Meier analyses showed better overall survival with higher TAPSE/PASP ratio (p<0.001). Other studies focusing on RVF development, mechanisms and particularly predictive risk score systems were mostly based on combination of clinical status, pre- and perioperative right ventricular function, and invasive parameters. Soliman et al.[24] demonstrated a novel risk score (EUROMACS-RHF score) to predict early postoperative RVF. They created a 9.5-point risk score incorporating five variables (INTERMACS class, use of multiple inotropes, severe right ventricular dysfunction on echocardiography, ratio of right atrial/pulmonary capillary wedge pressure, and hemoglobin). Early (<30 days) postoperative RHF was accepted if one or more following conditions exist; receiving short- or long-term right-sided circulatory support, continuous inotropic support for

≥14 days, or nitric oxide ventilation for ≥48 h. They investigated TAPSE, RV dysfunction on visual score, LV diastolic and systolic diameters and volumes, LVEF, and mitral, aortic, and tricuspid valvular regurgitation as echocardiographic parameters. Only echocardiographic parameter included in the EUROMACS-RHF score was RV dysfunction on visual score (also described as severe RV dysfunction on semiquantitative echocardiography). The authors investigated RV contractility at bedside as visual assessment, but there were no specified values or a method about this assessment and, thus, severe RV dysfunction remained controversial as they presented as a limitation of their study. Also, this score system was conducted to predict the risk of early RVF (<30 days) and was not validated for long-term prediction. Most studies attempting to identify preoperative risk factors for postoperative RVF are considered to be severe RV systolic dysfunction and RV strain, as demonstrated on preoperative transthoracic echocardiography: RV end-diastolic diameter (RVEDD) >35 mm, RVEF <30%, and right atrial diameter >50 mm.[25,26] A study by Raina et al.[27] combined the RV fractional area change (RV FAC), which is estimated by the RAP and the left atrial volume (LAV) index as shown on preoperative echocardiogram, into a scoring system and suggested that low RV FAC, high RAP and low LAV index might predict RHF post-LVAD implantation. Kato et al.[28] also suggested that signs of dilated ventricles (LVEDD, LA size relative to LVEDD and LVEF) were more prone to interventricular septum shift thus susceptible to RHF postoperatively. To the best of our knowledge, this is the first study to investigate TAPSE/PASP ratio as a post-LVAD RVF predictor.

Nonetheless, there are several limitations while reporting TAPSE/PASP ratio as a RVF predictor in LVAD patients. Although we demonstrated that this ratio could predict RVF after LVAD implantation, the LVAD implantation procedure itself, perioperative complications and variables have an important role in the development of postoperative RVF. However, we did not consider these factors in the outcomes due to perioperative mechanical complications in this study. Perioperative variables, complications, and related outcomes are the subject of another dedicated study. Similar to most of the previous LVAD studies, our study included relatively small samples of highly selected patients and, in the absence of sufficient donor supply, mechanical support devices are more frequently preferred as destination therapy instead of bridge to transplant.

In conclusion, the lower tricuspid annular plane systolic excursion and pulmonary arterial systolic pressure ratio strongly predicts right ventricular failure after left ventricular assist device implantation in patients with advanced heart failure in both short and long term. The threshold of this ratio may help to stratify patients who may be potentially at risk of right ventricular failure after left ventricular assist device implantation and lead to improved patient selection for left ventricular assist device therapy.

REFERENCES

1. Daneshmand MA, Rajagopal K, Lima B, Khorram N, Blue LJ, Lodge AJ, et al. Left ventricular assist device destination therapy versus extended criteria cardiac transplant. Ann Thorac Surg 2010;89:1205-9.

2. Holman WL, Naftel DC, Eckert CE, Kormos RL, Goldstein DJ, Kirklin JK. Durability of left ventricular assist devices: Interagency Registry for Mechanically Assisted Circulatory Support (INTERMACS) 2006 to 2011. J Thorac Cardiovasc Surg 2013;146:437-41.e1.

3. Westaby S. Rotary blood pumps as definitive treatment for severe heart failure. Future Cardiol 2013;9:199-213.

4. Orhan G, Mete EMT, Sargin M, Kudsioğlu T, Erdoğan SB, Güvenç TS, et al. Are mechanical assist devices life-saving in acute cardiogenic shock? Turk Gogus Kalp Dama 2016;24:454-61.

5. Takeda K, Takayama H, Colombo PC, Yuzefpolskaya M, Fukuhara S, Han J, et al. Incidence and clinical significance of late right heart failure during continuous-flow left ventricular assist device support. J Heart Lung Transplant 2015;34:1024-32.

6. Lampert BC, Teuteberg JJ. Right ventricular failure after left ventricular assist devices. J Heart Lung Transplant 2015;34:1123-30.

7. Mehra MR, Uriel N, Naka Y, Cleveland JC Jr, Yuzefpolskaya M, Salerno CT, et al. A fully magnetically levitated left ventricular assist device - final report. N Engl J Med 2019;380:1618-27.

8. Kalogeropoulos AP, Kelkar A, Weinberger JF, Morris AA, Georgiopoulou VV, Markham DW, et al. Validation of clinical scores for right ventricular failure prediction after implantation of continuous-flow left ventricular assist devices. J Heart Lung Transplant 2015;34:1595-603.

9. Miller LW, Pagani FD, Russell SD, John R, Boyle AJ, Aaronson KD, et al. Use of a continuous-flow device in patients awaiting heart transplantation. N Engl J Med 2007;357:885-96.

10. Slaughter MS, Rogers JG, Milano CA, Russell SD, Conte JV, Feldman D, et al. Advanced heart failure treated with continuous-flow left ventricular assist device. N Engl J Med 2009;361:2241-51.

11. Pagani FD, Miller LW, Russell SD, Aaronson KD, John R, Boyle AJ, et al. Extended mechanical circulatory support with a continuous-flow rotary left ventricular assist device. J Am Coll Cardiol 2009;54:312-21.

12. Matthews JC, Koelling TM, Pagani FD, Aaronson KD. The right ventricular failure risk score a pre-operative tool for assessing the risk of right ventricular failure in left ventricular assist device candidates. J Am Coll Cardiol 2008;51:2163-72.

13. Fitzpatrick JR 3rd, Frederick JR, Hiesinger W, Hsu VM, McCormick RC, Kozin ED, et al. Early planned institution of biventricular mechanical circulatory support results in improved outcomes compared with delayed conversion of a left ventricular assist device to a biventricular assist device. J Thorac Cardiovasc Surg 2009;137:971-7.

14. Kormos RL, Teuteberg JJ, Pagani FD, Russell SD, John R, Miller LW, et al. Right ventricular failure in patients with the HeartMate II continuous-flow left ventricular assist device: Incidence, risk factors, and effect on outcomes. J Thorac Cardiovasc Surg 2010;139:1316-24.

15. Imamura T, Kinugawa K, Kato N, Muraoka H, Fujino T, Inaba T, et al. Late-onset right ventricular failure in patients with preoperative small left ventricle after implantation of continuous flow left ventricular assist device. Circ J 2014;78:625-33.

16. Guazzi M, Dixon D, Labate V, Beussink-Nelson L, Bandera F, Cuttica MJ, et al. RV contractile function and its coupling to pulmonary circulation in heart failure with preserved ejection fraction: Stratification of clinical phenotypes and outcomes. JACC Cardiovasc Imaging 2017;10:1211-21.

17. Guazzi M, Bandera F, Pelissero G, Castelvecchio S, Menicanti L, Ghio S, et al. Tricuspid annular plane systolic excursion and pulmonary arterial systolic pressure relationship in heart failure: An index of right ventricular contractile function and prognosis. Am J Physiol Heart Circ Physiol 2013;305:H1373-81.

18. Cameli M, Lisi M, Righini FM, Focardi M, Lunghetti S, Bernazzali S, et al. Speckle tracking echocardiography as a new technique to evaluate right ventricular function in patients with left ventricular assist device therapy. J Heart Lung Transplant 2013;32:424-30.

19. Kato TS, Jiang J, Schulze PC, Jorde U, Uriel N, Kitada S, et al. Serial echocardiography using tissue Doppler and speckle tracking imaging to monitor right ventricular failure before and after left ventricular assist device surgery. JACC Heart Fail 2013;1:216-22.

20. Puwanant S, Hamilton KK, Klodell CT, Hill JA, Schofield RS, Cleeton TS, et al. Tricuspid annular motion as a predictor of severe right ventricular failure after left ventricular assist device implantation. J Heart Lung Transplant 2008;27:1102-7.

21. Vivo RP, Cordero-Reyes AM, Qamar U, Garikipati S, Trevino AR, Aldeiri M, et al. Increased right-to-left ventricle diameter ratio is a strong predictor of right ventricular failure after left ventricular assist device. J Heart Lung Transplant 2013;32:792-9.

22. Kukucka M, Stepanenko A, Potapov E, Krabatsch T, Redlin M, Mladenow A, et al. Right-to-left ventricular end-diastolic diameter ratio and prediction of right ventricular failure with continuous-flow left ventricular assist devices. J Heart Lung Transplant 2011;30:64-9.

23. Argiriou M, Kolokotron SM, Sakellaridis T, Argiriou O, Charitos C, Zarogoulidis P, et al. Right heart failure post left ventricular assist device implantation. J Thorac Dis. 2014;6 Suppl 1:S52-9.

24. Soliman OII, Akin S, Muslem R, Boersma E, Manintveld OC, Krabatsch T, et al. Derivation and validation of a novel right-sided heart failure model after implantation of continuous flow left ventricular assist devices: The EUROMACS (European Registry for Patients with Mechanical Circulatory Support) Right-Sided Heart Failure Risk Score. Circulation 2018;137:891-906.

25. Grant AD, Smedira NG, Starling RC, Marwick TH. Independent and incremental role of quantitative right ventricular evaluation for the prediction of right ventricular failure after left ventricular assist device implantation. J Am Coll Cardiol 2012;60:521-8.

26. Haneya A, Philipp A, Puehler T, Rupprecht L, Kobuch R, Hilker M, et al. Temporary percutaneous right ventricular support using a centrifugal pump in patients with postoperative acute refractory right ventricular failure after left ventricular assist device implantation. Eur J Cardiothorac Surg 2012;41:219-23.

27. Raina A, Seetha Rammohan HR, Gertz ZM, Rame JE, Woo YJ, Kirkpatrick JN. Postoperative right ventricular failure after left ventricular assist device placement is predicted by preoperative echocardiographic structural, hemodynamic, and functional parameters. J Card Fail 2013;19:16-24.

28. Kato TS, Farr M, Schulze PC, Maurer M, Shahzad K, Iwata S, et al. Usefulness of two-dimensional echocardiographic parameters of the left side of the heart to predict right ventricular failure after left ventricular assist device implantation. Am J Cardiol 2012;109:246-51.