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

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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 yetmezliği olan hastalarda triküspit annülar plan sistolik ekskürsiyon (TAPSE)/pulmoner arter sistolik basınçı (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.

Bulgarlar: Kırk bir (%55.4) hastada etyoloji iskemik kalp yetmezliği idi. Altmış dört (%85.3) hasta destek cihazının takılmasına endikasyonu nakile körpülme idi. Sol ventrikül destek cihazı takıldığdan sonra bir, üç ve beşinci yılda genel sağkalım oranları sırasıyla %82.7, %68 ve %49.3 idi. Takip sırasında 24 (%32) hasta sağ kalp yetmezliği gözlandı. Çok değişkenli analizde TAPSE/PASP oranı ameliyat sonrası sağ kalp yetmezliği ile bagimsız olarak ilişki bulundu (HR: 1.63; %95 GA: 1.49-2.23). 0.34 mm/mmHg’lik TAPSE/PASP oranı en doğru öngörürüğü değerlendirilirse olup, daha düşük oranların 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 öngörüdürüstüdür.

Anahat sözü: Sol ventrikül destek cihazı, pulmoner arter sistolik basınçı, sağ kalp yetmezliği, triküspit annülar 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 and right ventricular assist device placement 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/m²/beat)=(mPAP-RAP)xstroke volume (SV) index (mL/m²) * 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 ($\chi^2$) 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)

| Demographic parameters                                      | n  | %   | Mean±SD | Median | Min-Max |
|-------------------------------------------------------------|----|-----|---------|--------|---------|
| Age (year)                                                  | 54 | 0%  | 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

| Parameter                                |       |       |       |       |       |
|------------------------------------------|-------|-------|-------|-------|-------|
| 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

| Parameter                                |       |       |       |       |       |
|------------------------------------------|-------|-------|-------|-------|-------|
| mPAP (mmHg)                              | 37±10.6|       |       |       |       |
| PVR, Wood Units                          | 3.2   | 3.3-3.8|       |       |       |
| 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.
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 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.

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 |          |        |         |
| Sex                            |     |      |          |        |         |     |      |          |        |         |
| Male                           | 37  | 82.2 | 27±4.8  | 27±4.8 | 0.960   | 28  | 93.3  | 27±4.1  |        |         |
| BMI (kg/m²)                    |     |      |          |        |         |     |      |          |        |         |
| INTERMACS groups               |     |      |          |        |         |     |      |          |        |         |
| 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  |          |        |         |
| NT pro-BNP (pg/mL)             |     |      |          |        |         |     |      |          |        |         |
| Left ventricular end-diastolic |     |      |          |        |         |     |      |          |        |         |
| diameter (cm)                  |     |      |          |        |         |     |      |          |        |         |
| Left ventricular ejection      |     |      |          |        |         |     |      |          |        |         |
| fraction (%)                   |     |      |          |        |         |     |      |          |        |         |
| Estimated systolic pulmonary   |     |      |          |        |         |     |      |          |        |         |
| artery pressure (mmHg)         |     |      |          |        |         |     |      |          |        |         |
| Tricuspid annular plane systolic |   |      |          |        |         |     |      |          |        |         |
| excursion (mm)                 |     |      |          |        |         |     |      |          |        |         |
| Right ventricular systolic     |     |      |          |        |         |     |      |          |        |         |
| Doppler velocity (cm/sec)      |     |      |          |        |         |     |      |          |        |         |
| Right ventricle basal diameter |     |      |          |        |         |     |      |          |        |         |
| (cm)                           |     |      |          |        |         |     |      |          |        |         |
| Hemodynamic parameters         |     |      |          |        |         |     |      |          |        |         |
| mPAP (mmHg)                    | 33.2±8.6 | 41.8±11 |        |        |         | 3.2±1.3 | 3.6±1.8 |        |        |         |
| PVR, Wood Units                | 2.6  | 2.3-3.1 | 1.9     | 2.1-3.6 | 0.030*  |        |        |         |        |         |
| PAPI                           | 86.2±11.8 | 84.4±11.9 |        |        |         | 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 pressure index; PCWP: Pulmonary capillary wedge pressure; RVSWI: Right ventricular stroke work index; RAP: Right atrial pressure; MAP: Mean arterial pressure; TPG: Transpulmonary gradient.
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

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

INTERMACS: Interagency Registry for Mechanically Assisted Circulatory Support; TAPSE: Tricuspid annular plane systolic excursion; PASP: Systolic pulmonary artery pressure; RVF: Right ventricular failure.
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, 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. 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. 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. 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 \(<0.34 \text{ mmHg/mm} \) 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. 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 \( \geq 14 \) days, or nitric oxide ventilation for \( \geq 48 \) 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) \( \geq 35 \) mm, RVEF \(<30\%\), and right atrial diameter \( >50 \) mm. A study by Raina et al. 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. 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.

**Ethics Committee Approval:** The study protocol was approved by the Dr. Siyami Ersek Thoracic and Cardiovascular Surgery Training and Research Hospital Ethics Committee (27.07.2020 Versiyon 1-HNEAH-KAEK 2020/KK/262). The study was conducted in accordance with the principles of the Declaration of Helsinki.

**Patient Consent for Publication:** A written informed consent was obtained from each patient.

**Data Sharing Statement:** The data that support the findings of this study are available from the corresponding author upon reasonable request.

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