ORIGINAL ARTICLE

Mechanical circulatory support restores eligibility for heart transplant in patients with significant pulmonary hypertension

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KEY WORDS
continuous-flow left ventricular assist devices, heart transplant eligibility, pulmonary hypertension, survival

ABSTRACT

BACKGROUND An increasing number of patients with end-stage heart failure implies a wider use of left ventricular assist devices (LVADs). Irreversible pulmonary hypertension (PH) is a predictor of unfavorable prognosis and a contraindication to orthotopic heart transplant (OHT).

AIMS The aim of this study was to evaluate the effect of continuous-flow LVAD (CF-LVAD) support on pulmonary pressure and pulmonary vascular resistance (PVR) as well as the impact of pre-LVAD hemodynamic parameters on survival during LVAD support.

METHODS Data collected from 106 patients who underwent CF-LVAD implantation in the years 2009 to 2018 (men, 95.3%; mean [SD] age, 51.8 [12] years; mean [SD] INTERMACS profile, 2.9 [1.6]; mean [SD] LVAD support time, 661 [520] days; follow-up until May 2019) were retrospectively analyzed.

RESULTS Right heart catheterization was performed before LVAD implantation in 94 patients (88.7%), after implantation—in 31 (29.2%), and before and after implantation—in 28 (26.4%). We observed mean pulmonary artery pressure (mPAP) >25 mm Hg in 65 patients (61.3%) and PVR >2.5 Wood units in 33 patients (31.1%) before LVAD implantation. A significant improvement after CF-LVAD implantation was noted in mPAP, pulmonary capillary wedge pressure, transpulmonary gradient, PVR, cardiac output (P <0.001 for all parameters), and cardiac index (P = 0.003). All patients with initially irreversible PH became eligible for OHT during LVAD support. Survival during LVAD support did not depend on initial mPAP and PVR.

CONCLUSIONS In patients with end-stage heart failure, CF-LVAD support leads to a significant reduction of pre- and postcapillary PH. Survival on CF-LVAD support is independent of elevated mPAP and PVR before implantation, which suggests that LVADs decrease the risk associated with PH.

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INTRODUCTION A constant increase in the number of patients with end-stage heart failure (HF) and a shortage of heart donors worldwide implies a wider use of mechanical circulatory support, mainly continuous-flow left ventricular assist devices (CF-LVADs).[1]

Pulmonary hypertension (PH) due to increased pulmonary vascular resistance (PVR) significantly worsens prognosis in patients with HF and is considered one of key contraindications to orthotopic heart transplant (OHT).[2,9] Reversing increased pulmonary capillary pressure represents a therapeutic challenge, which would make OHT—a final resolution of congestive HF—possible.

There have been few studies that analyzed the impact of CF-LVAD implantation on pulmonary pressure and resistance. Some authors

WHAT'S NEW?

Due to an epidemic of heart failure (HF), the number of patients suffering from end-stage HF is also on the rise. In this population, optimal medical treatment often remains insufficient. In view of the shortage of heart donors, it results in a wider use of mechanical circulatory support—nowadays, mostly continuous-flow left ventricular assist devices (CF-LVADs). Among numerous benefits these devices could offer patients with end-stage HF, they can help restore eligibility for heart transplant in the case of irreversible pulmonary hypertension if a sufficient decrease in pulmonary pressure and pulmonary vascular resistance is achieved. This study shows a significant reduction of pre- and postcapillary hypertension after CF-LVAD implantation and not reduced survival rates in patients receiving CF-LVAD support, regardless of the initially elevated pulmonary pressure and pulmonary vascular resistance. Our study findings also contribute to establishing the optimal pulmonary pressure surveillance in patients awaiting heart transplant in whom CF-LVADs are used as a bridge therapy.

reported that these hemodynamic parameters significantly decreased as early as after 6 weeks of support, whereas others demonstrated that increased values persisted even after years of LVAD support.[3] Also, measurement methods varied from standard right heart catheterization (RHC) to remote recording with the use of CardioMEMS.[3-6]

The 2 key issues regarding the overall survival of patients with PH bridged with CF-LVAD are:

1 Can CF-LVADs significantly and effectively lower elevated pulmonary pressure and pulmonary vascular resistance to make patients eligible for OHT?

2 Is pre-LVAD PH associated with negative prognosis during CF-LVAD support?

We address these issues in the present study.

METHODS

The clinical and hemodynamic data of 106 patients implanted with CF-LVADs between the years 2009 and 2018 (101 men [95.3%]; follow-up until May 2019) were collected and retrospectively analyzed (as part of the EUROMACS [European Registry for Patients with Mechanical Circulatory Support] study). The study patients were censored at the end of care in our institution (1 patient), at OHT, at pump explantation due to heart regeneration, or death.

Patients with end-stage HF were evaluated for eligibility for CF-LVAD implantation according to the European and American guidelines. We adopted the definitions of pre- and postcapillary PH endorsed by the European Society of Cardiology.[7,8]

Hemodynamic measurements were performed using RHC via jugular or femoral vein access. Cardiac output was measured using thermodilution before and after LVAD implantation. In stable patients with PH and PVR higher than 2.5 Wood units, provided that sufficient systolic systemic arterial pressure was observed, a reversibility test was performed after the intravenous administration of sodium nitroprusside at increasing doses, according to the Polish and Stanford protocols.[9,10] If several RHC procedures were performed before LVAD implantation, the last measurements were analyzed. In the case of several post-LVAD measurements, the last one was taken into consideration. In view of national regulations, bridge therapy to OHT or bridge therapy to candidacy was the only strategy to implant CF-LVADs, which was allowed and used.

Out of 106 study patients (patient demographic data are shown in Supplementary material, *Table S1*), data on baseline RHC at the time of eligibility evaluation for OHT or mechanical circulatory support were available in 95 patients (89.6%) and in 31 (29.2%) after CF-LVAD implantation. In 11 patients before LVAD implantation, RHC was either not performed due to severe illness at implantation (Interagency Registry of Mechanically Assisted Circulatory Support [INTERMACS] profile 1) or performed outside our institution and data on patient outcomes were therefore unavailable. A single patient in the preimplantation group was excluded from the analysis, because the reversibility test was not performed according to standard protocols. Post-LVAD hemodynamic measurements were obtained in patients who had no other contraindications to OHT. All available pre- and post-LVAD hemodynamic measurements are shown in Supplementary material, *Table S2*.

The study population was divided according to RHC performed and its timing in reference to CF-LVAD implantation, with a special focus on the selected group of 28 patients who had complete pre- and post-LVAD RHC measurements performed (FIGURE 1). Eleven (39.2%) and 36 (38.3%) patients before LVAD implantation in the groups of 28 and 94 patients, respectively, and a single patient with severe right ventricular failure after CF-LVAD implantation had RHC performed being supported with inotropes because of catecholamine dependence.

In the next step, we analyzed the impact of mean pulmonary artery pressure (mPAP) higher than 25 mm Hg and PVR above 2.5 Wood units on survival during CF-LVAD support. These thresholds were chosen above the borderline value of mPAP, according to the European Society of Cardiology guidelines, similarly as in the studies by Mikus et al[11] and Selim et al.[6] If PVR surpassed 2.5 Wood units, OHT was not performed in our institution, which is a reminiscent of the Stanford initial experience, not in line with the current International Society for Heart and Lung Transplantation guidelines.

The study was approved by the appropriate ethics review board. Informed patient consent was not required owing to the retrospective data analysis.

Statistical analysis

Statistical analysis was performed using the Stata 15 software (StataCorp LLC, College Station, Texas, United States). Baseline patient characteristics were expressed

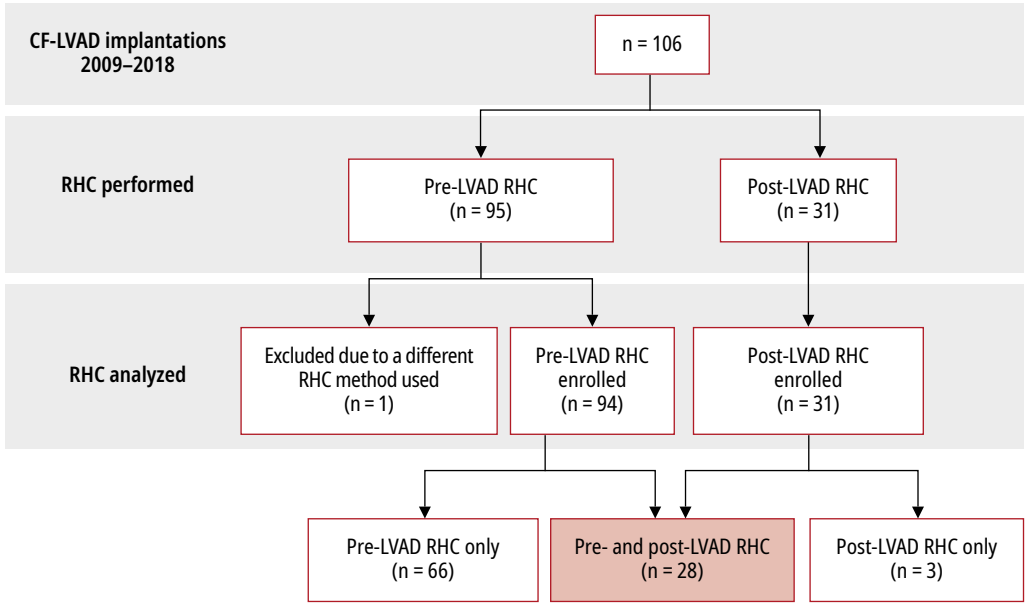

FIGURE 1 Right heart catheterization (RHC) in patients before and after continuous-flow left ventricular assist device (CF-LVAD) implantation

TABLE 1 Characteristics of the study patients before left ventricular assist device implantation (n = 28)

Characteristic		Patients, n (%)
Ischemic etiology of HF		13 (46.4)
Dilated cardiomyopathy		11 (39.3)
History of infection before HF symptoms		2 (7.1)
Inotropes at LVAD implantation		18 (64.3)
Diabetes		10 (35.7)
Arterial hypertension		10 (35.7)
Chronic kidney disease—stage 3 or higher		15 (53.6)
Chronic obstructive pulmonary disease / obstructive sleep apnea syndrome		0
Atrial fibrillation / flutter		18 (64.3)
History of ischemic stroke		3 (10.7)
INTERMACS profile at CF-LVAD implantation	1	4 (14.3)
	2	6 (21.4)
	3	8 (28.6)
	4	3 (10.7)
	5	4 (14.3)
	6	0
	7	3 (10.7)

Abbreviations: CF-LVAD, continuous-flow left ventricular assist device; HF, heart failure; INTERMACS, Interagency Registry of Mechanically Assisted Circulatory Support; LVAD, left ventricular assist device

as percentages for categorical variables and mean (SD) and median (interquartile range [IQR]) for continuous variables. The univariable comparison of categorical variables was performed using the 1-sided Fisher exact test. Survival was estimated by the Kaplan–Meier method. Log-rank tests were used to compare the study groups. All reported values were 1-tailed, and a *P* value less than 0.05 was considered significant.

RESULTS In a selected group of 28 patients in whom complete data on RHC before and after CF-LVAD implantation were available, 19 patients (67.9%) had the HeartWare device implanted, 5 (17.9%) HeartMate 3, and 4 (14.3%) HeartMate 2. The mean (SD) time of RHC was 106 (203) days (median [IQR], 28 [9–107] days) before and 622 (416) days (median [IQR], 521 [396–736] days) after CF-LVAD implantation.

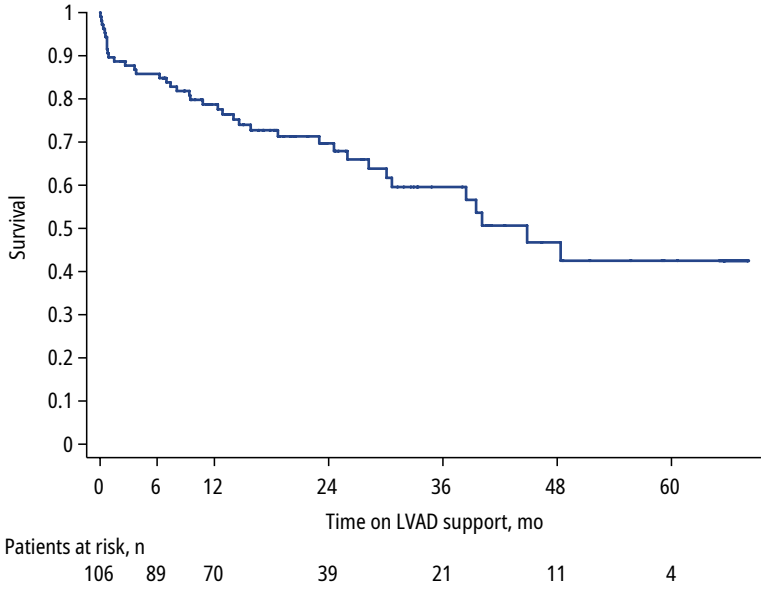

FIGURE 2 Survival during continuous-flow left ventricular assist device (CF-LVAD) support assessed by the Kaplan–Meier method in the whole study cohort of 106 patients

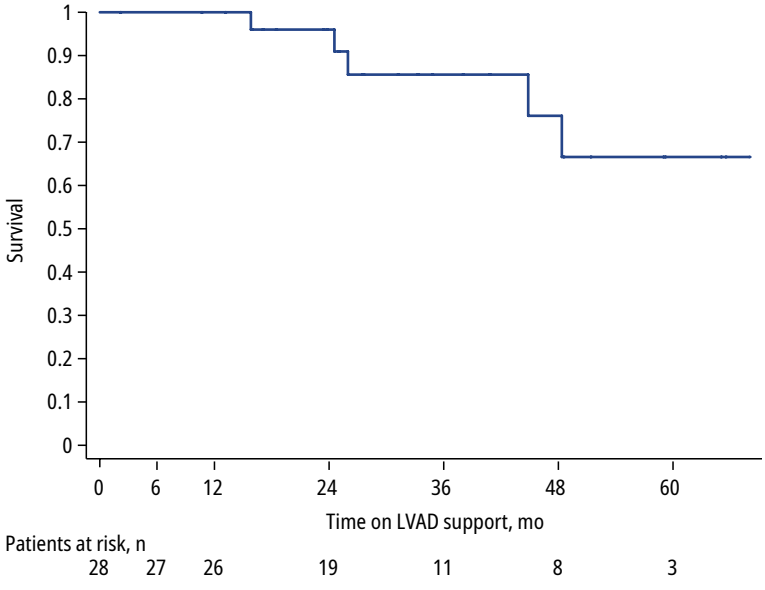

FIGURE 3 Survival during continuous-flow left ventricular assist device (CF-LVAD) support assessed by the Kaplan–Meier method in the selected group of 28 study patients in whom complete data on right heart catheterization before and after LVAD implantation were available

The mean (SD) CF-LVAD support duration was 1041 (555) days (range, 65–2068 days).

In this study group, the mean (SD) age at CF--LVAD implantation was 53.3 (9) years (range, 26.9–66.2 years). Further clinical preimplantation characteristics are reported in TABLE 1.

Data on overall survival during CF-LVAD support according to the Kaplan–Meier analysis for the whole cohort and the selected group of 28 patients are depicted in FIGURES 2 and 3. Heart transplant rates in those groups were 29.2% (31 out of 106 patients) and 53.6% (15 out of 28 patients), respectively.

Vasoreactivity testing Before LVAD implantation, 8 individuals in the group of 28 patients (28.6%) and 14 in the group of 94 patients (14.9%) with PVR higher than 2.5 Wood units had undergone a pulmonary artery pressure reversibility test. In the selected group of 28 patients, reversible PH was noted in 5 patients and a fixed form of the disease in 3 patients. In the group of 94 patients, these conditions were seen in 10 and 4 patients, respectively.

Indications for vasoreactivity testing were established according to the Polish recommendations on the hemodynamic assessment of pulmonary circulation.[10] No reversibility tests were performed in patients after CF-LVAD implantation owing to a sufficient decrease in pulmonary pressure and pulmonary vascular resistance.

The impact of continuous-flow left ventricular assist device support on hemodynamic measurements We compared hemodynamic measurements obtained in 28 patients (26.4%) who had RHC performed before and after LVAD implantation. A significant improvement after LVAD implantation was observed in mPAP, pulmonary capillary wedge pressure, transpulmonary gradient, PVR, cardiac output, and cardiac index (TABLE 2). Data on pharmacological therapy before and after CF-LVAD implantation are shown in TABLE 3.

Next, we examined the impact of pre-LVAD mPAP and PVR on survival during CF-LVAD support in the whole study group in which RHC was performed before LVAD implantation and, additionally, in the selected group of 28 patients.

Out of 94 patients, 65 (69.1%) had pulmonary hypertension with mPAP higher than 25 mm Hg, and 33 patients (35.1%) had PVR above 2.5 Wood units before LVAD implantation. Sixty seven patients (71.2%) had postcapillary PH with pulmonary capillary wedge pressure higher than 15 mm Hg at the pre-LVAD hemodynamic measurement.

Survival probability depending on the presence of initial (pre-LVAD) PH with mPAP higher than 25 mm Hg and increased PVR above 2.5 Wood units was analyzed using a log-rank test and no significant differences were found (FIGURE 4 and FIGURE 5; Supplementary material, *Figures S1* and *S2*).

None of the study patients had PVR above 2.5 Wood units (the biggest value was 2.5 Wood units) and only a single patient had mPAP higher than 25 mm Hg (27 mm Hg) during CF-LVAD support. In our study, all patients with fixed pre--LVAD PH who had undergone RHC after LVAD implantation became eligible for OHT.

DISCUSSION Used as a bridge therapy to candidacy, CF-LVADs seem to offer benefit, resulting not only in improved quality of life but also in the restored eligibility for OHT, especially in patients with fixed postcapillary PH.

TABLE 2 Hemodynamic measurements before and after continuous-flow left ventricular assist device implantation in 28 study patients

Parameter	Before LVAD implantation	After LVAD implantation	*P* value
mPAP, mm Hg	32.1 (10); 16–49	17.8 (4.2); 10–27	<0.001
PCWP, mm Hg	20 (8.1); 9–39	10.8 (5); 4–27	<0.001
TPG, mm Hg	12.1 (5.7); 5–26	7.6 (2.5); 2–12	<0.001
PVR, Wood units	3.3 (2.2); 0.9–10	1.5 (0.5); 0.4–2.5	<0.001
CO, l/min	4.2 (1.2); 2.1–7.8	5.2 (1.2); 2.8–8.4	<0.001
CI, l/min/m^2	2.2 (0.6); 1.2–3.7	2.6 (0.5); 1.5–4	0.004

Data are presented as mean (SD); range.

Abbreviations: CI, cardiac index; CO, cardiac output; mPAP, mean pulmonary artery pressure; PCWP, pulmonary capillary wedge pressure; PVR, pulmonary vascular resistance; TPG, transpulmonary gradient; others, see TABLE 1

TABLE 3 Pharmacological therapy before and after continuous-flow left ventricular assist device implantation in 28 study patients

Medication	Before CF-LVAD implantation	After CF-LVAD implantation
Loop diuretics	82.1	64.3
Spironolactone / eplerenone	82.1	96.4
β-Blocker	53.6	100
ACEI / ARB	32.1	75
Amiodarone	10.7	28.6
Digoxin	28.6	32.1
Sildenafil	28.5	89.2

Data are presented as the percentage of patients.

Abbreviations: ACEI, angiotensin-converting enzyme inhibitor; ARB, angiotensin II receptor blocker; others, see TABLE 1

Our study showed that CF-LVAD support successfully reduces PH, and elevated pulmonary pressure and PVR measured before LVAD implantation do not worsen survival during LVAD support.

In the whole CF-LVAD cohort, we observed survival rates similar to those reported in international registries, whereas the selected group of 28 patients achieved much higher survival rates in the first 2 years of LVAD support.[12,13] This could result from the fact that these patients survived the perioperative period and the time of CF-LVAD support without any serious complications and remained candidates for OHT. The results of the present study are in line with those reported by Tsiouris et al,[3] Zimpfer et al,[4] Selim et al,[6] and Mikus et al,[11] yet in contrary to recent studies on the use of CardioMEMS, in which 75% of the study patients maintained high mPAP during CF-LVAD support.[5] In all our patients who underwent RHC after CF-LVAD implantation, PVR decreased at least to 2.5 Wood units. A significant decrease in pulmonary pressure and PVR in a bigger fraction of patients in our study could be due to the fact that RHC was performed after a much longer time of CF-LVAD support. This might suggest that a longer LVAD support is necessary to achieve a sufficient reduction in PH. Also, our findings could be attributed to the uptitration of drugs such as β-blockers, angiotensin-converting enzyme inhibitors, angiotensin II receptor blockers, spironolactone, or eplerenone and a high rate of sildenafil use (89.2%) in our cohort after LVAD implantation. The use of pulmonary vasodilators in patients with HF including those with LVADs has been extensively studied, especially in patients with right ventricular failure, and a beneficial effect of sildenafil was noted, which is consistent with our findings.[15]

In a recent study, Ruan et al[16] reported PVR stabilization after 6 months of LVAD support, particularly in patients with PVR lower than or equal to 3 Wood units. The results of our study also suggest that, under proper medical treatment, strict pulmonary pressure surveillance during CF-LVAD support may not be necessary owing to a sufficient decrease in PH achieved with LVADs.[16] Another recent study by Ando et al[17] showed no significant differences in survival rates depending on pre-LVAD PVR, which is consistent with our findings. Of note, in a study by Schumer et al,[18] the authors emphasized the key

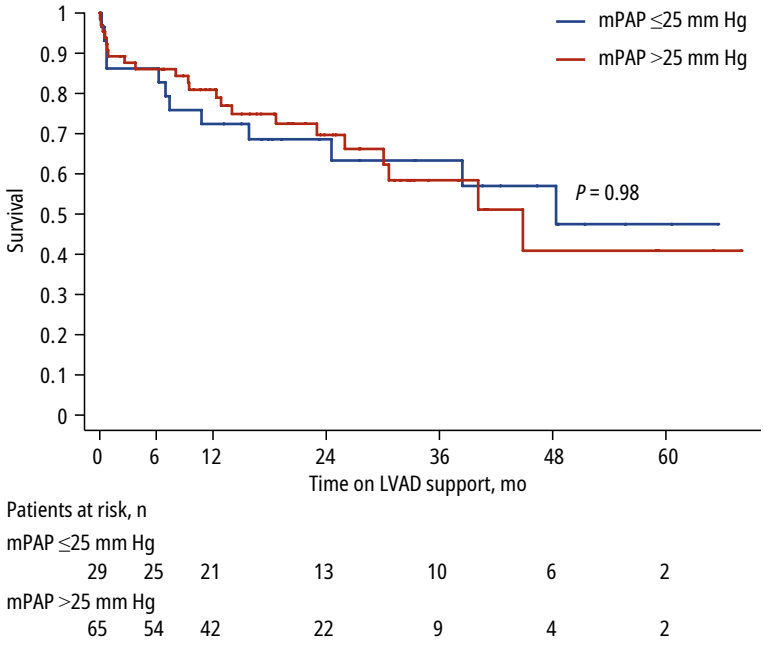

FIGURE 4 Survival probability during continuous-flow left ventricular assist device (CF-LVAD) support depending on pre-LVAD mean pulmonary artery pressure (mPAP) in 94 study patients

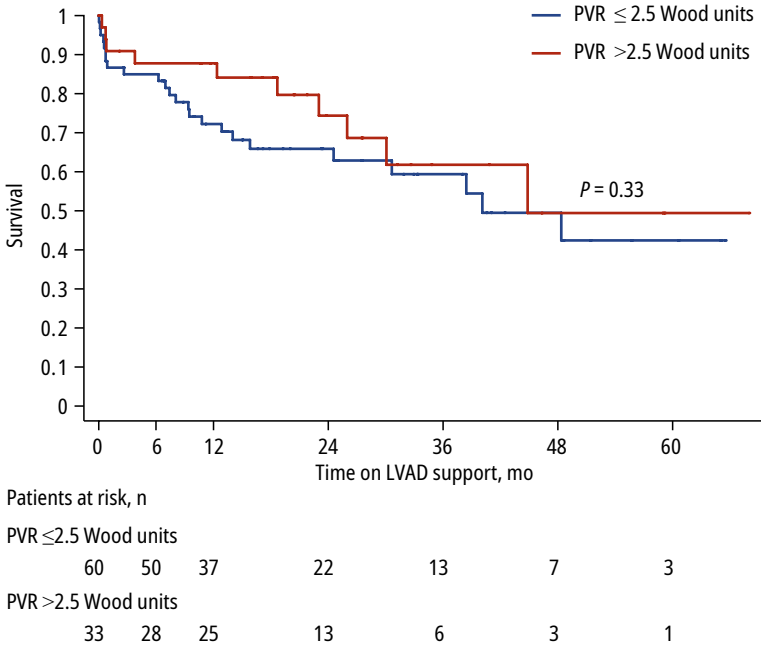

FIGURE 5 Survival probability during continuous-flow left ventricular assist device (CF-LVAD) support depending on pre-LVAD pulmonary vascular resistance (PVR) in 94 study patients

aspect of PH reversibility by showing that PH resolution during CF-LVAD support improved post-transplant survival.[18]

In some studies, pulmonary pressure was also assessed after OHT in patients previously bridged with LVADs and persistent PH after OHT was found in some of them.[19] Post-transplant survival depending on pre-and post-LVAD implantation pulmonary pressure and resistance varied among studies.[20] In an interesting study by Tsukashita et al,[19] PVR above 5 Wood units after LVAD implantation was a strong predictor of early mortality after OHT, which tripled the risk of death compared with the low-PVR group. In that study, the number of patients with high PVR during LVAD support increased after OHT and, then, gradually decreased over time. This may suggest that hemodynamic measurements taken during LVAD support do not fully reflect pulmonary pressure after OHT in patients formerly bridged with LVADs, although the values generally improve during post-OHT follow-up. Currently, RHC performed on an ongoing LVAD support, which has been widely used in various centers, still seems to remain the leading method of pulmonary pressure assessment before OHT, although it has some limitations. It is possible that hemodynamic parameters measured during LVAD support may not fully reflect true values and would be more reliable after stopping the pump, as it is sometimes done when pump explantation is considered owing to heart regeneration. However, this procedure carries a thrombotic risk and might therefore be unsuitable for routine use.[21]

In next studies including patients bridged with CF-LVADs, we will follow changes in pulmonary pressure after OHT to evaluate if PH reversibility is durable and to explore the association between pre-LVAD hemodynamic parameters and post-transplant survival rates. Developing a CF-LVAD-dedicated risk scale including hemodynamic, clinical, and biochemical factors—predictors of survival, could also be helpful in determining an optimal time frame for OHT during LVAD support, as it has been explored in some studies of non-LVAD patients with end-stage HF who awaited OHT.[22,23]

Study limitations Our study had some limitations owing to its retrospective design. In several patients, data were missing, including information on RHC before implantation. Furthermore, RHC was not performed in all patients before and after CF-LVAD implantation at previously set and standardized time points. As hemodynamic measurements were taken at various times before and after LVAD implantation, we cannot exclude that, in some cases, patients' hemodynamic parameters would be different when taken at another time point. Also, patients who died and had never had pulmonary pressure controlled could have had persistent PH despite CF-LVAD support. In our study, over 1/3 of the patients received catecholamines at the time of RHC measurement because of inotrope dependence. Though, we cannot exclude that pulmonary hemodynamic values would have been different when measured without inotropic support. However, it was the only possibility to measure pulmonary pressure and resistance in this group of

inotrope-dependent patients, which enabled us to qualify them for OHT following a sufficient decrease of PH.

Conclusions In conclusion, CF-LVAD implantation decreases the fluid overload of the pulmonary vascular bed, leading to a significant reduction of pulmonary pressure and resistance. This allows for heart transplant in patients with a history of pre- and postcapillary PH. There are no significant differences in survival during CF--LVAD support depending on the presence of PH (at mPAP >25 mm Hg) and increased vascular resistance (PVR >2.5 Wood units) before LVAD implantation, which suggests that CF-LVADs reduce the risk associated with PH. Further research is needed to establish an optimal pulmonary pressure surveillance protocol in patients bridged with CF-LVADs who await heart transplant.

SUPPLEMENTARY MATERIAL

Supplementary material is available at www.mp.pl/kardiologiapolska.

ARTICLE INFORMATION

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CONFLICT OF INTEREST MOZ is a consultant (proctor and member of advisory boards) in Abbott Inc., Boston Scientific, AtriCure, and Medtronic Inc. Other authors declare no conflict of interest.

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REFERENCES

1 Savarese G, Lund LH. Global public health burden of heart failure. Card Fail Rev. 2017; 3: 7-11.

2 Lam CSP, Roger VL, Rodeheffer RJ, et al. Pulmonary hypertension in heart failure with preserved ejection fraction. A community-based study. J Am Coll Cardiol. 2009; 31: 1119-1126.

3 Tsiouris A, Paone G, Nemeh HW, et al. Short and long term outcomes of 200 patients supported by continuous-flow left ventricular assist devices. World J Cardiol. 2015; 7: 792-800.

4 Zimpfer D, Zrunek P, Roethy W, et al. Left ventricular assist devices decrease fixed pulmonary hypertension in cardiac transplant candidates. Cardiopulmonary support and physiology. J Thorac Cardiovasc Surg. 2007; 133: 689-695.

5 De Bakker CC, Veenis JF, Manintveld OC, et al. Monitoring pulmonary pressures during long-term continuous-flow left ventricular assist device and fixed pulmonary hypertension: redefining alleged pathophysiological mechanisms? ESC Heart Fail. 2020; 7: 702-704.

6 Selim AM, Wadhwani L, Burdorf A, et al. Left ventricular assist devices in pulmonary hypertension group 2 with significantly elevated pulmonary vascular resistance: a bridge to cure. Heart Lung Circ. 2019; 28: 946-952.

7 Cook JL, Colvin M, Francis GS, et al. Recommendations for the use of mechanical circulatory support: ambulatory and community patient care: a scientific statement from the American Heart Association. Circulation. 2017; 135: 1145-1158.

8 Ponikowski P, Voors AA, Anker SD, et al. 2016 ESC Guidelines for the diagnosis and treatment of acute and chronic heart failure. Eur Heart J. 2016; 37: 2129-2200.

9 Costard-Jäckle A, Fowler MB. Influence of preoperative pulmonary artery pressure on mortality after heart transplantation: testing of potential reversibility of pulmonary hypertension with nitroprusside is useful in defining a high risk group. J Am Coll Cardiol. 1992; 19: 48-54.

10 Kurzyna M, Araszkiewicz A, Błaszczak P, et al. Summary of recommendations for the haemodynamic and angiographic assessment of the pulmonary circulation. Joint statement of the Polish Cardiac Society's Working group on pulmonary circulation and association of cardiovascular interventions. Kardiol Pol. 2015; 73: 63-68.

11 Mikus E, Stepanenko A, Krabatsch T, et al. Reversibility of fixed pulmonary hypertension in left ventricular assist device support recipients. Eur J Cardiothorac Surg. 2011; 40: 971-977.

12 Kirklin JK, Xie R, Cowger J, et al. Second annual report from the ISHLT Mechanically Assisted Circulatory Support Registry. J Heart Lung Transplant. 2018; 37: 685-691.

13 Kirklin JK, Pagani FD, Kormos RL, et al. Eighth annual INTERMACS report: special focus on framing the impact of adverse events. J Heart Lung Transplant. 2017; 36: 1080-1086.

14 Kilic A, Katz JN, Joseph SM, et al. Changes in pulmonary artery pressure before and after left ventricular assist device implantation in patients utilizing remote haemodynamic monitoring. ESC Heart Fail. 2019; 6: 138-145.

15 Sparrow CT, LaRue SJ, Schilling JD. Intersection of pulmonary hypertension and right ventricular dysfunction in patients on left ventricular assist device support: is there a role for pulmonary vasodilators? Circ Heart Fail. 2018; 11: e004255.

16 Ruan D, Farr M, Topkara V, et al. Routine right heart catheterization in LVAD patients awaiting heart transplant: what is the appropriate surveillance interval? J Heart Lung Transplant. 2019; 38: S150-S151.

17 Ando M, Takayama H, Kurlansky PA, et al. Effect of pulmonary hypertension on transplant outcomes in patients with ventricular assist devices. Ann Thorac Surg. 2020; 110: 158-164.

18 Schumer EM, Gallo M, Rogers MP, et al. The development of pulmonary hypertension results in decreased post-transplant survival. ASAIO Journal 2018; 64: 508-514.

19 Tsukashita M, Takayama H, Takeda K, et al. Effect of pulmonary vascular resistance before left ventricular assist device implantation on short and long-term post-transplant survival. J Thorac Cardiovasc Surg. 2015; 150: 1352-1361.

20 Moayedifar R, Zuckermann A, Aliabadi-Zuckermann A, et al. Long-term heart transplant outcomes after lowering fixed pulmonary hypertension using left ventricular assist devices. Eur J Cardio-thoracic Surg. 2018; 54: 1116-1121.

21 Potapov E V, Schweiger M, Krabatsch T, et al. Percutaneous balloon occlusion of a left ventricular assist device outflow cannula to facilitate evaluation of myocardial recovery. J Heart Lung Transplant. 2011; 30: 1300-1301.

22 Szczurek W, Szyguła-Jurkiewicz B, Zakliczyński MW, et al. Prognostic utility of the N-Terminal prohormone of brain natriuretic peptide and the modified Model for End-Stage Liver Disease in patients with end-stage heart failure. Pol Arch Intern Med. 2018; 128: 235-243.

23 Szczurek W, Szyguła-Jurkiewicz B, Zakliczyński MW, et al. Prognostic value of selected risk scales in patients with end-stage heart failure. Kardiol Pol. 2018; 76: 1320-1326.