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Original Article

Right Heart Catheterization Hemodynamic Parameters and Cardiovascular Adverse Events in Advanced Heart Failure: A Retrospective Cohort Study

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Abstract

Background: Right Heart Catheterization (RHC) is an important tool in advanced heart failure because it provides invasive assessment of hemodynamics, congestion, pulmonary hypertension, and right ventricular function, and helps determine candidacy for advanced therapies. However, the prognostic value of RHC-derived hemodynamic parameters in real-world advanced heart failure remains unclear. This study aimed to describe the clinical, echocardiographic, and invasive hemodynamic characteristics of patients with advanced heart failure undergoing RHC and to explore their association with Cardiovascular Adverse Events (CVAE).

Methods: This retrospective cohort study was conducted at two tertiary referral centers in Indonesia. Consecutive adult patients with advanced heart failure who underwent RHC were included. The primary outcome was CVAE, defined as a composite of cardiovascular death or rehospitalization due to acute heart failure, arrhythmia, or cardiogenic shock during a median follow-up of 6 (IQR 3-12) months after the index RHC. Baseline clinical, echocardiographic, and invasive hemodynamic data were collected from medical records and catheterization reports. No formal sample size calculation was performed. Patients with and without CVAE were compared, and bivariate logistic regression was used to explore associations between hemodynamic parameters and CVAE.

Results: A total of 33 patients were included, and 22 (68.6%) developed CVAE. Mean age was 48.0 ± 11.3 years, and 29 patients (87.9%) were male. Most patients were INTERMACS profile 4, and 27 (81.8%) had combined post- and pre-capillary pulmonary hypertension. Compared with 11 patients without CVAE, the 22 patients with CVAE had lower cardiac output (3.23 ± 0.8 vs 3.99 ± 1.1 L/min; p=0.027), lower cardiac index (1.85 ± 0.4 vs 2.34 ± 0.7 L/min/m^2; p=0.019), and lower pulmonary artery pulsatility index (0.56 [0.14-1.31] vs 1.35 [0.53-4.38]; p=0.044). Other hemodynamic parameters were not significantly different. In bivariate logistic regression, higher cardiac output, cardiac index, and pulmonary artery pulsatility index were associated with lower odds of CVAE.

Conclusions: In this two-center retrospective cohort of patients with advanced heart failure undergoing RHC, lower cardiac output, lower cardiac index, and lower pulmonary artery pulsatility index were associated with CVAE, whereas conventional pressure-based and pulmonary vascular parameters were not. These findings suggest that impaired forward flow and reduced right ventricular-pulmonary arterial pulsatile reserve may be important for risk stratification in advanced heart failure.

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Keywords: Advanced heart failure, Right heart catheterization, Hemodynamics, Cardiovascular adverse events

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Introduction

Advanced heart failure represents the most severe stage of the heart failure spectrum and is characterized by persistent symptoms, recurrent decompensation, poor exercise tolerance, repeated hospitalization, and high mortality despite guideline-directed therapy. In this population, accurate hemodynamic profiling is clinically important because bedside examination and noninvasive testing may not fully capture the severity or mechanism of circulatory impairment. Current heart failure guidance, therefore, recognizes Right Heart Catheterization (RHC) as a valuable tool in selected patients with advanced disease, particularly when there is persistent congestion, suspected low-output state, pulmonary hypertension, right ventricular dysfunction, cardiogenic shock, or the need to evaluate candidacy for advanced therapies such as durable mechanical circulatory support or heart transplantation.[1-3]

Beyond diagnosis, invasive hemodynamic assessment may provide prognostic information. Conventional RHC variables such as Right Atrial Pressure (RAP), Pulmonary Capillary Wedge Pressure (PCWP), Pulmonary Artery Pressure (PAP), Cardiac Output (CO), Cardiac Index (CI), and Pulmonary Vascular Resistance (PVR) reflect different but interrelated domains of advanced heart failure, including congestion, forward flow, pulmonary vascular load, and right ventricular–pulmonary arterial coupling. More recently, interest has expanded to integrative parameters such as Pulmonary Artery Pulsatility index (PAPi), Pulmonary Artery Compliance (PAC), and the RAP/PCWP ratio, which may better reflect right-sided reserve and the hemodynamic consequences of biventricular dysfunction. Contemporary reviews emphasize that these invasive measurements are not merely descriptive, but may help identify patients at higher risk of adverse outcomes and refine clinical decision-making in advanced heart failure and shock states.[3-5]

However, the prognostic relevance of individual RHC parameters remains incompletely defined, particularly in real-world populations with mixed etiologies of advanced heart failure. Most available evidence on advanced heart failure hemodynamics has been generated from high-volume centers, transplant-oriented cohorts, or healthcare systems with more established access to durable mechanical circulatory support and heart transplantation. In contrast, regional heart failure registries from Asia and Southeast Asia have described important differences in patient age, comorbidity profiles, treatment patterns, and outcomes, but invasive hemodynamic data remain limited. This gap is relevant because access to RHC, advanced heart failure programs, and mechanical circulatory support varies substantially across healthcare systems, potentially influencing case selection and the hemodynamic phenotype of patients undergoing invasive assessment.[1-4] In Indonesia, where RHC is still performed in a limited number of centers, local data describing the hemodynamic characteristics and clinical implications of invasive assessment in advanced heart failure are scarce. Accordingly, this study aimed to describe the clinical, echocardiographic, and invasive hemodynamic profiles of patients with advanced heart failure undergoing RHC in our center and to explore the association between RHC-derived parameters and Cardiovascular Adverse Events (CVAE), defined as cardiovascular death or rehospitalization due to acute heart failure, arrhythmia, or cardiogenic shock.

Methods

Study Design and Setting

This was a retrospective observational cohort study conducted at two tertiary referral centers in Indonesia: National Cardiovascular Center Harapan Kita, Jakarta, and Dr. Hasan Sadikin General Hospital, Bandung. Consecutive adult patients with advanced heart failure who underwent clinically indicated RHC between April 2023 and January 2026 were reviewed. We reviewed consecutive patients with advanced heart failure who underwent RHC as part of their clinical evaluation. The study was designed to describe the clinical, echocardiographic, and invasive hemodynamic characteristics of this population and to explore the association between RHC-derived parameters and subsequent CVAE. Because the study reflected real-world clinical practice in two tertiary referral centers where RHC is performed selectively in patients with advanced heart failure, no study-specific intervention was applied. All diagnostic and therapeutic decisions were made by the treating physicians according to routine institutional practice.

Study Population

The study population consisted of adult patients with advanced heart failure who underwent RHC during the study period. The process of patient screening, exclusion, and final cohort selection is summarized in Figure 1. Patients were eligible for inclusion if they had complete baseline clinical

data, echocardiographic assessment, and invasive hemodynamic measurements obtained during the index RHC procedure. Advanced heart failure was defined according to established clinical criteria, including persistent severe symptoms despite guideline-directed medical therapy, recurrent heart failure decompensation, evidence of low-output physiology or refractory congestion, need for advanced heart failure evaluation, or consideration for advanced therapies such as heart transplantation or durable mechanical circulatory support. Interagency Registry for Mechanically Assisted Circulatory Support (INTERMACS) profiles were used to further characterize the severity of advanced heart failure when available. INTERMACS profile 3 was defined as stable but inotrope dependent, whereas INTERMACS profile 4 was defined as resting symptoms despite optimized oral therapy.

Exclusion criteria were incomplete RHC data, unavailable key outcome data during follow-up, severe primary valvular heart disease as the main etiology of heart failure, and catheterization performed for indications not primarily related to advanced heart failure assessment. For patients who underwent more than one RHC, only data from the index catheterization were included in the analysis.

Data Collection

Clinical data were collected retrospectively, and baseline variables included demographic characteristics, cardiovascular risk factors, heart failure etiology, New York Heart Association (NYHA) functional class, cardiac rhythm, and echocardiographic parameters. Echocardiographic variables included Left Ventricular Ejection Fraction (LVEF), Left Ventricular End-Diastolic Diameter (LVEDD), Tricuspid Regurgitation Maximum velocity (TRVmax), and Left Atrial Volume Index (LAVI), where available.

Invasive hemodynamic data obtained from the index RHC included RAP, mean PAP, PCWP, CO, CI, PVR, PAC, Right Ventricular Stroke Work Index (RVSWI), PAPi, and RAP/PCWP ratio. CO was measured using thermodilution, according to the institutional catheterization protocol. Hemodynamic variables were recorded from the catheterization report and calculated according to standard definitions used in routine clinical practice. CI was calculated as cardiac output divided by body surface area. Pulmonary vascular resistance was calculated as PVR = (mean PAP − PCWP) / CO. PAPi was calculated as PAPi = (systolic PAP − diastolic PAP) / RAP. PAC was calculated as PAC = stroke volume / pulmonary artery pulse pressure. The RAP/PCWP ratio was calculated by dividing right atrial pressure by PCWP. RVSWI was calculated as RVSWI = (mean PAP − RAP) × stroke volume index × 0.0136. Detailed operational definitions of the hemodynamic parameters are provided in Supplementary Table S1.

Pulmonary hypertension subtype was categorized based on invasive hemodynamic measurements into isolated post-capillary pulmonary hypertension or combined post- and pre-capillary pulmonary hypertension. Right ventricular dysfunction was also evaluated using predefined study criteria based on the available hemodynamic parameters.

In addition, data on baseline heart failure treatment were collected, including guideline-directed medical therapy, selected adjunctive therapies, device therapy, and advanced heart failure status. Guideline-directed medical/device therapy included Angiotensin-Converting Enzyme inhibitor (ACEi) or Angiotensin Receptor–Neprilysin inhibitor (ARNI), beta-blocker, mineralocorticoid receptor antagonist, sodium-glucose cotransporter-2 inhibitor, loop diuretic, tolvaptan, ivabradine, levosimendan, and Implantable Cardioverter-Defibrillator (ICD)/Cardiac Resynchronization Therapy (CRT), where applicable. Advanced heart failure status was categorized according to the treating team's clinical assessment as a candidate for heart transplantation, a candidate for Left Ventricular Assist Device (LVAD), or end-stage heart failure/not suitable for advanced therapy.

Study Outcome

The primary outcome of this study was CVAE, defined as a composite of cardiovascular death or rehospitalization attributable to acute heart failure, arrhythmia, or cardiogenic shock. Outcome status was assessed using follow-up records after the index right heart catheterization, and patients were subsequently categorized as having CVAE or not for comparative analysis. Follow-up duration was calculated from the date of index RHC to the date of first CVAE, cardiovascular death, last clinical follow-up, or the end of the study observation period, whichever occurred first. Median follow-up duration was 6 (Interquartile Range [IQR] 3-12) months.

Statistical Analysis

Continuous variables are expressed as mean ± SD or median (IQR), as appropriate, and categorical variables as frequencies and percentages. Differences between patients with CVAE and patients without CVAE were assessed using the independent-samples t-test or Mann–Whitney U

test for continuous variables and the chi-square test or Fisher's exact test for categorical variables, as appropriate. Associations between hemodynamic parameters and CVAE were explored using bivariate logistic regression and are presented as Odds Ratios (ORs) with 95% Confidence Intervals (CIs). No formal sample size calculation was performed because this was a retrospective exploratory study based on all eligible patients who underwent clinically indicated RHC during the study period. Given the small sample size and limited number of events, no multivariable model was constructed, and all regression findings should be interpreted as exploratory and hypothesis-generating rather than confirmatory. In view of the small sample size and limited number of events, these regression analyses were considered exploratory. A two-sided p-value <0.05 was considered statistically significant. Statistical analyses were performed using IBM SPSS Statistics version 29.0.2.0 (IBM Corp., Armonk, NY, USA).

Ethical Approval

The study was conducted in accordance with the Declaration of Helsinki and was approved by the Research Ethics Committee of National Cardiovascular Center Harapan Kita, Jakarta (protocol no LB.02.01A/II/028/KEP028/2023) and Dr. Hasan Sadikin General Hospital, Bandung (protocol no. KP.04.04/D.XIV.3.4.23/271/2025). Because this study involved a retrospective analysis of anonymized registry data, the ethics committee waived the requirement for informed consent.

Results

A total of 113 adult patients who underwent RHC at the two participating centers were screened; of these, 33 met the study criteria and were included in the final analysis, as detailed in Figure 1. At a median follow-up of 6 months (IQR 3-12) after the index RHC, 22 patients (68.6%) experienced CVAE, while 11 (31.4%) did not. The mean age of the overall cohort was 48.0 ± 11.3 years, and most patients were male (87.9%). Most participants were in NYHA functional class III (75.8%), followed by class IV (24.2%). Ischemic cardiomyopathy was the most common etiology (48.5%), followed by non-ischemic cardiomyopathy (30.3%). Baseline clinical characteristics, cardiovascular risk factors, and heart failure etiology were generally comparable between patients with CVAE and patients without CVAE (Table 1). Echocardiographic parameters, including LVEF and LVEDD, also did not differ significantly between the two groups. Likewise, LAVI was not significantly different between patients with CVAE and patients without CVAE (p = 0.264) (Table 1).

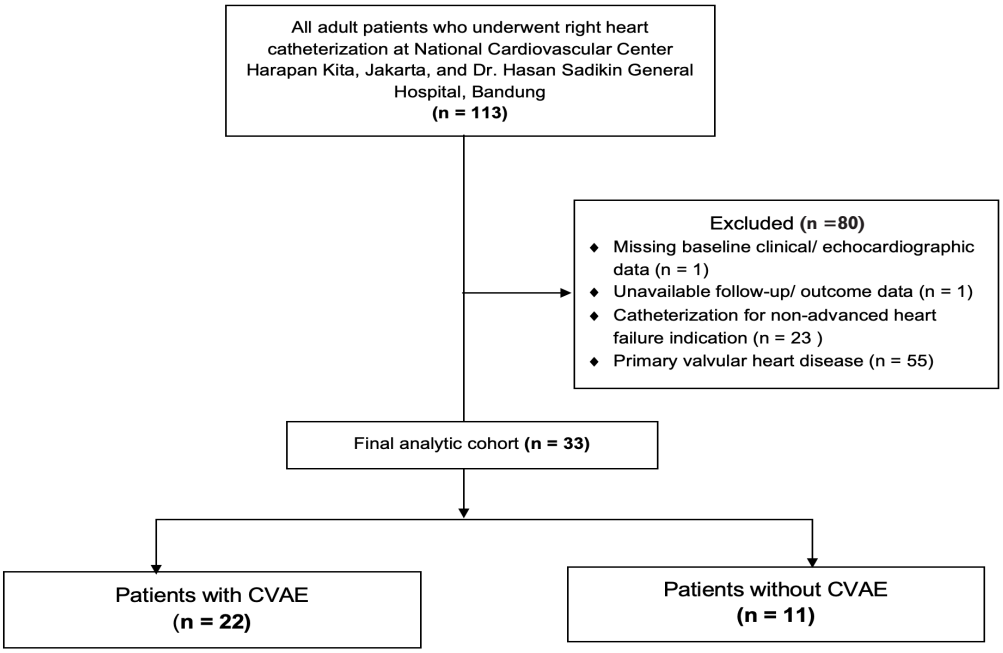

Figure 1. Flow diagram showing patient exclusion and inclusion in the final analytic cohort of patients with advanced heart failure who underwent right heart catheterization at National Cardiovascular Center, Harapan Kita, Jakarta, and Dr. Hasan Sadikin General Hospital, Bandung.

Table 1. Baseline characteristics of patients with advanced heart failure undergoing right heart catheterization.

Variable	All patients (n=33)	Patients with CVAE (n=22)	Patients without CVAE (n=11)	P-value
Age, years	48.00 ± 11.3	47.82 ± 10.9	48.36 ± 10.4	0.894
Male sex, n (%)	29 (87.9)	20 (90.9)	9 (81.8)	0.586
Body mass index category, n (%)				0.493
Normal	18 (54.5)	11 (50.0)	7 (63.6)	
Underweight	6 (18.2)	5 (22.7)	1 (9.1)	
Overweight	5 (15.2)	4 (18.2)	1 (9.1)	
Obesity grade 1	1 (3.0)	1 (4.5)	0 (0.0)	
Obesity grade 2	3 (9.1)	1 (4.5)	2 (18.2)	
NYHA functional class, n (%)				0.566
III	25 (75.8)	16 (72.7)	9 (81.8)	
IV	8 (24.2)	6 (27.3)	2 (18.2)	
INTERMACS profile, n (%)				0.132
Profile 3 (stable but inotrope dependent)	13 (39.4)	11 (50.0)	2 (18.2)	
Profile 4 (resting symptoms)	20 (60.6)	11 (50.0)	9 (81.8)	
Risk factors, n (%)				
Hypertension	11 (33.3)	8 (36.4)	3 (27.3)	0.709
Current/former smoker	16 (48.5)	9 (40.9)	7 (63.6)	0.218
Dyslipidemia	6 (18.2)	4 (18.2)	2 (18.2)	1.000
Diabetes mellitus	10 (30.3)	8 (36.4)	2 (18.2)	0.430
eGFR, mL/min/1.73 m²	61.20 ± 20.2	60.69 ± 19.1	62.21 ± 23.2	0.843
ECG rhythm, n (%)				0.071
Sinus rhythm	25 (75.8)	14 (63.6)	11 (100.0)	
Atrial fibrillation	7 (21.2)	7 (31.8)	0 (0.0)	
Atrial flutter	1 (3.0)	1 (4.5)	0 (0.0)	
Heart failure etiology, n (%)				
Ischemic cardiomyopathy	16 (48.5)	12 (54.5)	4 (36.4)	0.325
Non-ischemic cardiomyopathy	11 (33.3)	6 (27.3)	5 (45.5)	0.437
Valvular heart disease	4 (12.1)	3 (13.6)	1 (9.1)	1.000
Dual cardiomyopathy	2 (6.1)	1 (4.5)	1 (9.1)	1.000
Echocardiography				
LVEF, %	26.89 ± 12.4	25.84 ± 9.5	29.00 ± 17.2	0.500
LVEDD, mm	63.89 ± 11.7	66.14 ± 11.6	59.39 ± 11.0	0.260
Moderate/severe mitral regurgitation, n (%)	14 (42.4)	9 (40.9)	5 (45.5)	1.000
Moderate/severe mitral stenosis, n (%)	1 (3.0)	1 (4.5)	0 (0.0)	1.000
Moderate/severe tricuspid regurgitation, n (%)	18 (54.5)	11 (50.0)	7 (63.6)	0.458
Moderate aortic regurgitation, n (%)	1 (3.0)	0 (0.0)	1 (9.1)	0.333
Moderate aortic stenosis, n (%)	1 (3.0)	0 (0.0)	1 (9.1)	0.333
TAPSE, mm	14.42 ± 3.5	14.94 ± 3.5	13.61 ± 3.2	0.681
TR Vmax, m/s	2.53 ± 0.9	2.31 ± 0.7	2.88 ± 0.9	0.080

LAVI, mL/m²	63.00 (47.37–84.00)	69.44 (47.93–93.00)	53.20 (45.00–71.00)	0.264
Guideline-directed medical/device therapy, n (%)				
ACEi/ARNI	27 (81.8)	19 (86.4)	8 (72.7)	0.375
Beta-blocker	9 (27.3)	5 (22.7)	4 (36.4)	0.438
Mineralocorticoid receptor antagonist	28 (84.8)	20 (90.9)	8 (72.7)	0.304
SGLT2 inhibitor	5 (15.2)	2 (9.1)	3 (27.3)	0.304
Loop diuretic	29 (87.9)	19 (86.4)	10 (90.9)	1.000
Tolvaptan	4 (12.1)	2 (9.1)	2 (18.2)	0.586
Ivabradine	8 (24.2)	3 (13.6)	5 (45.5)	0.082
Levosimendan	11 (33.3)	8 (36.4)	3 (27.3)	0.709
ICD/CRT	3 (9.1)	1 (4.5)	2 (18.2)	0.252
Advanced HF status, n (%)				0.090
Candidate for heart transplant	10 (30.3)	4 (18.2)	6 (54.5)	
Candidate for LVAD	16 (48.5)	12 (54.5)	4 (36.4)	
End-stage HF/not suitable for advanced therapy	7 (21.2)	6 (27.3)	1 (9.1)	

Data are presented as mean ± standard deviation, median (interquartile range), or n (%), as appropriate. Continuous variables were compared using the independent-samples t-test or Mann-Whitney U test according to data distribution. Categorical variables were compared using the chi-square test or Fisher's exact test, as appropriate. ACEi, angiotensin-converting enzyme inhibitor; ARNI, angiotensin receptor-neprilysin inhibitor; BMI, body mass index; CRT, cardiac resynchronization therapy; CVAE, cardiovascular adverse event; ECG, electrocardiography; eGFR, estimated glomerular filtration rate; HF, heart failure; ICD, implantable cardioverter-defibrillator; INTERMACS, Interagency Registry for Mechanically Assisted Circulatory Support; LAVI, left atrial volume index; LVAD, left ventricular assist device; LVEDD, left ventricular end-diastolic diameter; LVEF, left ventricular ejection fraction; NYHA, New York Heart Association; SGLT2, sodium-glucose cotransporter-2; TAPSE, tricuspid annular plane systolic excursion; TR Vmax, tricuspid regurgitation maximum velocity.

Baseline treatment profiles also reflected an advanced heart failure cohort. Most patients were receiving renin–angiotensin system inhibition (ACEi/ARNI, 81.8%), mineralocorticoid receptor antagonists (84.8%), and loop diuretics (87.9%), whereas beta-blocker use was less frequent (27.3%). Device therapy with ICD/CRT was present in 9.1% of patients. Regarding advanced heart failure status, 30.3% were considered candidates for heart transplantation, 48.5% candidates for LVAD, and 21.2% were classified as end-stage heart failure/not suitable for advanced therapy. Most patients were classified as INTERMACS profile 4 (resting symptoms), while the remainder were in INTERMACS profile 3 (stable but inotrope-dependent), further supporting the conclusion that this was a clinically advanced and high-risk heart failure cohort.

The hemodynamic profile of the overall cohort showed a median RAP of 11.00 mmHg (IQR 6.50–18.00), mean PAP of 34.90 ± 9.1 mmHg, mean PCWP of 22.79 ± 6.2 mmHg, mean CO of 3.48 ± 0.9 L/min, and mean CI of 2.01 ± 0.6 L/min/m², which were consistent with advanced heart failure hemodynamic profiles. Most patients had combined post- and pre-capillary pulmonary hypertension (81.8%), while the remaining 18.2% had isolated post-capillary pulmonary hypertension; no patient had isolated pre-capillary pulmonary hypertension. RV dysfunction was present in 30.3% of the cohort (Table 2).

When stratified by outcome, patients with CVAE had significantly lower CO than those without CVAE (3.23 ± 0.8 vs 3.99 ± 1.1 L/min; p = 0.027). Similarly, CI was significantly lower in patients with CVAE than in those without CVAE (1.85 ± 0.4 vs 2.34 ± 0.7 L/min/m², p = 0.019). PAPi was also lower in patients with CVAE (0.56 [0.14–1.31]) than in patients without CVAE (1.35 [0.53–4.38]; p = 0.044). In contrast, no significant differences were observed in RAP, PAP, PCWP, RVSWI, PAC, RAP/PCWP, or PVR between patients with CVAE and patients without CVAE. Likewise, pulmonary hypertension subtypes were not significantly associated with outcome status (Table 2).

Table 2. Right heart catheterization hemodynamic parameters in patients with advanced heart failure according to CVAE status.

Variable	All patients (n=33)	Patients with CVAE (n=22)	Patients without CVAE (n=11)	P-value
RAP, mmHg	11.00 (6.50–18.00)	9.50 (6.75–18.00)	11.59 (6.00–23.00)	0.462
Mean PAP, mmHg	34.90 ± 9.1	35.18 ± 10.3	34.36 ± 6.6	0.812
PCWP, mmHg	22.79 ± 6.2	23.14 ± 6.3	22.09 ± 6.3	0.656
CO, L/min	3.48 ± 0.9	3.23 ± 0.8	3.99 ± 1.1	0.027
CI, L/min/m²	2.01 ± 0.6	1.85 ± 0.4	2.34 ± 0.7	0.019
RVSWI, g·m/m²/beat	561.00 (419.50–789.00)	586.12 (412.00–820.00)	554.00 (426.00–801.00)	0.807
PAPi, ratio	0.68 (0.16–1.61)	0.56 (0.14–1.31)	1.35 (0.53–4.38)	0.044
PAC, mL/mmHg	1.39 (1.05–2.47)	1.36 (0.97–1.78)	1.61 (1.11–2.86)	0.510
RAP/PCWP ratio	0.46 (0.27–0.79)	0.44 (0.27–0.66)	0.47 (0.23–1.00)	0.721
PVR, Wood units	3.89 ± 1.8	3.92 ± 1.7	3.86 ± 1.9	0.935
Pulmonary hypertension type, n (%)				0.637
Pre-capillary PH	0 (0.0)	0 (0.0)	0 (0.0)	
Isolated post-capillary PH	6 (18.2)	5 (22.7)	1 (9.1)	
Combined post- and pre-capillary PH	27 (81.8)	17 (77.3)	10 (90.9)	
RV dysfunction, n (%)	10 (30.3)	6 (27.3)	4 (36.4)	0.696

Data are presented as mean ± standard deviation, median (interquartile range), or n (%), as appropriate. Continuous variables were compared using the independent-samples t-test or Mann-Whitney U test according to data distribution. Categorical variables were compared using the chi-square test or Fisher's exact test, as appropriate. Units are shown in the variable column. CI, cardiac index; CO, cardiac output; CVAE, cardiovascular adverse event; PAC, pulmonary artery compliance; PAP, pulmonary artery pressure; PAPi, pulmonary artery pulsatility index; PCWP, pulmonary capillary wedge pressure; PH, pulmonary hypertension; PVR, pulmonary vascular resistance; RAP, right atrial pressure; RV, right ventricular; RVSWI, right ventricular stroke work index.

Table 3. Bivariate logistic regression analysis of right heart catheterization parameters associated with CVAE in patients with advanced heart failure.

Variable	OR (95% CI)	P-value
RAP, per 1 mmHg	1.075 (0.973–1.187)	0.156
Mean PAP, per 1 mmHg	1.010 (0.932–1.095)	0.805
PCWP, per 1 mmHg	1.029 (0.913–1.159)	0.254
CO, per 1 L/min	0.384 (0.171–0.987)	0.041
CI, per 1 L/min/m²	0.186 (0.038–0.911)	0.038
RVSWI, per 1 g·m/m²/beat	1.000 (0.999–1.002)	0.551
PAPi, per 1-unit increase	0.624 (0.393–0.977)	0.039
PAC, per 1 mL/mmHg	0.877 (0.467–1.618)	0.675
RAP/PCWP ratio, per 1-unit increase	3.652 (0.411–32.413)	0.245
PVR, per 1 Wood unit	1.045 (0.698–1.567)	0.830
Isolated post-capillary PH	2.941 (0.299–28.890)	0.355
Combined post- and pre-capillary PH	0.340 (0.035–3.340)	0.355

Data are presented as odds ratios (ORs) with 95% confidence intervals (CIs) from bivariate logistic regression. The outcome was CVAE. Because of the small sample size and limited number of events, the analyses should be interpreted as exploratory. CI, cardiac index; CO, cardiac output; CVAE, cardiovascular adverse event; PAC, pulmonary artery compliance; PAP, pulmonary artery pressure; PAPi, pulmonary artery pulsatility index; PCWP, pulmonary capillary wedge pressure; PH, pulmonary hypertension; PVR, pulmonary vascular resistance; RAP, right atrial pressure; RVSWI, right ventricular stroke work index.

In bivariate logistic regression analysis, higher CO was associated with lower odds of CVAE (OR 0.384; 95% CI 0.171–0.987; p = 0.041). A similar association was observed for CI (OR 0.186; 95% CI 0.038–0.911; p = 0.038) and PAPi (OR 0.624; 95% CI 0.393–0.977; p = 0.039). Other hemodynamic parameters, including RAP, PAP, PCWP, RVSWI, PAC, RAP/PCWP, PVR, and pulmonary hypertension subtype, were not significantly associated with CVAE (Table 3).

Overall, these exploratory findings suggest that among selected patients with advanced heart failure who underwent RHC, lower forward-flow parameters, particularly CO and CI, as well as lower PAPi, were more closely associated with CVAE than isolated resting pressure-based or pulmonary vascular indices.

Discussion

In this two-center retrospective cohort of patients with advanced heart failure undergoing RHC, an important finding was the relatively young age profile of the study population. The mean age was 48.0 ± 11.3 years, which is younger than that reported in broader contemporary heart failure registries from both Asia and Western populations, including ASIAN-HF (59.6 ± 13.1 years), the Malaysian MY-HF registry (60.2 ± 13.6 years), the European ESC-HF-LT chronic heart failure registry (median age 66 years), and the U.S. ADHERE acute heart failure registry, in which the average age was approximately 73 years.[6-9] In parallel, ischemic cardiomyopathy was the predominant etiology in our study, accompanied by a substantial burden of smoking, hypertension, and diabetes. Taken together, these findings suggest that in our setting, progression to advanced heart failure severe enough to warrant invasive hemodynamic evaluation may occur at a relatively earlier age, potentially reflecting premature cardiovascular risk exposure and delayed referral until a more advanced stage of disease. The INTERMACS distribution further supports this interpretation, as most patients were classified as profile 4 and the remainder as profile 3, indicating that invasive evaluation was performed predominantly in patients with clinically advanced heart failure rather than in less symptomatic ambulatory individuals.[10]

The main finding of this cohort was that lower CO, CI, and PAPi were associated with CVAE, whereas conventional pressure-based variables such as RAP, PAP, PCWP, and PVR were not significantly associated with the outcome. Taken together, these findings suggest that in this cohort, markers of impaired forward flow and reduced right ventricular–pulmonary arterial pulsatile reserve may have been more closely related to subsequent clinical deterioration than congestion-related indices alone. This interpretation is in line with contemporary heart failure guidance and recent hemodynamic reviews, which emphasize that right heart catheterization provides prognostic information not only through absolute filling pressures, but also through indices of circulatory performance, right-sided adaptation, and overall hemodynamic reserve.[1,3-4]

Importantly, the lack of significant associations between pressure-based variables and CVAE in this cohort should not be misinterpreted as diminishing the clinical importance of congestion. Congestion is a major determinant of symptoms, hospitalization, and adverse prognosis in heart failure, and prior studies have demonstrated that persistent congestion is associated with worse outcomes, whereas successful decongestion is linked to improved survival. In this context, our results should be understood more cautiously that in a small, highly selected advanced heart failure population undergoing RHC, indices of impaired forward flow and reduced right-sided pulsatile reserve showed stronger discriminatory value than isolated resting pressure measurements, but this does not negate the central role of congestion in the natural history of heart failure.[13-14]

Advanced heart failure is characterized by the inability of the circulation to maintain adequate tissue perfusion without requiring pathologically elevated intracardiac pressures. Although congestion is a major determinant of symptoms and rehospitalization, impaired forward flow reflects a more advanced stage of hemodynamic compromise and may identify patients who are less able to tolerate additional clinical stressors. In routine advanced heart failure practice, low-output physiology is often accompanied by progressive end-organ dysfunction, recurrent decompensation, and greater vulnerability to shock, all of which may contribute to cardiovascular death or rehospitalization. Current guidance and contemporary reviews continue to recognize CO and CI as core hemodynamic parameters for risk assessment, particularly in advanced heart failure, cardiogenic shock, and evaluation for advanced therapies such as transplantation or mechanical circulatory support.[4,15]

Another finding was the association between lower PAPi and CVAE. PAPi has increasingly been used as an integrative marker of right ventricular

functional reserve and right ventricular adaptation to pulmonary vascular load. Although its optimal threshold varies by clinical setting, a lower PAPi is generally interpreted as reflecting impaired right ventricular pulsatile performance and a reduced ability of the right ventricle to maintain output under increased afterload. In advanced heart failure, this may be particularly relevant because deterioration of right ventricular function often signals a more unstable hemodynamic state, greater systemic venous congestion, and poorer tolerance of acute decompensation. Recent reviews on invasive hemodynamic assessment in heart failure have highlighted PAPi as a potentially useful adjunct beyond traditional pressure measurements, especially in advanced heart failure and shock-related settings. [3,5,15] Our findings support the relevance of PAPi even in a small, real-world Indonesian cohort undergoing selective invasive evaluation.

By contrast, RAP, PAP, PCWP, PVR, PAC, RVSWI, and RAP/PCWP were not significantly associated with CVAE in this study. This should not be interpreted as evidence that these variables are clinically unimportant. Rather, several explanations are possible. First, the sample size was small, which limits statistical power. Second, this was a selected referral population from two tertiary centers, and the relatively narrow hemodynamic range of some variables may have reduced discriminatory capacity. Third, pressure-based variables often reflect a single moment in time and can be influenced by loading conditions, timing of measurement, and ongoing treatment. In contrast, output-related variables and composite indices, such as PAPi, may better reflect the overall severity of circulatory dysfunction. Contemporary hemodynamic literature likewise emphasizes that right heart catheterization should be interpreted as a physiological profile rather than as isolated numbers.[3-5]

In our study, pulmonary hypertension subtype was also not significantly associated with the composite outcome. This may be explained, at least in part, by the fact that most patients had combined post- and pre-capillary pulmonary hypertension, leaving limited variation for meaningful between-group comparison. In addition, the clinical impact of pulmonary hypertension in advanced heart failure depends not only on resting invasive classification, but also on chronicity, right ventricular adaptation, and treatment context. Therefore, the lack of statistical significance in this cohort should be interpreted with caution and not taken as proof of no clinical relevance. More likely, it reflects the limited sample size and the relatively homogeneous hemodynamic severity of this referral population.[1, 15]

The present findings are relevant in the Indonesian setting, where access to right heart catheterization in advanced heart failure remains limited to a small number of tertiary centers. In such settings, even descriptive data are valuable because they provide insight into the hemodynamic phenotype of patients selected for invasive evaluation. Our results suggest that among these patients, forward-flow indices may be more informative than pressure-derived variables alone when identifying those at higher risk of cardiovascular death or rehospitalization. From a practical perspective, this supports careful attention to CO, CI, and PAPi when interpreting invasive hemodynamic data in advanced heart failure, while recognizing that treatment decisions must still be based on the overall clinical context rather than on a single parameter. Clinically, patients with low CO, low CI, or reduced PAPi may require closer follow-up, optimization of advanced heart failure therapy, and timely multidisciplinary discussion regarding candidacy for LVAD implantation, heart transplantation, or palliative-oriented management when advanced therapies are not feasible. However, these parameters should not be used as standalone thresholds, and treatment decisions must remain individualized according to the overall clinical context. [1,3-4,15]

The baseline treatment and advanced heart failure status data further support the interpretation that this was a clinically high-risk referral cohort. Although most patients were receiving ACEi/ARNI, mineralocorticoid receptor antagonists, and loop diuretics, the relatively low use of beta-blockers, SGLT2 inhibitors, and device therapy likely reflects the severity, instability, and treatment constraints that commonly accompany advanced heart failure in routine practice. In addition, a substantial proportion of patients were categorized as candidates for heart transplantation or LVAD, while one-fifth were already considered unsuitable for advanced therapy. These findings help contextualize the observed event rates and suggest that invasive hemodynamic assessment in this cohort was performed not only for diagnostic profiling but also as part of broader advanced heart failure decision-making.[1,4,16]

Limitations and Strengths

Several limitations should be acknowledged. First, this was a retrospective study and is therefore subject to information bias and unmeasured confounding. Second, the study included only

patients who underwent clinically indicated RHC, representing a highly selected and high-risk advanced heart failure population. This selection limits generalizability to broader heart failure populations that do not undergo invasive hemodynamic assessment. Accordingly, the findings should be considered exploratory and hypothesis-generating. Third, the composite outcome combined cardiovascular death and rehospitalization due to several causes of decompensation, which improves clinical relevance but may introduce heterogeneity in event mechanisms. Finally, because the analysis was limited to descriptive comparisons and bivariate logistic regression, the present study cannot establish independent predictors or causal relationships.

Despite these limitations, this study has several strengths. It provides one of the few descriptions of invasive hemodynamic characteristics in patients with advanced heart failure from two tertiary Indonesian centers, and evaluates clinically meaningful outcomes using routinely obtained RHC variables. Importantly, the observed pattern was physiologically coherent: adverse events were associated primarily with lower output-related parameters and lower PAPi rather than with uniformly higher pressure-based measurements. This internal consistency supports the clinical plausibility of the findings, even within a modest sample.

Future Direction

Future studies should include larger prospective multicenter cohorts to validate the prognostic significance of invasive hemodynamic parameters in advanced heart failure. Broader recruitment would improve generalizability and allow more robust adjusted analyses to determine whether CO, CI, and PAPi remain associated with adverse outcomes after accounting for clinical confounders. Serial hemodynamic assessment, integrated with echocardiographic and laboratory markers, may also provide a more comprehensive strategy for risk stratification. In the Indonesian setting, expanding local data on RHC may help refine its role in identifying high-risk patients with advanced heart failure and in guiding clinical decision-making.

Conclusion

In this two-center retrospective cohort of patients with advanced heart failure undergoing clinically indicated RHC, lower CO, lower CI, and lower PAPi were associated with CVAE. Because of the small sample size and selected RHC population, these findings should be interpreted as exploratory and hypothesis-generating. Larger prospective multicenter studies are needed to validate whether these parameters improve risk stratification beyond routine clinical assessment.

List of Abbreviations

ACEi	Angiotensin-Converting Enzyme
ARNI	Angiotensin Receptor–Neprilysin inhibitor
CO	Cardiac Output
CI	Cardiac Index
CIs	Confidence Intervals
CRT	Cardiac Resynchronization Therapy
CVAE	Cardiovascular Adverse Events
ICD	Implantable Cardioverter-Defibrillator
IQR	Interquartile Range
LAVI	Left Atrial Volume Index
LVAD	Left Ventricular Assist Device
LVEDD	Left Ventricular End-Diastolic Diameter
LVEF	Left Ventricular Ejection Fraction
NYHA	New York Heart Association
OR	Odds Ratios
PAC	Pulmonary Artery Compliance
PAP	Pulmonary Artery Pressure
PAPi	Pulmonary Artery Pulsatility index
PCWP	Pulmonary Capillary Wedge Pressure
PVR	Pulmonary Vascular Resistance
RAP	Right Atrial Pressure
RHC	Right Heart Catheterization
RVSWI	Right Ventricular Stroke Work Index
TRVmax	Tricuspid Regurgitation Maximum velocity

Ethical Clearance

The study was conducted in accordance with the Declaration of Helsinki and was approved by the Research Ethics Committee of National Cardiovascular Center Harapan Kita, Jakarta (protocol no LB.02.01A/II/028/KEP028/2023) and Dr. Hasan Sadikin General Hospital, Bandung (protocol no. KP.04.04/D.XIV.3.4.23/271/2025). Because this study involved a retrospective analysis of anonymized registry data, the ethics committee waived the requirement for informed consent.

Publication Approval

All authors are consent to the publication of this manuscript.

Authors Contributions

All authors have made a significant intellectual contribution to the manuscript according to the criteria formulated by the International Committee of Medical Journal Editors

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Conflict of Interest

None.

Availability of Data and Materials

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References

1. Heidenreich PA, Bozkurt B, Aguilar D, et al. 2022 AHA/ACC/HFSA guideline for the management of heart failure: a report of the American College of Cardiology/American Heart Association Joint Committee on Clinical Practice Guidelines. Circulation. 2022;145:e895-e1032
2. Peled Y, Ducharme A, Kittleson M, et al. International Society for Heart and Lung Transplantation guidelines for the evaluation and care of cardiac transplant candidates-2024. J Heart Lung Transplant. 2024;43.
3. Rajagopalan N, Rajagopalan N, Borlaug B, Bailey A, et al. Practical guidance for hemodynamic assessment by right heart catheterization in management of heart failure. JACC Heart Fail. 2024;12:1141-56.
4. Zeder K, Mak S, Galie N, et al. Right heart catheterization in heart failure: indications, interpretation, and pitfalls. Eur Heart J. 2025;46:3354-72.
5. Grinstein J, Houston BA, Nguyen AB, et al. Standardization of the right heart catheterization and the emerging role of advanced hemodynamics in heart failure. J Card Fail. 2023;29:1543-55.
6. Lam CS, Teng TK, Tay WT, et al. Regional and ethnic differences among patients with heart failure in Asia: the Asian sudden cardiac death in heart failure registry. Eur Heart J. 2016;37:3141-53.
7. Wan Ahmad WA, Abdul Ghapar AK, Zainal Abidin HA, et al. Characteristics of patients admitted with heart failure: insights from the first Malaysian Heart Failure Registry. ESC Heart Fail. 2024;11:727-36.
8. Lainščak M, Milinkovic I, Polovina M, et al. Sex- and age-related differences in the management and outcomes of chronic heart failure: an analysis of patients from the ESC HFA EORP Heart Failure Long-Term Registry. Eur J Heart Fail. 2020;22:92-102.
9. Abraham WT, Adams KF, Fonarow GC, et al. In-hospital mortality in patients with acute decompensated heart failure requiring intravenous vasoactive medications: an analysis from the Acute Decompensated Heart Failure National Registry (ADHERE). J Am Coll Cardiol. 2005;46:57-64.
10. Stevenson LW, Pagani FD, Young JB, et al. INTERMACS profiles of advanced heart failure: the current picture. J Heart Lung Transplant. 2009;28:535-41.
11. Stewart GC, Kittleson MM, Patel PC, et al. INTERMACS (Interagency Registry for Mechanically Assisted Circulatory Support) profiling identifies ambulatory patients at high risk on medical therapy after hospitalizations for heart failure. Circ Heart Fail. 2016;9

12. Palardy M, McLean R, Pamboukian S, et al. The REVIVAL Registry of ambulatory advanced heart failure: baseline characteristics. J Heart Lung Transplant. 2017;36:S211.
13. Lucas C, Johnson W, Hamilton MA, et al. Freedom from congestion predicts good survival despite previous class IV symptoms of heart failure. Am Heart J. 2000;140:840-7.
14. Gheorghiade M, Filippatos G, De Luca L, et al. Congestion in acute heart failure syndromes: an essential target of evaluation and treatment. Am J Med. 2006;119:S3-S10.
15. Yoon M, Youn JC. Right heart catheterization in patients with advanced heart failure: novel hemodynamic parameters for risk stratification. Korean Circ J. 2025;55:148-50.
16. Gustafsson F, Damman K, Nalbantgil S, et al. Inotropic therapy in patients with advanced heart failure: a clinical consensus statement from the Heart Failure Association of the European Society of Cardiology. Eur J Heart Fail. 2023;25:457-68.