

Right Ventricular–Pulmonary Artery Coupling in Heart Failure: Assessment and Clinical Significance

Laila M. El-Maghawry, Hanan Abdal Salam Ali Samour, Ahmed Essam Hassan Elshetry, Shaimaa Wageeh

Department of Cardiology, Faculty of Medicine, Zagazig University, Egypt

***Corresponding author: Ahmed Essam Hassan Mohamed Elshetry,**

Abstract

Background: Right ventricular-pulmonary artery (RV-PA) coupling describes the relationship between right ventricular contractility and the afterload imposed by the pulmonary circulation. It has emerged as an integrated marker of cardiovascular performance and may provide greater diagnostic and prognostic information than conventional measurements of right ventricular function alone. In heart failure, progressive elevation of pulmonary pressures initially triggers compensatory right ventricular hypertrophy; however, persistent afterload leads to maladaptive remodeling, chamber dilation, systolic dysfunction, and eventual RV-PA uncoupling.

Objective: This review summarizes the physiological basis, invasive and non-invasive methods of assessment, clinical significance, prognostic value, and therapeutic implications of RV-PA coupling across heart failure phenotypes.

Review content: Pressure-volume loop analysis remains the invasive reference standard, using the ratio of end-systolic elastance to effective arterial elastance. Because catheter-based assessment is complex and invasive, cardiac magnetic resonance and echocardiographic surrogates are increasingly used in clinical practice. Among these, the ratio of tricuspid annular plane systolic excursion to pulmonary arterial systolic pressure (TAPSE/PASP) is the most extensively validated, while right ventricular free-wall strain-to-PASP is an emerging alternative. Impaired coupling is associated with pulmonary hypertension, elevated natriuretic peptide levels, renal dysfunction, reduced exercise capacity, hospitalization, and cardiovascular mortality. Serial assessment may also identify changes in ventricular-pulmonary vascular interaction after pharmacological or device-based treatment.

Conclusion: RV-PA coupling is a clinically valuable, dynamic measure that integrates right ventricular function and pulmonary vascular load. Its early assessment, particularly using validated non-invasive indices, can improve risk stratification, support treatment selection, and provide an objective measure of therapeutic response in patients with heart failure.

Keywords: Right ventricular–pulmonary artery coupling; Heart failure; TAPSE/PASP; Echocardiography; Right ventricular function; Pulmonary arterial systolic pressure.

Introduction

Right ventricular–pulmonary artery coupling, expressed as the ratio between pulmonary arterial elastance and right ventricular end-systolic function, reflects the dynamic relationship between contractility and afterload and serves as a stronger prognostic marker than conventional measures. In early pulmonary hypertension, the right ventricle compensates through hypertrophy to maintain normal function and preserve coupling. As pulmonary pressure rises, maladaptive remodeling develops, resulting in chamber dilation, increased volume, dysfunction, and ultimately right heart failure. (Figure 1) illustrates the progression from coupling to uncoupling as afterload and pulmonary vascular resistance increase. Right ventricular–pulmonary artery uncoupling signals advanced heart failure and is a sensitive indicator of dysfunction. Early recognition of this process is essential for guiding

management and predicting outcomes, and growing research highlights its critical role across heart failure subtypes.

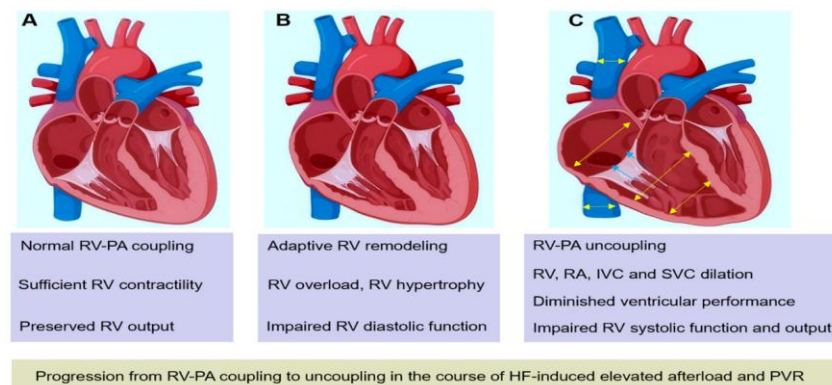


Figure 1: Progression from RV-PA coupling to uncoupling in the course of progressively increasing afterload and PVR caused by HF. (A) Normal RV-PA coupling. (B) With increasing RV afterload, RV adaptively remodels to maintain sufficient output, RV hypertrophy, diastolic dysfunction, and RV systolic function occur. (C) With progressively increasing afterload and PVR, RV dilates to maintain stroke volume, accompanied by tricuspid regurgitation, RA, IVC, and SVC dilation. RV systolic function and output are impaired when RV-PA uncoupling occurs.

Invasive Evaluation

Quantifying right ventricular–pulmonary artery coupling is complex because it requires simultaneous measurement of load-independent right ventricular contractility and afterload. The invasive right heart catheterization method remains the gold standard for this purpose, allowing assessment through pressure–volume relationships derived from single- or multi-beat loops. Right ventricular contractility and afterload are expressed as end-systolic elastance and effective arterial elastance, respectively, and their ratio defines the coupling index (Michael I. Brener et al., 2022).

Simplified volumetric estimation can also be obtained as the stroke volume-to-end-systolic volume ratio, illustrated in (Figure 2). An optimal coupling ratio between 1.5 and 2.0 indicates efficient ventricular performance, while reduced ratios signal progressive right ventricular–pulmonary artery uncoupling and diminished adaptation to rising afterload (Hsu et al., 2020).

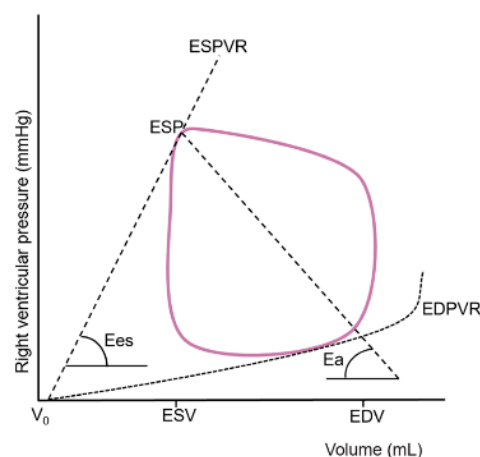


Figure 2: Right ventricular pressure–volume loop from which effective arterial elastance (E_a) and end-systolic elastance (E_{es}) are derived. EDV: end-diastolic volume; EDPVR: end-diastolic pressure–volume relationship; ESP: end-systolic pressure; ESPVR: end-systolic pressure–volume relationship; ESV: end-systolic volume; V_0 : hypothetical uncompressed ventricular volume

Although preserved during rest and exercise in healthy individuals, coupling becomes impaired in pulmonary hypertension or heart failure. Studies have shown that thresholds between 0.7 and 0.8 can predict right ventricular failure or adverse outcomes. Despite its diagnostic precision, the invasive approach is limited in clinical use due to its technical demands and procedural invasiveness (He et al., 2023).

Non-Invasive Assessment

Because catheter-based assessment of right ventricular–pulmonary artery coupling is invasive, complex, and costly, non-invasive alternatives have gained wide clinical adoption. Cardiac magnetic resonance imaging and echocardiography provide reliable surrogates for evaluating right ventricular function and afterload. Cardiac magnetic resonance has become the reference standard for quantifying right ventricular volumes and ejection fraction and allows calculation of the simplified stroke volume-to-end-systolic volume ratio, which closely correlates with invasive measures and predicts outcomes in pulmonary hypertension and heart failure (Li & Zhang, 2024).

Echocardiography, widely available and suitable for routine use, enables both two- and three-dimensional evaluation as well as strain analysis. The tricuspid annular plane systolic excursion-to-pulmonary arterial systolic pressure ratio is the most validated non-invasive surrogate of ventricular–arterial coupling, showing strong agreement with invasive indices and powerful prognostic value across heart failure, pulmonary hypertension, tricuspid regurgitation, and congenital heart disease. Tricuspid annular systolic velocity, right ventricular fractional area change, and strain-derived indices, also serve as coupling markers (Figure 3). Recent evidence highlights the right ventricular free-wall strain-to-pulmonary pressure ratio as an emerging, superior indicator of ventricular-arterial interaction.

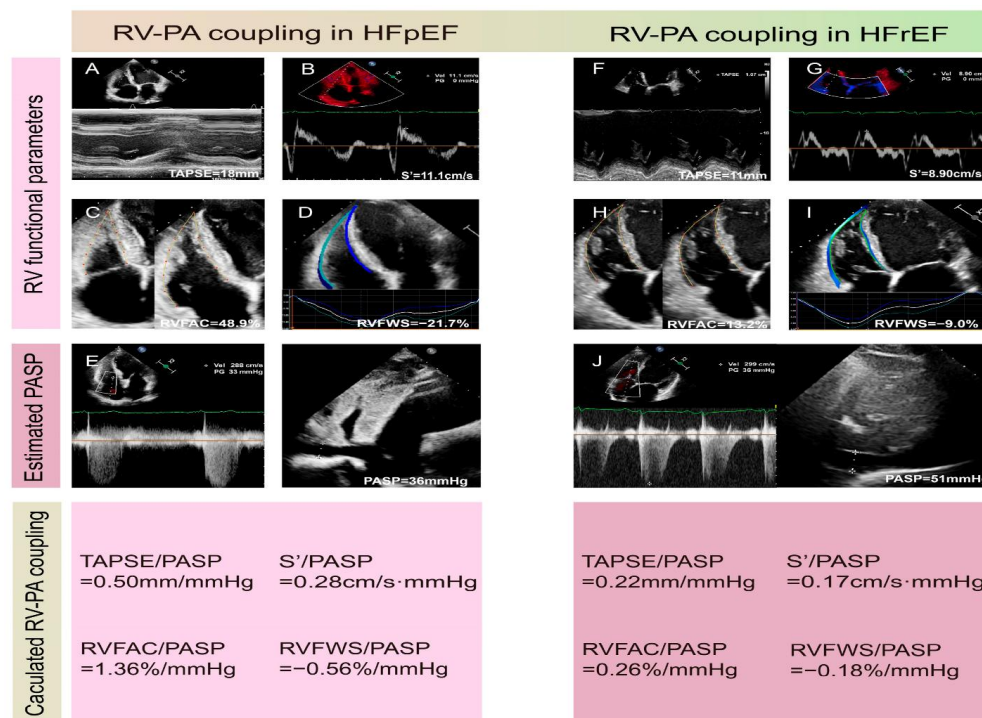


Figure 3: Measurements of right ventricular-pulmonary artery coupling in HFpEF (A–E) and HFrEF (F–J) patients using 2DE and speckle tracking echocardiography. (A,F) Measurements of TAPSE. (B,G) Measurement of S' . (C,H) Calculation of RVFAC. (D,I) Evaluation of RVFWS. (E,J) Estimation of PASP using peak tricuspid regurgitation velocity, RVSP, and inferior vena cava diameter. 2DE: two-dimensional echocardiography; FAC: functional area change; HFpEF: heart failure with preserved ejection fraction; HFrEF: heart failure with reduced ejection fraction; PASP: pulmonary arterial systolic pressure; RVFWS: free wall longitudinal strain; RVSP: right ventricular systolic pressure; S' : tricuspid annular systolic velocity; TAPSE: tricuspid annular plane systolic excursion.

Clinical Significance

Right ventricular–pulmonary artery (RV-PA) coupling integrates right ventricular contractility and afterload, providing a sensitive marker for disease phenotyping, prognosis, and therapeutic decision-making. Studies have demonstrated that impaired RV-PA coupling, measured by indices such as tricuspid annular plane systolic excursion-to-pulmonary arterial systolic pressure (TAPSE/PASP) or right ventricular free-wall strain (RVFWS/PASP), correlates with elevated natriuretic peptide levels, pulmonary hypertension, renal dysfunction, and adverse outcomes including hospitalization and cardiovascular death. Machine learning and exercise echocardiography studies have further stratified HFpEF into phenogroups characterized by varying degrees of RV-PA coupling, biventricular reserve, and exercise tolerance, linking the lowest coupling values to atrial fibrillation and poor prognosis (Wang et al., 2024).

Non-invasive indices such as TAPSE/PASP and S'/PASP also help differentiate HFpEF patients with pulmonary hypertension from those without, guiding timely diagnosis and intervention. Beyond prognostic use, RV-PA coupling plays a key role in therapeutic monitoring. Interventional studies have shown that pharmacologic and hemodynamic modulation such as β -stimulation with dobutamine or treatment with dapagliflozin can enhance pulmonary vascular compliance and improve coupling, translating to better clinical outcomes. Thus, evaluating RV-PA coupling provides not only diagnostic and prognostic insights but also a dynamic measure of treatment response in HFpEF management (Bok et al., 2023).

RV-PA Coupling in Heart Failure Phenotypes

Heart Failure With Mildly Reduced Ejection Fraction

Heart failure with mildly reduced ejection fraction has gained increasing clinical interest due to its growing prevalence and complex pathophysiology involving both left and right heart dysfunction. Patients with this condition often exhibit a prognosis comparable to or worse than that of those with reduced ejection fraction, highlighting the need for early risk identification. Right ventricular–pulmonary artery coupling indices, particularly the tricuspid annular plane systolic excursion-to-pulmonary arterial systolic pressure ratio, have proven valuable as independent predictors of adverse outcomes. Studies show that this index can outperform traditional left ventricular measures in identifying high-risk patients and guiding early therapeutic interventions.

Heart Failure With Reduced Ejection Fraction

In heart failure with reduced ejection fraction, right ventricular–pulmonary artery coupling plays a key role in disease progression and prognosis. Preserved coupling reflects stable cardiac performance, whereas uncoupling signals adverse remodeling and poor outcomes. Research indicates that exercise-based assessments can unmask hidden contractile limitations and differentiate clinical phenotypes beyond resting evaluations. Parameters such as the tricuspid annular plane systolic excursion-to-pulmonary arterial systolic pressure ratio, right ventricular free-wall strain-to-pulmonary arterial systolic pressure ratio, and right ventricular global longitudinal strain-to-pulmonary arterial systolic pressure ratio have shown strong prognostic value for mortality and exercise intolerance. Alternative coupling metrics, including combinations of tricuspid annular motion, pulmonary acceleration time, and stroke volume-to-end-systolic volume ratio, also enhance predictive accuracy.

Therapeutic Implications

Therapeutically, both pharmacologic and device-based interventions can modify coupling dynamics. Angiotensin receptor–neprilysin inhibitors, such as sacubitril/valsartan, have been shown to improve right ventricular–pulmonary artery coupling independent of left ventricular remodeling, while cardiac resynchronization therapy can restore mechanical synchrony and improve coupling in selected patients. Monitoring coupling changes during therapy provides an objective means to evaluate treatment response and refine clinical strategies for optimizing outcomes in both mildly and markedly reduced ejection fraction heart failure.

Conclusion

Right ventricular–pulmonary artery uncoupling signals advanced heart failure and is a sensitive indicator of dysfunction. Early recognition of this process is essential for guiding management and predicting outcomes, and growing research highlights its critical role across heart failure subtypes. Evaluating RV-PA coupling provides not only diagnostic and prognostic insights but also a dynamic measure of treatment response in HF management. Monitoring coupling changes during therapy provides an objective means to evaluate treatment response and refine clinical strategies for optimizing outcomes.

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