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THE EFFECT OF LEG ELEVATION ON PRELOAD RESPONSIVENESS IN HEART FAILURE PATIENTS

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ABSTRACT
Accurate hemodynamic assessment is critical for guiding fluid therapy and avoiding fluid overload in patients with heart failure (HF). Leg elevation maneuvers, including passive leg raising (PLR) and leg lifting (PLL), have emerged as functional diagnostic interventions. Still, their multifaceted roles across different HF phenotypes have not been fully synthesized. This literature review aimed to evaluate the effect of leg elevation on preload responsiveness and its broader clinical applications in adult patients with HF. A comprehensive search of online studies published between 2019 and 2025 was conducted across multiple databases (Sage Journals, Scopus, ScienceDirect, PubMed, Wiley Online Library, and ProQuest). Keywords included “heart failure”, “passive leg raising”, and “hemodynamics.” A total of 1551 articles were identified, and 5 articles were thoroughly reviewed. Five articles that met the inclusion criteria were systematically analyzed to synthesize evidence on the impact of PLR on key hemodynamic parameters. Leg elevation serves distinct, context-dependent roles. PLR/PLL is a provocative test in patients with suspected HF with preserved ejection fraction (HFpEF), confirming latent diastolic dysfunction with a significant PCWP increase. A blunted increase in the stroke volume index (SVi) during PLR/PLL signifies exhausted preload reserve and is an independent predictor of poor clinical outcomes in patients with HF with reduced ejection fraction (HFrEF). A significant decrease in PPV during the maneuver accurately predicts fluid responsiveness, which is particularly crucial for vulnerable patients, such as those with heart failure, as it remains accurate even with low-tidal-volume ventilation. Leg elevation is a versatile and reliable non-invasive maneuver with a multifaceted role in the management of HF. Beyond simply predicting fluid responsiveness, it functions as a crucial diagnostic tool for HFpEF, a prognostic tool for HFrEF, and an accurate predictor of fluid needs in critical care settings. Integrating PLR/PLL into clinical practice allows for precise, physiology-based decision-making, fluid management optimization, and improved patient outcomes.

Keywords: fluid responsiveness; heart failure; hemodynamics; passive leg raising

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INTRODUCTION

Heart failure (HF) has become a global health concern due to its complex etiology and high rates of morbidity and mortality. An estimated 64 million people worldwide were affected by HF in 2023, particularly those over 60 years of age who face a 20-fold higher risk (Savarese et al., 2023). It remains the leading cause of hospitalization among the elderly and imposes a substantial burden on healthcare systems (Chen-Scarabelli et al., 2015). In Indonesia, risk factors such as smoking, diabetes, hypertension, and obesity contribute to the rising prevalence of HF, with hypertension affecting 13.21% of the population in North Sulawesi and 9.67% in West Java (Health Research and Development Agency, 2019). Ischemic heart disease accounts for 53.2% of deaths related to hypertension, emphasizing the need for early detection and management (Health Research and Development Agency, 2019; Jatmiko et al., 2016; Ministry of Health, 2024). The challenge of HF management is further complicated by uneven healthcare infrastructure, including a shortage of cardiologists and limited access to advanced cardiac monitoring facilities (Klabunde, 2023).

One of the most frequent clinical challenges in HF management is optimizing fluid status. Excessive fluid administration can trigger pulmonary edema and prolong ventilator use, while inadequate intravascular volume may lead to organ hypoperfusion (Kapur et al., 2024). Therefore, accurately predicting a patient's positive response to fluid administration known as preload responsiveness is crucial. Traditional static hemodynamic assessments such as central venous pressure (CVP) have been shown to be unreliable in predicting fluid response due to multiple measurement errors and variations in ventricular compliance (Araos et al., 2020; Matolinets & Yakymenko, 2024). As a result, clinicians have shifted toward dynamic functional hemodynamic assessments (Araos et al., 2020).

The passive leg raising (PLR) maneuver serves as a diagnostic intervention in a non-invasive preload stress test. Functionally, it acts as a reversible “endogenous fluid challenge,” temporarily shifting approximately 150–300 mL of blood from the lower extremities and splanchnic circulation to the central circulation (Fudim et al., 2022; Kar, 2025). This transient increase in preload allows clinicians to assess cardiac response according to the Frank-Starling curve without the risks associated with external fluid loading (Alvarado-Sánchez, 2015; Matolinets & Yakymenko, 2024). Dynamic functional hemodynamics can be evaluated through three categories of “sensors” to understand the patient's response to fluid maneuvers. The **first** is forward flow assessing whether the heart can effectively convert increased preload into systemic circulation. This can be measured through cardiac output (CO), stroke volume (SV), and left ventricular ejection fraction (LVEF) (Barjaktarevic et al., 2018; Eder et al., 2023). An increase in CO indicates preload responsiveness and potential benefit from future fluid boluses (Alvarado-Sánchez, 2015; Fudim et al., 2022). The **second** is backward pressure, evaluating whether the heart can tolerate added volume without backward congestion (Tabucanon & Tang, 2020).

In patients with HF, particularly those with heart failure with preserved ejection fraction (HFpEF), the ventricles become stiff, making the addition of fluid akin to pouring water into a full bottle, where overflow represents backward congestion. The primary parameter used is pulmonary capillary wedge pressure (PCWP), which evaluates the backward transmission of pressure from the left ventricle to the left atrium and lungs (Eder et al., 2023; Van De Bovenkamp et al., 2022). Elevated PCWP often indicates pulmonary congestion (Eder et al., 2023). The **third** involves assessing cardiopulmonary interaction, as mechanical ventilation causes cyclic intrathoracic pressure changes that influence venous return and stroke volume (Berger et al., 2023). Functional hemodynamic parameters such as stroke volume variation (SVV) and pulse pressure variation (PPV) are commonly used to evaluate fluid responsiveness (Berger et al., 2023; Teboul et al., 2019). The passive leg raising maneuver offers a simple, rapid, and non-invasive bedside method for assessing patients' functional hemodynamics, particularly in critical care settings. The ability to determine fluid responsiveness is vital in HF management to prevent adverse effects of fluid overload, such as pulmonary edema and prolonged mechanical ventilation (Jaenputra et al., 2024). Passive leg elevation enhances HF management by facilitating precise fluid therapy adjustments, improving cardiac output, and promoting better overall patient outcomes (Bhadade et al., 2022; Cherpanath et al., 2016). This literature review aims to examine the effects of passive leg elevation on preload responsiveness in patients with heart failure.

METHOD

This literature review was conducted to identify relevant studies evaluating the effect of leg elevation on preload responsiveness among adult patients with heart failure (HF). The search process was systematically performed based on a clinical question using the PICO framework, which includes: (i) Population/Problem, (ii) Intervention, (iii) Comparison, and (iv) Outcome. The literature search was carried out in May 2025 across several online databases, including Sage Journals, Scopus, ScienceDirect, PubMed, Wiley Online Library, and ProQuest. The review process followed the PRISMA guidelines (Moher et al., 2009). Search strategies utilized Boolean operators and specific keywords, namely: "(heart failure patient OR cardiac dysfunction)” AND “(passive leg raising OR leg lifting)" AND "(circulation OR hemodynamics)" NOT "(narrative review OR case study)."

Studies were included based on the following criteria: (1) written in English, (2) published within the last seven years (2019–2025), (3) classified as research articles, and (4) available in open-access format. Exclusion criteria included pediatric populations, case reports, and narrative reviews. The first screening stage involved 1,551 documents retrieved from the Boolean search. Language, publication year, and article type filters eliminated 1,387 documents, leaving 164 articles. The second stage involved screening titles and/or abstracts for relevance and full-text availability, reducing the total to 14 articles. In the third stage, duplicate and irrelevant articles were excluded after abstract review, leaving five studies for full-text assessment. In the fourth stage, the five full-text articles were critically appraised using the Joanna Briggs Institute (JBI) critical appraisal tool to assess methodological quality. Articles that met the quality standards were included in the final synthesis. The study selection process was illustrated using a PRISMA flow diagram (Figure 1).

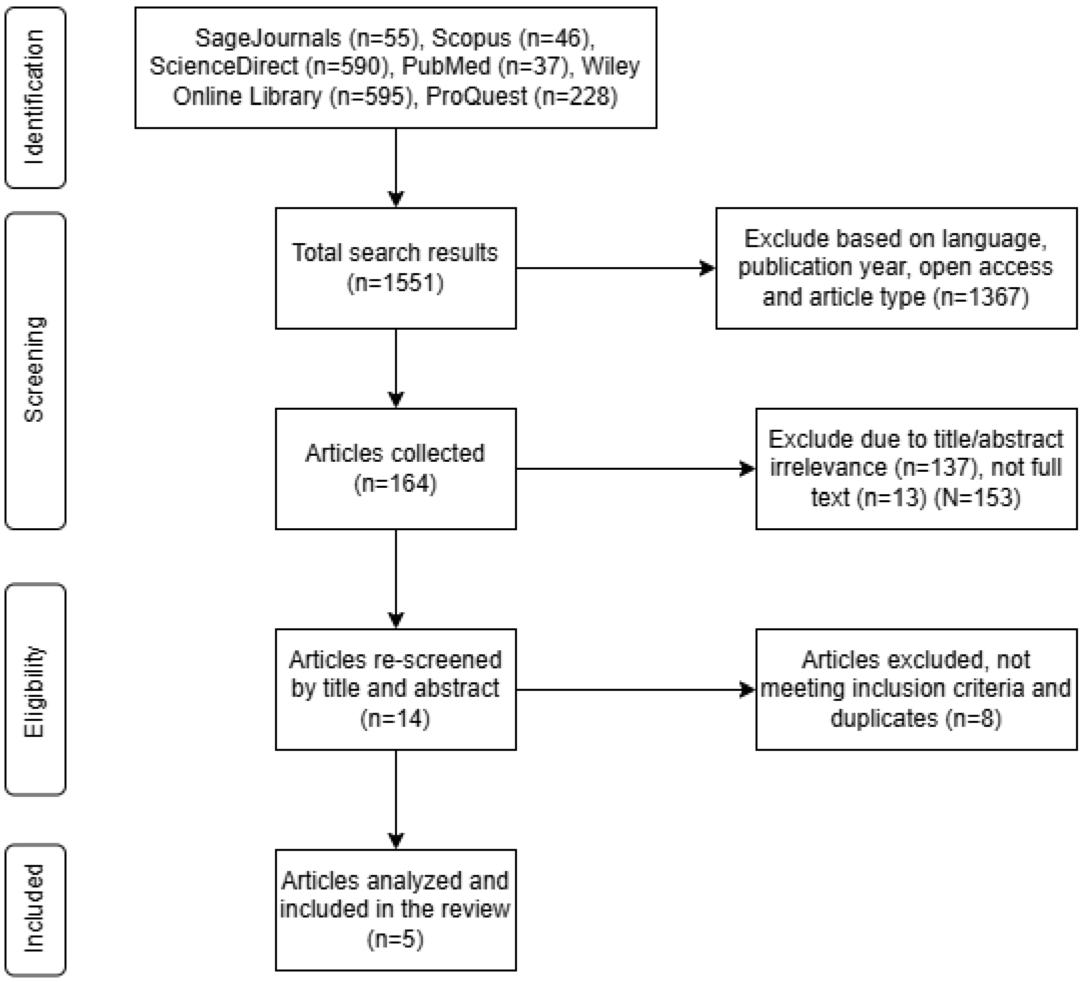

Figure 1. Literature Search Flowchart

RESULT

Five studies published between 2019 and 2025 were systematically synthesized, involving a total of 994 adult cardiac patients. Following the identification and classification process based on similarities in key elements related to the topic, the researchers conducted an integrated analysis of each article, resulting in a collective conclusion as presented in Table 1 below.

Table 1.
Synthesis Matrix of Selected Journals

No	Writer (Year) *Country*	Objective	Method	Results
1	Henein et et al., (2019)	To assess whether *passive leg lifting* (PLL) in suspected patients heart failure (HF) can be used to estimate *Left Ventricular Filling* high *Pressure (LVFP) using Echo-Doppler measurements*.	Prospective study. Measurement echocardiography *Doppler* and *right heart catheterization* (RHC) time rest; during *passive leg lifting* (PLL) in 29 patients (*consecutive sampling*) with symptom shortness of breath when activity and suspected fail heart disease (HF). After inspection moment *supine* (phase rest), the patient's legs lifted in a way passive 45 degrees on pillow for 2 minutes for evaluation repeat.	PLL in general significant increase *pulmonary capillary wedge pressure* (PCWP) average 10±3 mmHg which indicates patient suspected HF experienced instability pressure filling heart that is not observed when rest. Decrease mark *left atrial strain rate at atrial contraction* (LASRa) when elevation legs show correlation strong with PCWP (p = 0.004). Findings diagnostic existence dysfunction latent diastolic (consistent with HFpEF) identified consequence addition (temporary) fluid that eventually impact on increasing *backward pressure* consequence filling left ventricle that is not stable.
2	Tossavainen et et al., (2020) *Sweden*	To assess the current PCWP PLL in two groups of patients who had *Left Ventricular Ejection Fraction* (LVEF) was normal; one group with increased NT-proBNP (eBNP), and one group with normal plasma NT-proBNP (nBNP) concentrations.	Comparative study retro-spective. 85 patients with normal LVEF (>50%) was selected from the database (eBNP = 51; nBNP = 34) which has been through RHC (range 2008–2015). PCWP was measured under conditions rest, during PLL, and training *supine bicycle*. Other parameters assessed including *mean pulmonary arterial pressure* (mPAP) and *cardiac output* (CO).	Patient with normal EF and eBNP it turns out experience improvement significant at PCWP values >15 mmHg when elevation legs with sensitivity of 91% and specificity of 92% in predict PCWP increase >25 mmHg when activity. This study precisely evaluates addition *preload* temporary as an actual provocative test for diagnose fail hidden heart (*occult* HFpEF). Patients expe-rience increase pressure filling heart in a way pathological when activity – consistent with HFpEF.
3	Shibata & Katsumoto, (2021) *Japan*	To assess the hemodynamic characteristics of patients with *Heart Failure with reduced Ejection Fraction* (HFrEF) in response to non-invasive *preload stress* during stress changes dynamic postural-combina-tion position *semi-sitting* and PLL; and evaluate whether postural stress can be used for risk stratifi-cation.	Prospective study. Comparison of 101 patients HFrEF (LVEF<40%) with 35 patients healthy everyone measurements were taken echocardiography from corner parasternal and apical LV *probing*, followed by postural stress testing (April 2019 to February 2020). Position gradually from position *left decubitus* (left lateral), *semi-sitting*, PLL and postural stress (*semi-sitting* plus elevation legs 45º) with period equalization every 2 minutes. Other parameters recorded namely ECG monitor, blood pressure blood, and pulse during the procedure.	PLL results in improvement significant *stroke volume index* (SVi) in patients HFrEF. Meanwhile, changes mark SVi (Δ SVi) relatively small or none. There is precisely found in patients known to have There is problem *adverse* cardiovascular, refers to the output poor clinical outcome (3.4 ± 4.0 vs. 6.4 ± 3.8 mL/m², p = 0.002). This become marker that Δ SVi which is not tall signify condition *exhausted preload reserve*, meaning reserves limited *preload* and becomes predictor problem cardiovascular so that PLL can determine stratification risk HFrEF in the future upcoming non - invasively (*hazard ratio* 0.81, p = 0.02).
4	Mallat et et al., (2022) *French*	To determine whether *passive leg raising-*	Multicenter prospective study. 270 critically ill patients (aged ≥18 years) on ventilators due to	PLR results in decline significant on PPV which is accurate with AUROC = 0.92 (95% CI; 0.88-

No	Writer (Year) *Country*	Objective	Method	Results
		induced changes in mark *pulse pressure variation* (ΔPPV_{PLR}) can predict fluid response in patients using mechanical ventilation.	failure of circulation. Acute cardiac arrhythmias were diagnosed between September 21, 2017, and September 21, 2021, in 11 intensive care units across 6 teaching hospitals and 5 general *hospitals*. *index* (CI) and PPV were measured before/during PLR and before/after *volume expansion*. Furthermore, *areas under the receiver operating charac-teristic curves* (AUROC) and *grey zones* will be determined to differentiate responsiveness fluid relative and absolute ΔPPV_{PLR}.	0.95, p<0.001), so can predict response positive (*preload responsiveness*) on fluid bolus plan patient later; where change relative ΔPPV_{PLR} shows small grey *zone* (4.8%), meaning PLR as intervention good diagnostics in HF patients, because consistent accurate in patients installed ventilation mechanic with low tidal volume.
5	Mallat et et al., (2025) *Multiple*	To evaluate whether *passive leg raising-induced* changes in mean *pulse pressure variation* (PPV) can predict *preload*/fluid response in patients using mechanical ventilation with tidal volume (VT) low in the intensive care unit (ICU).	*Systematic review and meta-analysis. Screening of* PubMed, Embase, and Cochrane databases until August 2024; 5 articles found studies involving 474 patients. The QUADAS-2 scale was used to evaluate risk of bias. *Summary* curve *receiving operating charac-teristic* (SROC), combined sensitivity, and specificity also measured.	PLR results in a significant decline in PPV with a sensitivity of 0.88 (95% CI; 0.82–0.91) and specificity of 0.83 (95% CI; 0.76–0.89). This is relevant for HF patients who are at high risk for *fluid overload*, where this maneuver is considered safe to assess the *preload reserve* without give a fluid bolus moreover formerly.

DISCUSSION

The studies reviewed in Table 1 indicate that the leg elevation maneuver serves as a diagnostic intervention to assess functional hemodynamics, with diverse clinical applications in patients with heart failure. Analysis of the five included studies revealed not only preload responsiveness but also the diagnostic and prognostic significance of cardiac maneuvers in these patients. Two studies from Sweden highlighted the crucial diagnostic role of leg elevation in identifying HFpEF (Heart Failure with Preserved Ejection Fraction). These studies reported cases with normal left ventricular filling pressure at rest, termed occult HFpEF. When the leg elevation maneuver was performed, PCWP (Pulmonary Capillary Wedge Pressure) increased significantly, supported by echocardiographic parameters such as LASRa (Left Atrial Strain Rate during atrial contraction), which strongly correlated with elevated PCWP during the maneuver (Henein et al., 2019). An increase in PCWP does not necessarily indicate tolerance to additional external fluid; rather, it suggests that the preload increase from leg elevation cannot be accommodated (Van De Bovenkamp et al., 2022). Consequently, left ventricular pressure rises sharply after the maneuver, reflected by a significant PCWP increase (>15 mmHg or ≥19 mmHg) (Henein et al., 2019; Van De Bovenkamp et al., 2022).

These findings are further supported by subsequent studies reporting that PCWP >15 mmHg during the maneuver may predict a pathological rise in PCWP among patients with elevated NT-proBNP, indicating latent diastolic dysfunction (Hotz et al., 2024; Tossavainen et al., 2020). Thus, patients with initially normal LVEF (Left Ventricular Ejection Fraction) may fall under the category of occult HFpEF, or hidden heart failure. Additional parameters associated with PCWP include: (i) Left atrial strain rate (LASRa), where high filling pressure in a stiff heart impairs left atrial function

(Henein et al., 2019); (ii) E/e′ and LAVI, which increase in parallel with PCWP findings (Shibata et al., 2021); and (iii) NT-proBNP, a biomarker reflecting myocardial stretch, supporting clinical assessment of PCWP (Tossavainen et al., 2020). Furthermore, mean pulmonary arterial pressure (mPAP) can be evaluated to provide broader insight into pulmonary circulatory pressure beyond PCWP (Mallat et al., 2022).

A study from Japan demonstrated the prognostic value of leg elevation in patients with heart failure, particularly those with HFrEF (Heart Failure with Reduced Ejection Fraction). Results from dynamic postural stress testing (semi-seated and leg-elevated positions) enabled measurement of preload reserve through changes in stroke volume index (ΔSVi) (Shibata et al., 2021). When SVi or cardiac index (CI) increased significantly (e.g., ≥10–15%), the patient's heart was functioning along the ascending limb of the Frank-Starling curve, indicating adequate preload reserve or "responsiveness" (Kar, 2025; Shibata et al., 2021). On the other hand, patients with a relatively low ΔSVi response exhibited a higher risk of cardiovascular events and poorer long-term prognosis (hazard ratio 0.81, $p = 0.02$) (Shibata et al., 2021). Therefore, leg elevation can serve as a risk stratification tool for identifying high-risk HFrEF patients who may require more aggressive management.

Two additional studies, though not exclusively conducted in heart failure patients, illustrated hemodynamic patterns like those observed during acute decompensation. Leg elevation induced changes in pulse pressure variation (ΔPPV_{PLR}), accurately predicting fluid responsiveness (AUROC 0.92) with a narrow gray zone (Mallat et al., 2022). A 2025 meta-analysis further confirmed that absolute changes in PPV resulting from leg elevation have strong diagnostic accuracy (sensitivity 0.88; specificity 0.83), even in patients with low tidal volumes (Mallat et al., 2025). This finding is particularly relevant to heart failure patients prone to fluid overload (Bhadade et al., 2022; Mallat et al., 2025). The preload increase from leg elevation helps stabilize circulation, and patients who are "responsive" demonstrate a significant decrease in PPV (e.g., an absolute reduction of 2%) (Mallat et al., 2025; Teboul et al., 2019). Thus, this maneuver provides individualized insight into fluid requirements and aids clinical decision-making regarding fluid administration to prevent pulmonary congestion.

The synthesis of five studies demonstrated that leg elevation serves as a comprehensive functional hemodynamic assessment tool, providing diagnostic, prognostic, and therapeutic insights in heart failure management. The maneuver enables simultaneous evaluation of forward flow (SVi/CI), backward pressure (PCWP), and, when applicable, cardiopulmonary interaction (PPV). A positive response marked by an increase in cardiac output or stroke volume (≥10–15%) and a decrease in PPV indicates adequate preload reserve and guides safe fluid administration. Conversely, a non-response suggests exhausted preload reserve, signaling the need to avoid additional fluids and consider alternative treatments such as inotropes. In cases of occult HFpEF, a significant rise in PCWP during leg elevation reflects diastolic stiffness and an inability to tolerate increased preload. Beyond assessing preload responsiveness, this maneuver aligns with broader heart failure care principles, emphasizing the role of exercise and non-pharmacological nursing interventions, such as breathing exercises, to enhance activity tolerance and quality of life (Kurniyanti et al., 2023; Chandra et al., 2025). Despite the strong empirical evidence, the authors acknowledge several limitations. Some studies involved relatively small sample sizes and heterogeneous patient populations (suspected HF, HFrEF, general ICU patients), which limits the generalizability of findings to all heart failure cases. Nevertheless, the consistency of the clinical context across studies supports the clinical utility of leg elevation as a diagnostic intervention for assessing essential functional hemodynamics.

CONCLUSION

The use of leg elevation as a non-invasive diagnostic intervention is beneficial for providing clinical insight into a patient's preload status through dynamic functional hemodynamic parameters. This maneuver serves as a practical and informative tool to assist healthcare professionals in making clinical decisions related to risk stratification, fluid responsiveness, and significant hemodynamic alterations. Moreover, its ease of implementation and non-invasive nature make leg elevation a clinically relevant intervention for evaluating cardiac function and optimizing management strategies in patients. The long-term impact on patient outcomes can be further validated through collaboration between competent nurses, particularly specialist nurses and physicians in administering fluid therapy to achieve optimal therapeutic goals.

REFERENCES

Alvarado-Sánchez, J. I. (2015). The passive leg raising test (PLR). Colombian Journal of Anesthesiology, 43(3), 214–218. https://doi.org/10.1016/j.rcae.2015.03.005

Araos, J., Kenny, J. E. S., Rousseau-Blass, F., & Pang, D. S. (2020). Dynamic prediction of fluid responsiveness during positive pressure ventilation: A review of the physiology underlying heart-lung interactions and a critical interpretation. Veterinary Anaesthesia and Analgesia, 47(1), 3–14. https://doi.org/10.1016/j.vaa.2019.08.004

Barjaktarevic, I., et al. (2018). Ultrasound assessment of the change in carotid corrected flow time in fluid responsiveness in undifferentiated shock. Critical Care Medicine, 46(11), e1040–e1046. https://doi.org/10.1097/CCM.0000000000003356

Berger, D., Moller, P. W., & Bachmann, K. F. (2023). Cardiopulmonary interactions—Which monitoring tools to use? Frontiers in Physiology, 14. https://doi.org/10.3389/fphys.2023.1234915

Bhadade, R., Harde, M., de Souza, R., & Madke, T. (2022). Assessment of fluid responsiveness by changes in end tidal carbon dioxide during passive leg raising test and fluid challenge. Journal of the Association of Physicians of India, 70(5), 70–75.

Chandra, K. A., Herawati, T., & Zahra, A. N. (2025). The effectiveness of breathing exercises in reducing dyspnea in patients with heart failure: A systematic review. Malahayati International Journal of Nursing and Health Science, 8(3), 389–398. https://doi.org/10.33024/minh.v8i3.913

Chen-Scarabelli, C., Saravolatz, L., Hirsh, B., Agrawal, P., & Scarabelli, T. M. (2015). Dilemmas in end-stage heart failure. Journal of Geriatric Cardiology, 12(1), 57–65. https://doi.org/10.11909/j.issn.1671-5411.2015.01.007

Cherpanath, T. G. V., et al. (2016). Predicting fluid responsiveness by passive leg raising: A systematic review and meta-analysis of 23 clinical trials. Critical Care Medicine, 44(5), 981–991. https://doi.org/10.1097/CCM.0000000000001556

Eder, M., et al. (2023). The importance of forward flow and venous congestion in diuretic response in acute heart failure: Insights from the ESCAPE trial. International Journal of Cardiology, 381, 57–61. https://doi.org/10.1016/j.ijcard.2023.04.002

Fudim, M., Khan, M. S., Paracha, A. A., Sunagawa, K., & Burkhoff, D. (2022). Targeting preload in heart failure: Splanchnic nerve blockade and beyond. Circulation: Heart Failure, 15(3), 211–220. https://doi.org/10.1161/CIRCHEARTFAILURE.121.009340

Health Research and Development Agency. (2019). National Riskesdas Report 2018. Jakarta: Health Research and Development Agency Publishing Institute (LPB).

Henein, M. Y., Tossavainen, E., A'roch, R., Söderberg, S., & Lindqvist, P. (2019). Can Doppler echocardiography estimate raised pulmonary capillary wedge pressure provoked by passive leg lifting in suspected heart failure? Clinical Physiology and Functional Imaging, 39(2), 128–134. https://doi.org/10.1111/cpf.12547

Hotz, E., van Gemmern, T., & Kriege, M. (2024). Are we always right? Evaluation of the performance and knowledge of the passive leg raise test in detecting volume responsiveness in critical care patients: A German national survey. Journal of Clinical Medicine, 13(9), 2518. https://doi.org/10.3390/jcm13092518

Jaenputra, J. J., Sigit, R., Harsono, T., & Firdaus, A. A. A. (2024). Heart disease detection from PSAX echocardiography view using ultrasound portable based on machine learning method.

In Proceedings of the 2024 International Electronics Symposium: Shaping the Future: Society 5.0 and Beyond (pp. 637–643). IEEE. https://doi.org/10.1109/IES63037.2024.10665785

Jatmiko, W., Ma'Sum, M. A., Isa, S. M., Imah, E. M., Rahmatullah, R., & Wiweko, B. (2016). Developing smart telehealth system in Indonesia: Progress and challenge. 2015 International Conference on Advanced Computer Science and Information Systems (ICACSIS), 29–36. https://doi.org/10.1109/ICACSIS.2015.7415199

Kapur, N. K., et al. (2024). Mechanical preload reduction: Harnessing a cornerstone of heart failure management to improve clinical outcomes. ASAIO Journal, 70(10), 821. https://doi.org/10.1097/MAT.0000000000002240

Kar, A. (2025). What happens to preload and afterload in heart failure? Narayana Health. https://www.narayanahealth.org/blog/what-happens-to-preload-and-afterload-in-heart-failure

Klabunde, R. E. (2025). CV Physiology: Pathophysiology of heart failure. Wolters Kluwer. https://cvphysiology.com/heart-failure/hf003

Kurniyanti, W. S., Herawati, T., & Aryani, D. F. (2023). Effect of physical exercise on heart failure patients. Journal of Telenursing (JOTING), 5(2), 2650–2659. https://doi.org/10.31539/joting.v5i2.5854

Mallat, J., et al. (2022). Passive leg raising-induced changes in pulse pressure variation to assess fluid responsiveness in mechanically ventilated patients: A multicenter prospective observational study. British Journal of Anaesthesia, 129(3), 308–316. https://doi.org/10.1016/j.bja.2022.04.031

Mallat, J., et al. (2025). Changes in pulse pressure variation induced by passive leg raising test to predict preload responsiveness in mechanically ventilated patients with low tidal volume in ICU: A systematic review and meta-analysis. Critical Care, 29(1), 18. https://doi.org/10.1186/s13054-024-05238-x

Matolinets, N., & Yakymenko, I. (2024). Assessment of fluid responsive unity as a component of hemodynamic monitoring in the operating room and intensive care unit. Emergency Medicine (Ukraine), 20(6), 475–481. https://doi.org/10.22141/2224-0586.20.6.2024.1759

Ministry of Health, Republic of Indonesia. (2024). Thematic Report of the 2023 Indonesian Health Survey: Portrait of a Healthy Indonesia. Jakarta: Ministry of Health.

Moher, D., et al. (2009). Preferred reporting items for systematic reviews and meta-analyses: The PRISMA statement. PLoS Medicine, 6(7), e1000097. https://doi.org/10.1371/journal.pmed.1000097

Savarese, G., Becher, P. M., Lund, L. H., Seferovic, P., Rosano, G. M. C., & Coats, A. J. S. (2023). Global burden of heart failure: A comprehensive and updated review of epidemiology. Cardiovascular Research, 118(17), 3272–3287. https://doi.org/10.1093/cvr/cvac013

Shibata, N., et al. (2021). Easy-to-use preload stress echocardiography by using combined dynamic postural stress can identify high-risk patients with heart failure with reduced ejection fraction. ESC Heart Failure, 8(4), 2765–2775. https://doi.org/10.1002/ehf2.13346

Tabucanon, T., & Tang, W. H. W. (2020). Right heart failure and cardiorenal syndrome. Cardiology Clinics, 38(2), 185–202. https://doi.org/10.1016/j.ccl.2020.01.004

Teboul, J. L., Monnet, X., Chemla, D., & Michard, F. (2019). Arterial pulse pressure variation with mechanical ventilation. American Journal of Respiratory and Critical Care Medicine, 199(1), 22–31. https://doi.org/10.1164/rccm.201801-0088CI

Tossavainen, E., Wikström, G., Henein, M. Y., Lundqvist, M., Wiklund, U., & Lindqvist, P. (2020). Passive leg-lifting in heart failure patients predicts exercise-induced rise in left ventricular filling pressures. Clinical Research in Cardiology, 109(4), 498–507. https://doi.org/10.1007/s00392-019-01531-

Van De Bovenkamp, A. A., et al. (2022). The value of passive leg raise during right heart catheterization in diagnosing heart failure with preserved ejection fraction. Circulation: Heart Failure, 15(4), e008935. https://doi.org/10.1161/CIRCHEARTFAILURE.121.008935