



REVIEWS

RETHINKING PREHOSPITAL FLUID RESUSCITATION FOR MASSIVE PULMONARY EMBOLISM: A NARRATIVE LITERATURE REVIEW

Elena Kalkidis^{*1}; Joshua Martin¹; Jean-Paul Veronese¹

Author Affiliations: 1. School of Medicine and Dentistry, Bachelor of Paramedicine Program, Griffith University, Gold Coast Campus, QLD, Australia.

Recommended Citation: Kalkidis, E., Martin, J., & Veronese, J. (2026). Rethinking prehospital fluid resuscitation for massive pulmonary embolism: A narrative literature review. *International Journal of Paramedicine*. (16). 286-300. <https://doi.org/10.56068/FUZU7938>

Keywords: pulmonary embolism, fluid resuscitation, right ventricular dysfunction, hemodynamics, emergency medical services, EMS, paramedicine

Disclosures: The author declares no known competing financial interests or personal relationships that could appear to influence the work reported in this paper.

Funding: No external funding or financial support was received for this work.

Acknowledgements: The author thanks the Griffith University Paramedicine faculty for academic support and guidance during manuscript development.

Received: June 15, 2026

Revised: September 6, 2026

Revised: September 25, 2026

Accepted: September 29, 2026

Published: October 22, 2026

**Corresponding Author:*

etrinity10@outlook.com

ABSTRACT

Background: Massive pulmonary embolism (PE) is characterized by sustained hypotension and right ventricular (RV) dysfunction, resulting in high morbidity and mortality. Although these patients present hemodynamically unstable, hypotension arises from obstructive shock rather than hypovolemia. Despite this, fluid resuscitation (FR) remains common in prehospital care, and its role in massive PE remains controversial.

Objective: This review aimed to evaluate the efficacy of FR in adult patients with massive PE, with consideration of its implications for prehospital care.

Methods: A narrative literature review was conducted in April 2026 using Ovid MEDLINE and EMBASE (1950–April 2026). Due to the paucity of prehospital data, both human and animal studies examining any form of fluid therapy in massive PE were included. Non-peer-reviewed literature, unrelated conditions, and systematic reviews were excluded. Nine peer-reviewed studies met inclusion criteria.

Results: Fluid administration in massive PE was associated with worsened RV dysfunction, reduced cardiac output (CO), and increased hemodynamic instability. In contrast, alternative interventions, including positive inotropes and diuretic therapy (DT), were associated with improved RV function, stroke volume (SV), and hemodynamic stability.

Conclusion: The available evidence, although derived largely from animal, retrospective, and hospital-based studies, suggests routine FR in hypotensive patients with massive PE may exacerbate RV failure and compromise CO. Prehospital management should therefore consider strategies that support RV function and hemodynamic stability. These findings support reconsideration of FR as a primary intervention in massive PE and highlight the need for evidence-informed prehospital guidelines.

INTRODUCTION

Pulmonary embolism (PE) is a potentially life-threatening condition caused by obstruction of the pulmonary arteries, with an overall mortality of approximately 14.7% even among patients receiving treatment (Fernandes et al., 2019; Konstantinides et al., 2019). Clinical presentation varies according to clot burden and location, ranging from mild dyspnea to profound respiratory and hemodynamic compromise (Mata et al., 2020). Massive PE

(MPE), defined by sustained hypotension with a systolic blood pressure < 90 mmHg (Banerjee & Mora, 2020; Vyas et al., 2024), carries particularly high risk, with thirty-day mortality reported as high as 57.1%. Sub-massive PE is associated with mortality of approximately 6.7%, and low-risk PE around 3.5% (Gupta et al., 2020). In severe cases, MPE may precipitate cardiac arrest within one to two hours of symptom onset (Mata et al., 2020).

In MPE, hypotension arises from obstructive shock and right ventricular (RV) failure rather than true intravascular volume loss (McGuire et al., 2024). Obstruction of pulmonary blood flow reduces left ventricular preload and cardiac output (CO), producing hypotension despite normal or elevated circulating volume. Although fluid resuscitation (FR) is a mainstay of hypotension management in other shock states, its physiological rationale in MPE is uncertain. Evidence suggests FR may worsen RV dilatation, increase myocardial oxygen demand, and further compromise hemodynamics, with alternative hemodynamic strategies proving more beneficial (Belenkie et al., 1989; Mercat et al., 1999; Mortensen et al., 2020).

Despite evidence questioning the physiological benefit of FR in MPE, many ambulance services both locally (AV, 2025; QAS, 2020) and globally (BCEHS, 2026; NHS, 2025) continue to list FR as a treatment consideration for hypotensive PE in the prehospital setting. This persists in the face of growing literature suggesting FR may exacerbate RV failure and worsen outcomes, while strategies such as vasopressor support or diuretic therapy (DT) with volume removal may better preserve CO and hemodynamic stability (Ferrari et al., 2022; Ternacle et al., 2013). As paramedics are often the first clinicians to manage these patients, early resuscitation decisions may substantially influence hemodynamic trajectory and survival. This review aims to examine and synthesize the current literature on FR in adult patients with MPE, addressing the uncertainty surrounding its hemodynamic effects and informing prehospital clinical management. It evaluates whether FR confers benefit or harm in this high-risk cohort and explores the role of alternative strategies, including DT and vasopressor support, in informing safer and more physiologically aligned prehospital care for patients with MPE.

METHODS

REVIEW APPROACH

This study utilized a narrative literature review to synthesize existing evidence on FR in PE, with a particular focus on MPE. Narrative reviews aim to consolidate and interpret the current body of knowledge without necessarily undertaking exhaustive searching or formal quality appraisal (Grant & Booth, 2009). They are particularly suited to topics where evidence is limited, heterogeneous, or emerging, and where conceptual understanding is required (Snyder, 2019).

This approach was selected over more structured methodologies (e.g., systematic or scoping reviews) due to the limited and varied nature of the available evidence examining FR in MPE, particularly in the prehospital setting. Additionally, the purpose of this review was to explore physiological and clinical implications of FR rather than formally evaluate the effectiveness of a single intervention.

SEARCH STRATEGY

A preliminary search of the literature was conducted to refine key terms, followed by electronic searches of Ovid MEDLINE (1950–April 2026) and EMBASE (1966–April 2026). Searches combined Medical Subject Headings (MeSH) and plain-text keywords using Boolean operators (AND, OR), outlined in Table 1. Searches were limited to English-language, peer-reviewed primary research, with grey literature and clinical practice guidelines excluded. Records from both databases were combined and de-duplicated using Ovid’s built-in function before title and abstract screening. Reference lists of included studies were also screened for additional relevant literature.

Database	Search Strategy
Ovid MEDLINE	(exp Emergency Medical Services/ OR Emergency Medical Technicians/ OR Emergency Responders/ OR First Aid/ OR exp Ambulances/ OR Air Ambulances/ OR Paramedics/ OR (emergency care OR emergency management OR emergency medical service* OR EMS OR emergency medical team* OR emergency medical technician* OR EMT OR EMTs OR emergency response OR first aid OR first responder* OR prehospital care OR pre-hospital care OR prehospital emergency medical care OR pre-hospital emergency medical care OR acute care OR ambulance service* OR air ambulance* OR paramedic service* OR paramedic*).ti,ab,kf.) AND (exp Fluid Therapy/ OR (fluid* OR fluid therap* OR fluid resuscitat* OR volume expansion OR volume resuscitat* OR intravenous fluid therap* OR hemodynamic support OR haemodynamic support).ti,ab,kf.) AND (exp Pulmonary Embolism/ OR exp Thromboembolism/ OR (pulmonary embol* OR PE OR pulmonary arterial embol* OR thromboembol* OR sub-massive pulmonary embol* OR submassive pulmonary embol* OR massive pulmonary embol*).ti,ab,kf.)
Ovid Embase	(exp emergency health service/ OR exp ambulance/ OR exp Air Ambulances/ OR paramedical personnel/ OR (emergency care OR emergency management OR emergency medical service* OR EMS OR emergency medical team* OR emergency medical technician* OR EMT OR EMTs OR emergency response OR first aid OR first responder* OR prehospital care OR pre-hospital care OR prehospital emergency medical care OR pre-hospital emergency medical care OR acute care OR ambulance service* OR air ambulance* OR paramedic service* OR paramedic*).ti,ab,kw.) AND (exp fluid therapy/ OR (fluid* OR fluid therap* OR fluid resuscitat* OR volume expansion OR volume resuscitat* OR intravenous fluid therap* OR hemodynamic support OR haemodynamic support).ti,ab,kw.) AND (exp pulmonary embolism/ OR exp thromboembolism/ OR (pulmonary embol* OR PE OR pulmonary arterial embol* OR thromboembol* OR sub-massive pulmonary embol* OR submassive pulmonary embol* OR massive pulmonary embol*).ti,ab,kw.)

Table 1. Database search strategies.
Limits: Publication years 1950 to April 2026.
Abbreviations: EMS: emergency medical services; EMT: emergency medical technician; PE: pulmonary embolism.

INCLUSION/EXCLUSION CRITERIA

Studies were included if they were English-language, peer-reviewed primary research examining the hemodynamic effects of FR in PE in adult populations (18 years), conducted in either prehospital or hospital settings. Where relevant, experimental animal studies were also included to provide mechanistic insight into RV hemodynamics in acute PE, particularly given the limited availability of prehospital human data examining FR in MPE.

Studies were excluded if they focused on unrelated therapies (e.g., thrombolysis, anticoagulation, or embolectomy), non-PE pathologies, or pediatric populations. Abstracts, review articles, clinical practice guidelines, grey literature, non-English-language publications, and non-peer-reviewed publications were also excluded.

EXTRACTION

Elements of the PRISMA framework were used to guide reporting of the search and screening process (Moher et al., 2009). Figure 1 outlines the number of records identified, screened, excluded, and included in the final synthesis.

Two reviewers (EK, JM) independently screened titles and abstracts for relevance, followed by full-text assessment against the inclusion and exclusion criteria. Any differences in study selection were resolved through discussion, with a third reviewer (JV) providing final oversight where required. Following selection, included studies were analyzed to extract key findings relating to hemodynamic outcomes and treatment effects.

As this review was narrative in design, formal critical appraisal tools (e.g., CASP, JBI) were not applied. However, study relevance and methodological quality were considered during the screening process.

RESULTS

The database search identified 542 records across Ovid MEDLINE and EMBASE. Following removal of duplicates and screening of titles and abstracts, 41 full-text articles were assessed for eligibility. Of these, 32 studies were excluded based on predefined criteria, resulting in nine studies included in the final synthesis. The study selection process is illustrated in Figure 1. A summary of included studies is presented in Table 2, and excluded studies are outlined in Table 3.

STUDY CHARACTERISTICS

The nine included studies comprised a mix of experimental (animal) and clinical (human) designs. Four studies utilized animal models (canine and porcine) to investigate hemodynamic responses to acute PE, while five studies involved human populations, including prospective, retrospective, and randomized controlled trials (Belenkie et al., 1989; Ferrari et al., 2022; Ghignone et al., 1984; Mercat et al., 1999; Molloy et al., 1984; Mortensen et al., 2020; Nguyen et al., 2021; Schouver et al., 2017; Ternacle et al., 2013). Sample sizes ranged from 8 to 122 participants, with animal studies generally involving smaller cohorts (Belenkie et al., 1989; Ghignone et al., 1984; Molloy et al., 1984; Mortensen et al., 2020). Human studies primarily focused on patients with massive or sub-massive PE, with several comparing FR to alternative management strategies, including DT and vasopressor support (Ferrari et al., 2022; Mercat et al., 1999; Nguyen et al., 2021; Schouver et al., 2017; Ternacle et al., 2013).

Interventions varied across studies, including isolated FR, comparisons between FR and DT, and comparisons between FR and vasoactive agents such as noradrenaline. Outcomes assessed included hemodynamic parameters, RV function, biomarker changes, and adverse clinical events. Animal studies primarily informed physiological mechanisms, while human studies contributed to clinical and outcome-based findings.

HEMODYNAMIC EFFECTS OF FLUID RESUSCITATION

Across both experimental (animal) and clinical (human) studies, FR was consistently associated with increased RV preload, filling pressures, and overall hemodynamic burden (Belenkie et al., 1989; Ghignone et al., 1984; Molloy et al., 1984; Mortensen et al., 2020).

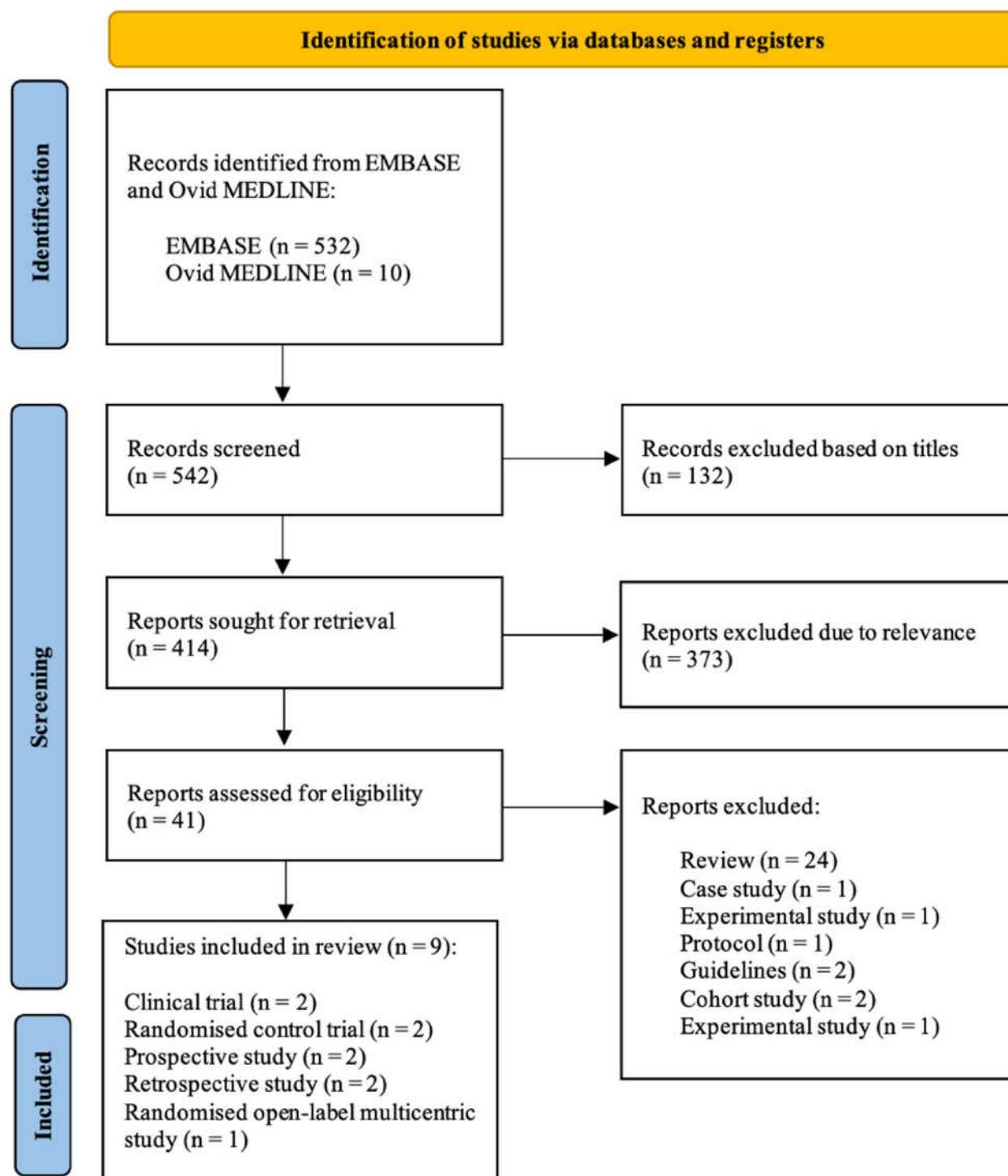


Figure 1. PRISMA flow diagram of retrieved included and excluded studies.

In animal models, FR increased left ventricular (LV) filling prior to embolization; however, following repeated embolic events, reductions in LV stroke work and cardiac output were observed (Belenkie et al., 1989).

In human studies, FR resulted in increases in right atrial pressure and RV end-diastolic volume, with only transient improvements in cardiac output reported (Mercat et al., 1999). These findings indicate that while FR may initially augment preload, this effect is not sustained in the setting of PE.

Author (Year)	Population [Sample Size]	Study Design / Intervention	Key Findings	Limitations
Belenkie et al. (1989)	Animal (canine) [n = 10]	Experimental FR (200–600 mL Ringer's lactate–blood mixture)	FR increased LV stroke work prior to embolization (188 to 260 mm Hg mm ; $p < 0.05$). Following embolization, FR resulted in reduced LV area index and stroke work (133 to 45 mm Hg mm ; $p < 0.001$), with septal shift consistent with RV dilatation and impaired LV filling.	The use of an animal model limits applicability to human physiology. Experimental conditions involving anesthesia and mechanical ventilation may have influenced hemodynamic responses. The study reflects acute changes only, and the fluid type is not standard in clinical practice.
Ferrari et al. (2022)	Human [n = 60]	Randomized controlled trial DT versus FR	FR was associated with slower normalization of BNP compared to DT (108 vs 56 hours; $p = 0.05$). DT resulted in faster biomarker reduction and greater early improvement (42% vs 12%; $p < 0.001$), with no deterioration in RV function.	Outcomes were primarily based on biomarkers rather than clinical endpoints. Potential allocation bias and patient heterogeneity may have influenced results.
Ghignone et al. (1984)	Animal (canine) [n = 8]	Experimental Dextran FR versus noradrenaline	FR increased SV and BP prior to embolization but resulted in reduced SV (9.1 to 6.3 mL; $p < 0.01$), decreased BP (97 to 65 mmHg; $p < 0.05$), and increased RV filling pressures following embolization, consistent with RV failure. Noradrenaline improved SV (6.2 to 11.3 mL; $p < 0.01$) and reduced filling pressures.	The small sample size increases the risk of statistical variability. The animal model and induced embolization may not accurately reflect human PE. Anesthesia and controlled ventilation may have influenced cardiovascular responses.
Ghignone et al. (1984)	Animal (canine)	Experimental Dextran FR versus noradrenaline	FR increased SV and BP prior to embolization but resulted in reduced SV (9.1 to 6.3 mL; $p < 0.01$), decreased BP (97 to 65 mmHg; $p < 0.05$), and increased RV filling pressures following embolization, consistent with RV failure. Noradrenaline improved SV (6.2 to 11.3 mL; $p < 0.01$) and reduced filling pressures.	The small sample size increases the risk of statistical variability. The animal model and induced embolization may not accurately reflect human PE. Anesthesia and controlled ventilation may have influenced cardiovascular responses.
Mercat et al. (1999)	Human [n = 13]	Prospective observational FR (500 mL dextran)	FR increased right atrial pressure (9 to 17 mmHg) and RV end-diastolic volume (123 to 150 mL/m ; $p < 0.05$). Cardiac index increased transiently (1.6 to 2.0 L/min/m ; $p < 0.05$), with no sustained improvement in RV function or pulmonary vascular resistance.	The small sample size and absence of a control group limit interpretation. Only a single FR bolus was assessed, and the fluid type used is not standard in current clinical practice.
Molloy et al. (1984)	Animal (canine) [n = 24]	Randomized controlled trial Control, FR (dextran), isoproterenol, noradrenaline	FR did not improve hemodynamic stability or survival. Noradrenaline improved BP and RV perfusion, with all animals in the noradrenaline group surviving compared to no survivors in the FR and control groups ($p < 0.01$).	The use of an animal model limits generalizability to human patients. Variability in animal size and experimental conditions may have influenced hemodynamic responses.
Mortensen et al. (2020)	Animal (porcine) [n = 22]	Randomized controlled trial FR versus DT versus control	FR increased RV end-diastolic volume (31 mL; $p = 0.004$), CO (approximately 2 L; $p = 0.002$), and RV ejection fraction ($p = 0.032$). DT reduced RV preload and pulmonary pressures and increased RV contractility despite reduced filling volumes.	The use of a porcine model limits translation to human physiology. Experimental conditions may not reflect clinical practice, and findings may not be directly applicable to patient care.

Table 2. Summary of included studies.

Note: Abbreviations: BNP: B-type natriuretic peptide; BP: blood pressure; CO: cardiac output; DT: diuretic therapy; LV: left ventricle; LVEDV: left ventricular end diastolic volume; MAP: mean arterial pressure; PAP: pulmonary artery pressure; PVR: pulmonary vascular resistance; RV: right ventricle; RVEDP: right ventricular end-diastolic pressure; RVEDV: right ventricular end-diastolic volume; RVD: right ventricular dysfunction; RVEF: right ventricular ejection fraction; RVSP: right ventricular systolic pressure; sPESI: simplified pulmonary embolism severity index; SV: stroke volume; SVR: systemic vascular resistance; TrnI: troponin I; VE: volume expansion.

Levels of evidence are consistent with the National Health and Medical Research Council (NHMRC) guidelines (NHMRC, 2009).

Author (Year)	Population [Sample Size]	Study Design / Intervention	Key Findings	Limitations
Nguyen et al. (2021)	Human [n = 122]	Retrospective FR	Increasing FR volume was associated with a higher likelihood of adverse events, with an odds ratio of 2.1 per liter (95% CI 1.4–3.2). Overall, 41% of patients experienced complications, suggesting a dose–response relationship.	The retrospective design introduces potential bias and confounding. The absence of control group limits comparison, and patient heterogeneity may have influenced outcomes.
Schouwer et al. (2017)	Human [n = 46]	Prospective DT versus FR	FR was associated with slower biomarker normalization. DT resulted in faster normalization of BNP and troponin (67.5 vs 111.6 hours; $p = 0.006$) and improvements in HR and RV function. No significant difference in major clinical outcomes was observed at short-term follow-up.	The small sample size and non-randomized design limit generalizability. Short follow-up duration restricts assessment of longer-term outcomes.
Ternacle et al. (2013)	Human [n = 70]	Retrospective DT versus FR	FR was associated with less favorable hemodynamic profiles. DT improved SBP, reduced shock index, improved renal function, and reduced oxygen requirements compared to FR.	The retrospective design introduces potential bias and confounding. Baseline differences between groups may have influenced outcomes.

Table 2 (continued). Summary of included studies.

Source	Reason for Exclusion
Aggarwal (2017)	Review article; did not specifically address fluid resuscitation in PE.
Banerjee and Mora (2020)	Review article; provided clinical overview without primary data on fluid therapy.
Becattini et al. (2016)	Systematic review; focused on mortality risk associated with DVT rather than fluid therapy.
Belenkie et al. (1988)	Experimental study; examined baseline cardiac function without evaluating fluid resuscitation effects.
Belohlávek et al. (2013)	Review article; discussed volume expansion broadly without PE-specific fluid therapy data.
Chatterjee et al. (2014)	Meta-analysis; focused on thrombolytic therapy rather than fluid management.
Chopard et al. (2022)	Review article; general overview of PE without specific analysis of fluid therapy.
Cruz et al. (2023)	Literature review; focused on interventional and surgical PE management strategies.
Dal et al. (2024)	Review article; discussed general treatment approaches without specific fluid therapy data.
Dudzinski et al. (2017)	Review article; focused on interventional therapies, not fluid resuscitation.
Febra et al. (2024)	Review article; focused on diuretic therapy without comparison to fluid resuscitation.
Fernandes et al. (2019)	Review article; general overview without primary data on fluid therapy.
Gallet (2015)	Protocol paper; described study design without reported results.
Group (2016)	Observational study; focused on post-resuscitation outcomes in cardiac arrest rather than fluid therapy in PE.
Harvey et al. (2022)	Systematic review; examined catheter-directed therapies, not fluid management.
Hao et al. (2015)	Systematic review; focused on thrombolysis rather than fluid therapy.
Hussain et al. (2024)	Review article; focused on RV function without fluid therapy data.
Jaff et al. (2011)	Guideline document; provided management recommendations without primary data.
Kasper et al. (1997)	Cohort study; focused on thrombolysis and diagnostics rather than fluid therapy.
Konstantinides et al. (2019)	Guideline document; provided recommendations without primary research data.
Martinez Licha et al. (2020)	Systematic review; focused on interventional and surgical management strategies.
Meyer et al. (2016)	Narrative review; discussed volume loading without primary experimental data.
Moorjani and Price (2013)	Review article; focused on endovascular and interventional management.
Pérez-Nieto et al. (2023)	Review article; discussed fluid management conceptually without primary data.
QiMin et al. (2020)	Retrospective study; focused on anticoagulation and interventional therapies rather than fluid resuscitation.

Table 3. Summary of excluded studies.

Abbreviations: AIS: Acute Ischemic Stroke; COVID-19: Coronavirus Disease 2019; DVT: Deep Vein Thrombosis; LV: Left Ventricular; PE: Pulmonary Embolism; PERT: Pulmonary Embolism Response Team; RV: Right Ventricular.

Source	Reason for Exclusion
Rali and Criner (2018)	Review article; focused on sub-massive PE management without fluid therapy analysis.
Root et al. (2018)	Review article; focused on multidisciplinary PE response teams (PERT).
Sakr et al. (2020)	Narrative review; focused on anticoagulation in COVID-19-related PE.
Silveira et al. (2024)	Case report; single patient study not generalizable.
Tapson and Weinberg (2020)	Review article; guideline-based discussion without primary data.
Vyas et al. (2024)	Review article; provided general recommendations without experimental data.
Yamamoto (2018)	Narrative review; discussed management strategies without primary data on fluid therapy.

Table 3 (continued). Summary of excluded studies.

RIGHT VENTRICULAR DYSFUNCTION AND CARDIAC OUTPUT

Several studies demonstrated that FR contributed to worsening RV dysfunction in the setting of increased afterload (Belenkie et al., 1989; Ghignone et al., 1984; Mortensen et al., 2020). Experimental models showed that increased RV distension following FR resulted in interventricular septal shift toward the LV, impairing LV filling and reducing overall cardiac output (Belenkie et al., 1989).

In comparative studies, FR was associated with declining stroke volume (SV) and systolic blood pressure (SBP) following embolization, whereas vasopressor support improved CO and systemic perfusion (Ghignone et al., 1984; Molloy et al., 1984). Clinical data further demonstrated increasing volumes of FR were associated with hemodynamic deterioration, with a dose-dependent relationship observed between fluid administration and adverse outcomes (Nguyen et al., 2021).

CLINICAL OUTCOMES AND ADVERSE EVENTS

Clinical studies examining patient outcomes demonstrated limited benefits of FR. In retrospective cohorts, increasing fluid volumes were associated with higher rates of adverse events, including hemodynamic instability (Nguyen et al., 2021).

In contrast, studies comparing FR to DT reported improved biomarker profiles and hemodynamic parameters in patients receiving DT (Ferrari et al., 2022; Schouver et al., 2017; Ternacle et al., 2013). Faster normalization of biomarkers such as B-type natriuretic peptide (BNP) and improvements in heart rate and SBP were observed in DT groups, although differences in major clinical outcomes were not consistently demonstrated.

ALTERNATIVE MANAGEMENT STRATEGIES

Alternative strategies, including DT and vasopressor therapy, were evaluated across several studies. DT was associated with reductions in RV preload, improved hemodynamic parameters, and enhanced renal function (Ferrari et al., 2022; Mortensen et al., 2020; Schouver et al., 2017; Ternacle et al., 2013).

Vasopressor therapy, particularly noradrenaline, in experimental models improved SBP, RV perfusion, and overall CO (Ghignone et al., 1984; Molloy et al., 1984). Improved survival was observed in vasopressor-treated groups compared to those receiving FR (Molloy et al., 1984).

DISCUSSION

This review examined the role of FR in the management of MPE, with a focus on its hemodynamic effects and implications for prehospital care. Across the limited available evidence, FR was associated with increased RV preload but little sustained hemodynamic benefit (Belenkie et al., 1989; Mercat et al., 1999; Mortensen et al., 2020). While transient improvements in CO have been reported, these effects were not consistently sustained and occurred alongside evidence of RV dysfunction and dilatation (Mercat et al., 1999; Nguyen et al., 2021). Observational data also suggest an association between increasing fluid volumes and adverse clinical outcomes (Nguyen et al., 2021). However, these findings should be interpreted cautiously. The evidence base is small and heterogeneous, comprising experimental animal models and observational human studies, with some clinical evidence derived from patients with intermediate risk rather than massive PE. No included studies specifically examined FR in the prehospital setting.

An understanding of the underlying pathophysiology provides a plausible explanation for these findings. In MPE, hypotension primarily results from acute RV pressure overload caused by obstruction of the pulmonary vasculature rather than intravascular volume depletion (Konstantinides et al., 2019; McGuire et al., 2024). This increases RV afterload, resulting in progressive RV dilatation and interventricular septal shift, which may impair left ventricular (LV) filling and reduce CO (Bryce et al., 2019). Under normal physiological conditions, increased preload augments SV through the Frank–Starling mechanism. In MPE, however, the pressure-overloaded RV may have limited capacity to accommodate additional volume. Further volume expansion may therefore exacerbate RV dilatation and ventricular interdependence without meaningfully improving forward flow (Belenkie et al., 1989; Ghignone et al., 1984). This provides a physiological rationale for why responses to FR in MPE may differ from those observed in hypovolemic shock.

The limited clinical evidence is broadly consistent with this physiological rationale. Although FR may produce short-term increases in CO, available studies have not demonstrated sustained hemodynamic or clinical benefit (Mercat et al., 1999). Increasing fluid volumes have also been associated with worsening hemodynamic profiles and markers of RV dysfunction (Nguyen et al., 2021). These associations do not establish causation, and the limited observational evidence precludes firm conclusions regarding optimal fluid volumes in MPE. Nevertheless, the findings raise concern that indiscriminate volume loading may be poorly suited to a condition characterized predominantly by acute RV pressure overload rather than volume depletion.

Limited evidence has also explored hemodynamic strategies other than volume expansion. Studies examining DT have reported reductions in RV preload and improvements in selected hemodynamic and biomarker parameters (Ferrari et al., 2022; Mortensen et al., 2020; Schouver et al., 2017; Ternacle et al., 2013). However, these findings should not be interpreted as supporting routine diuretic therapy in MPE, particularly in the prehospital setting. The available studies are limited by their design, setting and patient populations, and the safety and clinical benefits of prehospital DT remain uncertain. Rather, these findings reinforce the potential importance of avoiding unnecessary volume loading and highlight the need for further investigation of strategies that target RV dysfunction and systemic perfusion.

Vasopressor therapy, particularly noradrenaline, has demonstrated improvements in SBP and CO in experimental models without increasing venous return or RV wall stress (Ghignone et al., 1984; Molloy et al., 1984). Physiologically, maintaining systemic and coronary perfusion pressure may support RV function in the presence of increased pulmonary vascular resistance (McGuire et al., 2024). However, much of this evidence is experimental, and its direct applicability to prehospital patients with MPE remains uncertain. Further clinical research is required before comparative conclusions can be drawn regarding vasoactive therapy and FR in this population.

These findings have important implications for prehospital care but should be interpreted within the limitations of the available evidence. Paramedics frequently encounter hypotension, for which FR may be considered as an initial intervention. In suspected MPE, however, hypotension may reflect acute RV pressure overload rather than intravascular volume depletion. The available evidence therefore supports caution against indiscriminate or unnecessary volume loading rather than establishing the superiority of an alternative treatment strategy. Current evidence is insufficient to support routine prehospital diuretic therapy, and further research is required to determine optimal fluid strategies and evaluate alternative hemodynamic approaches, including vasoactive medications, in patients with MPE.

LIMITATIONS

Several limitations should be considered when interpreting the findings of this review. First, a substantial proportion of included studies utilized animal models. While these designs allow controlled hemodynamic experimentation, they may not fully replicate human cardiopulmonary physiology. Experimental conditions frequently involved anesthesia or mechanical ventilation, both of which may influence hemodynamic responses and limit translation to clinical practice.

Second, many studies were limited by small sample sizes, absence of control groups, and reliance on surrogate biochemical markers rather than patient-centered clinical outcomes. These factors reduce statistical power and limit generalizability. Variability in fluid type (e.g., Ringer's lactate, Dextran 6%) and administration protocols further reduced comparability across studies.

Third, several included studies were retrospective in design, introducing potential selection bias and confounding. Follow-up durations were often short, preventing assessment of longer-term outcomes. Notably, there is a lack of prehospital-specific research, resulting in a significant evidence gap in the paramedic management of PE-associated hypotension.

Future research should focus on prospective clinical studies evaluating hemodynamic management strategies in patients with MPE, particularly in prehospital settings. Studies examining patient-centered outcomes, standardized fluid protocols, and early vasoactive strategies would strengthen the evidence base and better inform clinical practice.

CONCLUSION

This narrative review examined the role of FR in the management of MPE, with a focus on its hemodynamic effects in the acute setting. The available evidence demonstrates

that FR is associated with worsening RV dysfunction and dilatation, reduced CO, and hemodynamic instability. These findings are consistent with the pathophysiology of MPE, where acute increases in RV afterload impair ventricular filling and limit effective CO. Observational human data also suggests that increasing fluid volumes are associated with adverse clinical outcomes. While the evidence for hemodynamic compromise is more consistent than that for clinical endpoints, no included study demonstrated a sustained clinical benefit from FR.

In contrast, strategies targeting RV function and systemic perfusion, including vasopressor therapy and DT, were associated with improved hemodynamic parameters. Although much of the evidence is derived from limited experimental, animal, and in-hospital settings, the findings suggest relevance to prehospital management. The available evidence supports a more targeted approach to hemodynamic management in MPE, prioritizing strategies that address RV failure rather than routine volume expansion. Further research is required to determine the optimal hemodynamic management of PE in the prehospital setting and inform the development of evidence-based clinical guidelines, with potential for changes to future clinical practice.

REFERENCES

- Aggarwal, V., Nicolais, C., Lee, A., & Bashir, R. Aggarwal, V., Nicolais, C., Lee, A., & Bashir, R. . (2017). *Acute management of pulmonary embolism*. American College of Cardiology. <https://cmcoem.info/pdf/curso/tep/acutaemanagment.pdf>
- AV. (2025). *Clinical Practice Guidelines: Pulmonary Embolism*. Ambulance Victoria <https://cpg.ambulance.vic.gov.au/#/tabs/tab-0/info>
- Banerjee, T. P., & Mora, J. C. (2020). The management of pulmonary embolism. *Anaesthesia & Intensive Care Medicine*, 21(3), 139-146. <https://doi.org/10.1016/j.mpaic.2019.12.008>
- BCEHS. (2026). *B06: Pulmonary Embolism*. <https://handbook.bcehs.ca/clinical-practice-guidelines/b-airway-and-breathing/b06-pulmonary-embolism>
- Becattini, C., Cohen, A. T., Agnelli, G., Howard, L., Castejón, B., Trujillo-Santos, J., Monreal, M., Perrier, A., Yusen, R. D., & Jiménez, D. (2016). Risk Stratification of Patients With Acute Symptomatic Pulmonary Embolism Based on Presence or Absence of Lower Extremity DVT: Systematic Review and Meta-analysis. *Chest*, 149(1), 192-200. <https://doi.org/10.1378/chest.15-0808>
- Belenkie, I., Dani, R., Smith, E. R., & Tyberg, J. V. (1988). Ventricular interaction during experimental acute pulmonary embolism. *Circulation*, 78(3), 761-768. <https://doi.org/10.1161/01.cir.78.3.761>
- Belenkie, I., Dani, R., Smith, E. R., & Tyberg, J. V. (1989). Effects of volume loading during experimental acute pulmonary embolism. *Circulation*, 80(1), 178-188. <https://doi.org/doi:10.1161/01.CIR.80.1.178>
- Belohlávek, J., Dytrych, V., & Linhart, A. (2013). Pulmonary embolism, part II: Management. *Experimental and Clinical Cardiology*, 18(2), 139–147. <https://pmc.ncbi.nlm.nih.gov/articles/PMC3718594>
- Bryce, Y. C., Perez-Johnston, R., Bryce, E. B., Homayoon, B., & Santos-Martin, E. G. (2019). Pathophysiology of right ventricular failure in acute pulmonary embolism and chronic thromboembolic pulmonary hypertension: A pictorial essay for the interventional radiologist. *Insights Imaging*, 10(1), 18. <https://doi.org/10.1186/s13244-019-0695-9>

- Chatterjee, S., Chakraborty, A., Weinberg, I., Kadakia, M., Wilensky, R. L., Sardar, P., Kumbhani, D. J., Mukherjee, D., Jaff, M. R., & Giri, J. (2014). Thrombolysis for pulmonary embolism and risk of all-cause mortality, major bleeding, and intracranial hemorrhage: a meta-analysis. *Jama*, 311(23), 2414-2421. <https://doi.org/10.1001/jama.2014.5990>
- Chopard, R., Behr, J., Vidoni, C., Ecarnot, F., & Meneveau, N. (2022). An Update on the Management of Acute High-Risk Pulmonary Embolism. *Journal of Clinical Medicine*, 11(16), 4807. <https://www.mdpi.com/2077-0383/11/16/4807>
- Cruz, G., Pedroza, S., Giraldo, M., Peña, A. D., Calderón, C. A., & Quintero, I. F. (2023). Intraoperative circulatory arrest secondary to high-risk pulmonary embolism. Case series and updated literature review. *BMC Anesthesiol*, 23(1), 415. <https://doi.org/10.1186/s12871-023-02370-z>
- Dal, E., Eraybar, S., Bulut, M., & Avcı, A. (2024). Pulmonary Embolism Treatment: Current Developments and Approaches. *Global Emergency and Critical Care*, 3, 51-57. <https://doi.org/10.4274/globecc.galenos.2024.07279>
- Dudzinski, D. M., Giri, J., & Rosenfield, K. (2017). Interventional Treatment of Pulmonary Embolism. *Circ Cardiovasc Interv*, 10(2). <https://doi.org/10.1161/circinterventions.116.004345>
- Febrá, C., Santos, A. R., Cabrita, I., Bento, J., Pacheco, J., Mendes, M., Isidro, M., Batista, R., & Macedo, A. (2024). Comparison of diuretics and fluid expansion in the initial treatment of patients with normotensive acute pulmonary embolism: a systematic review and meta-analysis. *Emerg Med J*, 41(3), 187-192. <https://doi.org/10.1136/emermed-2023-213525>
- Fernandes, C. J., Luppino Assad, A. P., Alves-Jr, J. L., Jardim, C., & de Souza, R. (2019). Pulmonary Embolism and Gas Exchange. *Respiration*, 98(3), 253-262. <https://doi.org/10.1159/000501342>
- Ferrari, E., Sartre, B., Labbaoui, M., Heme, N., Asarisi, F., Redjimi, N., Fourrier, E., Squara, F., Bun, S., Berkane, N., Breittmayer, J. P., Doyen, D., & Mocerri, P. (2022). Diuretics Versus Volume Expansion in the Initial Management of Acute Intermediate High-Risk Pulmonary Embolism. *Lung*, 200(2), 179-185. <https://doi.org/10.1007/s00408-022-00530-5>
- Gallet, R., Meyer, G., Ternacle, J., Biendel, C., Brunet, A., Meneveau, N., Rosario, R., Couturaud, F., Sebbane, M., Lamblin, N., Bouvaist, H., Coste, P., Maitre, B., Bastuji-Garin, S., Dubois-Rande, J., & Lim, P. (2015). Diuretic versus placebo in normotensive acute pulmonary embolism with right ventricular enlargement and injury: a double-blind randomised placebo controlled study. Protocol of the DIPER study. *BMJ Open* <https://doi.org/10.1136/bmjopen-2014-007466>
- Ghignone, M., Girling, L., & Prewitt, R. M. (1984). Volume expansion versus norepinephrine in treatment of a low cardiac output complicating an acute increase in right ventricular afterload in dogs. *Anesthesiology*, 60(2), 132-135. <https://doi.org/10.1097/00000542-198402000-00009>
- Grant, M. J., & Booth, A. (2009). A typology of reviews: an analysis of 14 review types and associated methodologies. *Health Information & Libraries Journal*, 26(2), 91-108. <https://doi.org/10.1111/j.1471-1842.2009.00848.x>

- Group, S.-K. S. (2016). Investigation and treatment of pulmonary embolism as a potential etiology may be important to improve post-resuscitation prognosis in non-shockable out-of-hospital cardiopulmonary arrest: report on an analysis of the SOS-KANTO 2012 study. *Acute Medicine & Surgery*, 3(3), 250-259. <https://doi.org/10.1002/ams2.183>
- Gupta, R., Ammari, Z., Dasa, O., Ruzieh, M., Burlen, J. J., Shunnar, K. M., Nguyen, H. T., Xie, Y., Brewster, P., Chen, T., Aronow, H. D., & Cooper, C. J. (2020). Long-term mortality after massive, submassive, and low-risk pulmonary embolism. *Vasc Med*, 25(2), 141-149. <https://doi.org/10.1177/1358863x19886374>
- Hao, Q., Dong, B. R., Yue, J., Wu, T., & Liu, G. J. (2015). Thrombolytic therapy for pulmonary embolism. *Cochrane Database Syst Rev*(9), Cd004437. <https://doi.org/10.1002/14651858.CD004437.pub4>
- Harvey, J. J., Huang, S., & Uberoi, R. (2022). Catheter-directed therapies for the treatment of high risk (massive) and intermediate risk (submassive) acute pulmonary embolism. *Cochrane Database Syst Rev*, 8(8), Cd013083. <https://doi.org/10.1002/14651858.CD013083.pub2>
- Hussain, K., Mandras, S. A., & Desai, S. (2024). *Right Heart Failure*. In StatPearls. StatPearls Publishing. <https://www.ncbi.nlm.nih.gov/books/NBK459381/>
- Jaff, M. R., McMurtry, M. S., Archer, S. L., Cushman, M., Goldenberg, N., Goldhaber, S. Z., Jenkins, J. S., Kline, J. A., Michaels, A. D., Thistlethwaite, P., Vedantham, S., White, R. J., & Zierler, B. K. (2011). Management of Massive and Submassive Pulmonary Embolism, Iliofemoral Deep Vein Thrombosis, and Chronic Thromboembolic Pulmonary Hypertension. *Circulation*, 123(16), 1788-1830. <https://doi.org/doi:10.1161/CIR.0b013e318214914f>
- Kasper, W., Konstantinides, S., Geibel, A., Olschewski, M., Heinrich, F., Grosser, K. D., Rauber, K., Iversen, S., Redecker, M., & Kienast, J. (1997). Management strategies and determinants of outcome in acute major pulmonary embolism: results of a multicenter registry. *J Am Coll Cardiol*, 30(5), 1165-1171. [https://doi.org/10.1016/s0735-1097\(97\)00319-7](https://doi.org/10.1016/s0735-1097(97)00319-7)
- Konstantinides, S. V., Meyer, G., Becattini, C., Bueno, H., Geersing, G.-J., Harjola, V.-P., Huisman, M. V., Humbert, M., Jennings, C. S., Jiménez, D., Kucher, N., Lang, I. M., Lankeit, M., Lorusso, R., Mazzolai, L., Meneveau, N., Ní Áinle, F., Prandoni, P., Pruszczyk, P.,...Group, E. S. D. (2019). 2019 ESC Guidelines for the diagnosis and management of acute pulmonary embolism developed in collaboration with the European Respiratory Society (ERS): The Task Force for the diagnosis and management of acute pulmonary embolism of the European Society of Cardiology (ESC). *European Heart Journal*, 41(4), 543-603. <https://doi.org/10.1093/eurheartj/ehz405>
- Martinez Licha, C. R., McCurdy, C. M., Maldonado, S. M., & Lee, L. S. (2020). Current Management of Acute Pulmonary Embolism. *Ann Thorac Cardiovasc Surg*, 26(2), 65-71. <https://doi.org/10.5761/atcs.ra.19-00158>
- Mata, R., McDermott, G., & Diaz, L. (2020). Massive Pulmonary Embolism as a Cause of Cardiac Arrest: Navigating Unknowns in Life After Death. *Cureus*, 12(5), e8361. <https://doi.org/10.7759/cureus.8361>
- McGuire, W. C., Sullivan, L., Odish, M. F., Desai, B., Morris, T. A., & Fernandes, T. M. (2024). Management Strategies for Acute Pulmonary Embolism in the ICU. *Chest*, 166(6), 1532-1545. <https://doi.org/10.1016/j.chest.2024.04.032>

- Mercat, A., Diehl, J. L., Meyer, G., Teboul, J. L., & Sors, H. (1999). Hemodynamic effects of fluid loading in acute massive pulmonary embolism. *Critical care medicine*, 27(3), 540-544. <https://doi.org/10.1097/00003246-199903000-00032>
- Meyer, G., Vieillard-Baron, A., & Planquette, B. (2016). Recent advances in the management of pulmonary embolism: focus on the critically ill patients. *Ann Intensive Care*, 6(1), 19. <https://doi.org/10.1186/s13613-016-0122-z>
- Moher, D., Liberati, A., Tetzlaff, J., & Altman, D. G. (2009). Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *PLoS Med*, 6(7), e1000097. <https://doi.org/10.1371/journal.pmed.1000097>
- Molloy, W. D., Lee, K. Y., Girling, L., Schick, U., & Prewitt, R. M. (1984). Treatment of shock in a canine model of pulmonary embolism. *Am Rev Respir Dis*, 130(5), 870-874. <https://doi.org/10.1164/arrd.1984.130.5.870>
- Moorjani, N., & Price, S. (2013). Massive pulmonary embolism. *Cardiology Clinics*, 31(4). <https://doi.org/10.1016/j.ccl.2013.07.005>
- Mortensen, C. S., Kramer, A., Schultz, J., Lyhne, M. D., Nielsen-Kudsk, J. E., & Andersen, A. (2020). Impact of Preload on Right Ventricular Hemodynamics in Acute Pulmonary Embolism. *Crit Care Med*, 48(12), e1306-e1312. <https://doi.org/10.1097/ccm.0000000000004643>
- Nguyen, H. T., Leffers, P., Smotherman, C., & Ferreira, J. A. (2021). Clinical factors associated with adverse outcomes in the acute period of management of submassive pulmonary embolism. *Blood Coagulation & Fibrinolysis*, 32(5), 335-339. <https://doi.org/10.1097/mbc.0000000000001030>
- NHS. (2025). *Pulmonary embolism (Guidelines)*. NHS Scotland <https://www.rightdecisions.scot.nhs.uk/tam-treatments-and-medicines-nhs-highland/adult-therapeutic-guidelines/respiratory/pulmonary-embolism-guidelines>
- Pérez-Nieto, O. R., Gómez-Oropeza, I., Quintero-Leyra, A., Kammar-García, A., Zamarón-López, E. I., Soto-Estrada, M., Morgado-Villaseñor, L. A., & Meza-Comparán, H. D. (2023). Hemodynamic and respiratory support in pulmonary embolism: a narrative review. *Front Med (Lausanne)*, 10, 1123793. <https://doi.org/10.3389/fmed.2023.1123793>
- QAS. (2020). *Clinical practice guidelines: Respiratory/Pulmonary embolus* (CPG_RE_PE_0416). Q. A. Service. https://www.ambulance.qld.gov.au/data/assets/pdf_file/0016/219103/cpg_pulmonary-embolus.pdf
- QiMin, W., LiangWan, C., DaoZhong, C., HanFan, Q., ZhongYao, H., XiaoFu, D., XueShan, H., Feng, L., & HuaBin, C. (2020). Clinical outcomes of acute pulmonary embolectomy as the first-line treatment for massive and submassive pulmonary embolism: a single-centre study in China. *J Cardiothorac Surg*, 15(1), 321. <https://doi.org/10.1186/s13019-020-01364-z>
- Rali, P. M., & Criner, G. J. (2018). Submassive Pulmonary Embolism. *Am J Respir Crit Care Med*, 198(5), 588-598. <https://doi.org/10.1164/rccm.201711-2302CI>
- Root, C. W., Dudzinski, D. M., Zakhary, B., Friedman, O. A., Sista, A. K., & Horowitz, J. M. (2018). Multidisciplinary approach to the management of pulmonary embolism patients: the pulmonary embolism response team (PERT). *J Multidiscip Healthc*, 11, 187-195. <https://doi.org/10.2147/jmdh.S151196>
- Sakr, Y., Giovini, M., Leone, M., Pizzilli, G., Kortgen, A., Bauer, M., Tonetti, T., Duclos, G., Zieleskiewicz, L., Buschbeck, S., Ranieri, V. M., & Antonucci, E. (2020). Pulmonary embolism in patients with coronavirus disease-2019 (COVID-19) pneumonia: a narrative review. *Ann Intensive Care*, 10, 124. <https://doi.org/10.1186/s13613-020-00741-0>

- Schouver, E. D., Chiche, O., Bouvier, P., Doyen, D., Cerboni, P., Moceri, P., & Ferrari, E. (2017). Diuretics versus volume expansion in acute submassive pulmonary embolism. *Arch Cardiovasc Dis*, 110(11), 616-625. <https://doi.org/10.1016/j.acvd.2017.01.016>
- Silveira, P., McCloskey, J., & Kassir, M. (2024). Thrombolysis of incidental pulmonary embolism in a stroke patient. *Radiol Case Rep*, 19(7), 2600-2602. <https://doi.org/10.1016/j.radcr.2024.03.053>
- Snyder, H. (2019). Literature review as a research methodology: An overview and guidelines. *Journal of Business Research*, 104, 333-339. <https://doi.org/10.1016/j.jbusres.2019.07.039>
- Tapson, V. F., & Weinberg, A. S. (2020). Overview of Management of Intermediate- and High-Risk Pulmonary Embolism. *Critical Care Clinics*, 36(3), 449-463. <https://doi.org/10.1016/j.ccc.2020.02.003>
- Ternacle, J., Gallet, R., Mekontso-Dessap, A., Meyer, G., Maitre, B., Bensaid, A., Jurzak, P., Gueret, P., Dubois Randé, J. L., & Lim, P. (2013). Diuretics in normotensive patients with acute pulmonary embolism and right ventricular dilatation. *Circ J*, 77(10), 2612-2618. <https://doi.org/10.1253/circj.cj-13-0404>
- Vyas, V., Sankari, A., & Goyal, A. (2024). *Acute Pulmonary Embolism*. In StatPearls. StatPearls Publishing. <https://www.ncbi.nlm.nih.gov/books/NBK560551/>
- Yamamoto, T. (2018). Management of patients with high-risk pulmonary embolism: a narrative review. *J Intensive Care*, 6, 16. <https://doi.org/10.1186/s40560-018-0286-8>