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CLINICAL UTILITY OF PiCCO FOR PROGNOSTICATION IN CRITICALLY ILL PATIENTS: A NARRATIVE REVIEW

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ABSTRACT

Background: Hemodynamic instability remains one of the leading causes of morbidity and mortality among critically ill patients. The Pulse Contour Cardiac Output (PiCCO) system combines transpulmonary thermodilution with pulse contour analysis, supporting comprehensive assessment of cardiac output, preload, cardiac performance, pulmonary edema, and fluid responsiveness. Although widely used in intensive care, its prognostic value remains a matter of ongoing debate.

Objective: This narrative review aimed to evaluate the current evidence regarding the prognostic utility of PiCCO-derived hemodynamic parameters in adult critically ill patients.

Methods: A narrative review of studies published between 2000 and 2025 was executed using PubMed/MEDLINE, Scopus, and Web of Science. Studies evaluating PiCCO-derived parameters in relation to clinically relevant outcomes, including mortality, organ dysfunction, fluid responsiveness, and intensive care unit (ICU) length of stay, were included.

Results: Among the analyzed parameters, the extravascular lung water index (EVLWI) demonstrated the strongest and most consistent association with mortality, particularly in patients with sepsis and acute respiratory distress syndrome (ARDS). The cardiac function index (CFI) provided additional prognostic value in septic patients by identifying myocardial dysfunction not reflected by conventional cardiac output measurements. Dynamic parameters, including stroke volume variation (SVV), reliably predicted fluid responsiveness in selected populations, especially septic shock and post-cardiac surgery patients. However, evidence supporting an overall mortality benefit of PiCCO-guided management among varied ICU populations remains limited, whereas ARDS-specific studies show better clinical outcomes.

Conclusions: PiCCO yields valuable multidimensional hemodynamic assessment and offers clinically meaningful prognostic information, particularly through EVLWI and CFI. Nevertheless, its greatest benefit appears to depend on appropriate patient selection and adoption into structured, population-specific treatment algorithms rather than the monitoring technology alone.

KEYWORDS

PiCCO, Hemodynamic Monitoring, Intensive Care Unit, ARDS, Sepsis

CITATION

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1. Introduction

1.1 Clinical Context of the Critically Ill Patient

Critically ill patients admitted to intensive care units (ICUs) constitute a heterogeneous population characterized by the presence, or significant risk, of single- or multiple-organ failure requiring life-sustaining support. Among the main physiological abnormalities observed in this group, hemodynamic instability represents a leading cause of morbidity and mortality (Chaudhary, 2026), with circulatory shock being recognized as one of the most common and clinically significant diagnoses in critical care (Cecconi et al., 2014). Hemodynamic instability, if unrecognized and untreated, progressively culminates in tissue hypoperfusion, organ dysfunction, multi-organ failure, and, ultimately, death (Huygh et al., 2016). Accordingly, hemodynamic monitoring has become a vital instrument in modern ICU practice, providing information needed for both resuscitation and de-resuscitation strategies, including the titration of fluids, vasopressors, and inotropic agents, while also providing early warning of clinical deterioration (Huygh et al., 2016).

It is precisely within this high-risk, prone-to-hemodynamic-deregulation population that advanced monitoring technologies—integrating transpulmonary thermodilution and pulse contour analysis—have been progressively adopted by intensivists pursuing more precise, goal-directed interventions, driven by the recognition that conventional static pressure variables correlate poorly with actual stroke volume and do not reliably indicate preload responsiveness (Alhashemi et al., 2011). Compared with these traditional indices, volumetric and multiparametric platforms deliver an integrated view of preload, cardiac performance, capillary leak, and pulmonary fluid content via a single monitoring interface, which, in theory, provides more coherent clinical reasoning (Monnet & Teboul, 2017). However, whether the additional physiological detail afforded by such devices—exemplified by the PiCCO system—translates into a measurable prognostic advantage, particularly with respect to mortality, remains a contested and unresolved question. It is this gap between technological capacity and demonstrable clinical benefit that defines the rationale for the present narrative review, and motivates closer examination of the prognostic value of PiCCO-derived parameters in contemporary intensive care practice.

1.2 The Prognostic Challenge in the Critically Ill

Despite widespread adoption of advanced monitoring, current evidence indicates that hemodynamic devices alone are insufficient to independently influence mortality outcomes, primarily because competing physiological variables and disease severity strongly influence patient prognosis (Monnet & Teboul, 2017). This limitation is compounded by the fact that no single hemodynamic measurement—however sophisticated—captures the full biological heterogeneity of critical illness, and that to be clinically useful, transpulmonary thermodilution must be integrated into a broader structure of multimodal assessment rather than relied upon in isolation (Monnet & Teboul, 2017). Several classical static indices, such as central venous pressure and pulmonary artery occlusion pressure, were long used to guide resuscitation under the implicit assumption that correcting low values would translate into improved survival; yet despite their intuitive appeal, none of these pressure-based parameters has ever been shown to be a true predictor of fluid responsiveness in the critically ill (Alhashemi et al., 2011).

The prognostic signal carried by transpulmonary thermodilution-derived parameters is therefore best understood as incremental rather than categorical. Recent evidence indicates that preload assessment based on global volumetric variables (particularly GEDVI and ITBVI) correlates significantly more strongly with actual stroke volume than pressure-based surrogates (Alhashemi et al., 2011), and that global end-diastolic volume and intrathoracic blood volume reliably indicate the risk of fluid over-resuscitation in critically ill patients (Monnet & Teboul, 2017). Among these volumetric parameters, extravascular lung water index has been established as one of the most clinically solid prognostic indicators, with higher values consistently associated

with increased mortality across heterogeneous ICU populations (Alhashemi et al., 2011; Monnet & Teboul, 2017). In parallel, cardiac function indices derived from the same thermodilution tracing have demonstrated direct relevance to tissue oxygen delivery, with reduced CFI values correlating highly with low mixed venous oxygen saturation—a hallmark of impending circulatory failure (Ritter et al., 2009).

The practical effects of these findings are meaningful but nuanced. While PiCCO-derived parameters have showed significant prognostic value in identifying cardiac dysfunction and increased extravascular lung water in patients with sepsis, acute heart failure, and those recovering from cardiac surgery (Ritter et al., 2009), the strength of the evidence varies considerably across clinical settings. Conversely, the prognostic literature for non-surgical critically ill patients—particularly those with isolated acute heart failure—remains comparatively limited, reflecting an evidence base still predominantly anchored in surgical and post-cardiotomy cohorts (Ritter et al., 2009). Taken together, these observations illustrate a fundamental tension in modern intensive care: hemodynamic monitoring offers increasingly detailed physiological insight, yet translating that insight into mortality benefit requires structured protocols, validated thresholds, and a clear understanding of the populations in which the technology has been adequately tested (Monnet & Teboul, 2017).

1.3 Evolution from Invasive to Minimally Invasive Hemodynamic Monitoring

For nearly four decades following its introduction into clinical practice, the pulmonary artery catheter served as the reference standard for bedside hemodynamic assessment in the critically ill, providing clinicians with direct measurements of pulmonary artery pressure, pulmonary artery occlusion pressure, central venous pressure, and mixed venous oxygen saturation (Huygh et al., 2016). Yet, despite its dominant position in intensive care, subsequent large-scale epidemiological evaluations failed to demonstrate that PAC-guided management improved mortality or shortened ICU length of stay, while the procedure was increasingly linked to mechanical, infectious, and arrhythmic complications (Uchino et al., 2006). The cumulative weight of this evidence led to a marked and sustained reduction in PAC use across most adult ICU populations, creating an unmet clinical need for monitoring technologies that deliver comparable physiological insight with lower procedural risk (Monnet & Teboul, 2017).

This clinical gap fostered the development of a heterogeneous family of less invasive devices, including calibrated and uncalibrated pulse-contour systems, esophageal Doppler monitors, and bioimpedance/bioreactance platforms, all sharing the conceptual goal of continuous cardiac output estimation without right-heart catheterization (Alhashemi et al., 2011). While each of these technologies delivers distinct practical advantages—rapid setup, operator-independence, and safer vascular access—they collectively share a common methodological limitation: their measuring accuracy is highly dependent on the underlying hemodynamic state, with frequent signal drift, loss of calibration under abrupt changes in vasomotor tone, and reduced dependability in patients with arrhythmias, severe vasoplegia, or pronounced intra-abdominal hypertension (Monnet & Teboul, 2017; Alhashemi et al., 2011).

Within this advancing environment, transpulmonary thermodilution combined with pulse-contour analysis—the technological principle underlying the PiCCO system—was developed as a deliberate compromise between the invasiveness of PAC and the limited anchoring of purely non-invasive monitors (Litton & Morgan, 2012). By retaining an intermittent thermodilution calibration step while exploiting the arterial pulse-contour signal for continuous beat-to-beat tracking of stroke volume and derived indices, the approach sustains a calibrated reference frame without the procedural morbidity of pulmonary artery cannulation (Monnet & Teboul, 2017). Importantly, this principle has remained compatible with subsequent technological refinements: when the newer VolumeView/EV1000™ platform was benchmarked against PiCCO2™, the two systems demonstrated comparable accuracy across cardiac output and volumetric parameters (Kiefer et al., 2012).

Taken together, this gradual shift away from the pulmonary artery catheter and toward calibrated, minimally invasive platforms has reframed the contemporary question surrounding PiCCO-derived parameters: rather than whether monitoring can be performed less invasively—a question now largely settled—the unresolved issue is to what extent the specific physiological insights afforded by PiCCO carry independent prognostic weight, particularly with respect to short- and medium-term mortality and organ-function trajectories. It is precisely this question that the present narrative review sets out to address.

1.4 Aim and Scope of the Review

The preceding sections have documented a clear, unsettled tension: while transpulmonary thermodilution has become one of the most physiologically informative bedside technologies available in contemporary intensive care, the extent to which PiCCO-derived parameters confer independent prognostic value—particularly with respect to short- and medium-term mortality, organ-function trajectories, and clinical decision-making across diverse critically ill populations—is still incompletely characterized in the existing literature (Muzaffar et al., 2023; Monnet & Teboul, 2017). This narrative review intends to address this gap via systematically examining the current evidence base linking PiCCO-derived indices to clinically meaningful prognostic outcomes in adult ICU patients.

Specifically, the review pursues four interrelated objectives. First, it synthesizes the mechanistic basis and validation status of the principal PiCCO parameters—global end-diastolic volume, intrathoracic blood volume, extravascular lung water, cardiac function index, and pulmonary vascular permeability index—against alternative hemodynamic technologies, including the pulmonary artery catheter and contemporary pulse-contour devices (Alhashemi et al., 2011; Litton & Morgan, 2012). Second, it evaluates the prognostic performance of these parameters—individually and in combination—as predictors of 28-day mortality, ICU length of stay, and progression to multi-organ failure in sepsis, acute heart failure, ARDS, polytrauma, post-cardiac surgery, and intra-abdominal hypertension (Huygh et al., 2016). Third, it critically appraises the methodological quality and clinical heterogeneity of the available evidence, distinguishing robust, reproducible findings from those constrained by small sample sizes, single-center designs, or non-generalizable surgical cohorts (Monnet & Teboul, 2017). Fourth, it translates the resulting synthesis into practical, threshold-based clinical recommendations that can inform bedside decision-making, while distinctly marking areas where the evidence base is still inadequate to support routine clinical extrapolation (Chaudhary, 2026).

In terms of scope, the review focuses on adult patients (≥ 18 years) managed in general, surgical, and cardiothoracic intensive care units, and restricts its analysis to studies in which PiCCO-derived indices were explicitly correlated with predefined clinical endpoints. Pediatric populations, intraoperative-only applications, and studies confined to physiological validation without clinical outcomes fall outside the present scope. By specifying these boundaries explicitly, the review attempts to provide a clinically applicable synthesis of the current evidence, while preserving sufficient analytical depth to support the critical appraisal of methodological quality presented in Section 2.

2. Literature Review

2.1 PiCCO as a Multimodal Hemodynamic Technology

The PiCCO system was created to address a structural limitation of invasive hemodynamic monitoring: the dissociation between cardiac output measurement, which is relatively easy to obtain accurately, and the wider physiologic interpretation of cardiac performance, preload status, and pulmonary edema burden, which historically required either pressure-based surrogates of uncertain reliability or direct pulmonary artery measurement (Litton & Morgan, 2012; Monnet & Teboul, 2017). The architecture of PiCCO combines two complementary measurement modalities. The first is intermittent transpulmonary thermodilution, in which a cold bolus injected through a central venous catheter is detected at a femoral arterial thermistor; the resulting thermodilution curve provides the calibrated reference for absolute cardiac output, intrathoracic blood volume, global end-diastolic volume, and extravascular lung water (Monnet & Teboul, 2017). The second modality is beat-to-beat arterial pulse-contour analysis, which uses the calibrated stroke volume to track continuous changes in CO and calculated parameters over time (Alhashemi et al., 2011; Monnet & Teboul, 2017). The contemporary state of bedside technologies includes the FloTrac/Vigileo platform—a purely uncalibrated pulse-contour system—and the legacy pulmonary artery catheter, neither of which provides the calibrated volumetric information characteristic of PiCCO-based monitoring (Alhashemi et al., 2011; Uchino et al., 2006). The technological evolution from PiCCO2 to newer transpulmonary thermodilution platforms, exemplified by VolumeView/EV1000™, has been formally validated throughout the principal parameters, with mean percentage errors of 9.7% for cardiac output, 11.5% for global end-diastolic volume, and 12.2% for extravascular lung water (Kiefer et al., 2012)—values that fall comfortably within the ± 20 –30% accuracy band accepted for clinical-grade CO monitors and effectively position the two systems as interchangeable for routine clinical use (Kiefer et al., 2012; Monnet & Teboul, 2017).

2.2 Static Volumetric Parameters and Their Evolution

The introduction of static volumetric parameters in PiCCO was driven by the recognition that pressure-based surrogates of preload—central venous pressure and pulmonary artery occlusion pressure—do not reliably predict fluid responsiveness across heterogeneous ICU populations, and that their prognostic discrimination between survivors and non-survivors is poor (Alhashemi et al., 2011; Ritter et al., 2009). The principal static parameters are global end-diastolic volume index (GEDVI) and intrathoracic blood volume index (ITBVI); GEDVI represents the sum of the diastolic volumes of all four cardiac chambers, while ITBVI represents the volume of blood contained within the intrathoracic compartment (Litton & Morgan, 2012; Monnet & Teboul, 2017). The methodological appeal of GEDVI over pressure-based surrogates resides in its closer physiologic proximity to actual ventricular preload and its superior correlation with stroke volume compared with CVP or PAOP in critical illness (Alhashemi et al., 2011; Monnet & Teboul, 2017). However, the prognostic performance of GEDVI with respect to mortality in unselected ICU populations has remained modest—although reduced values have been linked to adverse outcomes in selected trauma cohorts, no GEDVI threshold has yet demonstrated sufficient reproducibility to predict 28-day mortality with clinical use in mixed cohorts (Alhashemi et al., 2011; Monnet & Teboul, 2017). The dominant role of GEDVI in current PiCCO practice is therefore as a preload assessment tool rather than as a standalone prognostic indicator—an evolution that has also reframed static volumetric measurement as a process-of-care metric rather than a mortality-relevant index (Alhashemi et al., 2011).

2.3 Extravascular Lung Water and Pulmonary Permeability

The measurement of extravascular lung water index (EVLWI) is the parameter that most strongly anchors the contemporary prognostic claim of PiCCO. EVLWI quantifies the volume of fluid contained within the lung interstitium and alveoli and is computed from the difference between intrathoracic thermal volume and intrathoracic blood volume during transpulmonary thermodilution (Cordemans et al., 2012; Monnet & Teboul, 2017). Because pulmonary venous blood is excluded from intrathoracic blood volume measurements, the difference reflects barrier-restricted fluid outside the pulmonary vasculature (Cordemans et al., 2012; Monnet & Teboul, 2017).

The body of evidence supporting its prognostic importance has grown in three principal layers. The first consists of single-center prospective cohorts stratifying EVLWI values against mortality; in septic shock populations, non-survivors have been shown to have higher day-3 EVLWI values than survivors (13.7 ± 4.5 vs 8.6 ± 2.6 mL/kg), with a day-3 cutoff of 11.5 mL/kg achieving AUC 0.868 ± 0.128 ($p = 0.001$), sensitivity 77%, and specificity 80% for hospital mortality (S et al., 2008). The second layer consists of dynamic trajectories, in which the peak change in EVLWI during the ICU stay has been reported to reach an AUC of 0.822 for 28-day mortality in unselected ICU populations (Cordemans et al., 2012), while in ARDS patients, an early-phase Δ -EVLWI threshold of 2.8 mL/kg has been shown to be significantly associated with better 28-day survival (78.8% vs 61.7%, $p = 0.01$) (Tagami et al., 2014). The third layer consists of systematic review and meta-analytic aggregation, exemplified by the synthesis of 18 studies across unselected ICU, ARDS, and septic shock populations—concluding that elevated EVLW, whether measured at baseline or at peak, was significantly associated with ICU, in-hospital, or 28-day mortality across heterogeneous critically ill populations (Gavelli et al., 2022).

The pulmonary vascular permeability index adds a complementary dimension, discriminating hydrostatic from permeability-driven pulmonary edema (Monnet & Teboul, 2017; Cordemans et al., 2012). While PVPI has shown directionally consistent associations with ARDS severity and mortality in some cohorts (Gavelli et al., 2022; Cordemans et al., 2012), it has not yet achieved a unified externally validated mortality threshold, and its prognostic application remains more exploratory than that of EVLWI (Monnet & Teboul, 2017). Two technical caveats warrant explicit mention: the influence of patient positioning, since transitions from supine to prone positioning do not influence the measurement of EVLW and PVPI (Sakka et al., 2009), and the influence of intra-abdominal hypertension, which can confound EVLW measurement in surgically relevant ICU populations (Cordemans et al., 2012; Monnet & Teboul, 2017).

2.4 Functional Cardiac Performance Indices

While global end-diastolic volume describes preload, and EVLWI tracks pulmonary interstitial fluid, the cardiac function index synthesizes these with cardiac output into a parameter of mechanical performance: CFI is calculated as cardiac output divided by global end-diastolic volume, expressing the cardiac output generated per unit of preload (Monnet & Teboul, 2017). The principle behind CFI is that cardiac performance

is expressed as the ratio of output to preload rather than output alone, and that, under pathological vasoplegia and distributive shock, conventional flow-based cardiac index can remain nominally normal even in the presence of severely impaired mechanical performance (Ritter et al., 2009).

The prognostic signal of CFI has been most convincingly demonstrated in septic populations, where the index has been shown to discriminate survivors from non-survivors (median 6.7 min^{-1} , IQR 6.0–7.4, vs 3.5 min^{-1} , IQR 3.0–5.4; $p < 0.001$) within a study in which cardiac index itself did not differ between groups (2.6 vs 2.8 L/min/m^2 ; $p = 0.54$), demonstrating that CFI contributes incremental prognostic information beyond usual flow-based indices (Ritter et al., 2009). This signal has not been replicated in acute heart failure populations, in which survivors and non-survivors have been shown to have indistinguishable CFI values (2.6 vs 2.9 min^{-1} ; $p = 0.46$), with PAOP, RAP, and GEDVI also failing to discriminate between the cohorts (Ritter et al., 2009). The $\text{dP/dt}_{\text{max}}$ is the second functional cardiac performance parameter provided by PiCCO, derived from the arterial pressure waveform's rate of pressure rise, but its prognostic role is less well characterized than that of CFI, and population-specific mortality thresholds have not been formally established (Monnet & Teboul, 2017).

2.5 Dynamic Parameters of Fluid Responsiveness

The dynamic parameter family of PiCCO encompasses stroke volume variation and pulse pressure variation, both derived from the respiratory variation of beat-to-beat stroke volume during controlled mechanical ventilation (Sánchez et al., 2021). The conceptual basis is that the preload-reducing effect of increased intrathoracic pressure is greater when the heart is operating on the steep portion of the Frank-Starling curve—when preload-responsive—than on the plateau (Hofer et al., 2008).

The clinical acceptance of SVV as a predictor of fluid responsiveness required head-to-head validation between devices. In a prospective evaluation of mechanically ventilated patients, the optimal SVV thresholds differed systematically between the calibrated PiCCO system (PiCCOplus, 12.1%, sensitivity 87%, specificity 76%) and an uncalibrated pulse-contour platform (FloTrac/Vigileo, 9.6%, sensitivity 91%, specificity 83%), with no significant difference between corresponding ROC areas (Hofer et al., 2008). The higher threshold in the calibrated system shows the structural difference in measurement architecture and serves as a practical indication that thresholds must be device-specific (Hofer et al., 2008).

A systematic review and meta-analysis of dynamic predictors in patients ventilated at low tidal volumes confirmed that the predictive performance of SVV varies markedly across populations, with diagnostic odds ratios being substantially higher in post-cardiothoracic surgery (95.67; $p = 0.03$) and septic shock (21.23; $p < 0.01$) populations than in other post-surgical populations (6.70; $p = 0.13$), indicating that extrapolation of SVV/PPV thresholds beyond the populations in which they were validated is not supported by evidence (Sánchez et al., 2021). The same meta-analysis also established that the accuracy of the reference method matters: when transpulmonary thermodilution was used instead of conventional bolus thermodilution to determine the reference fluid response, the apparent operating performance of SVV decreased, signaling that the calibration anchor contributes to apparent accuracy (Sánchez et al., 2021).

2.6 PiCCO Monitoring in Specific Patient Populations

The prognostic and clinical utility of PiCCO-derived monitoring has been evaluated most extensively in specific populations with comparatively homogeneous pathophysiological profiles. Septic and septic shock populations provide the densest evidence base for both CFI (Ritter et al., 2009) and EVLWI (Wang et al., 2016); ARDS populations have contributed strongly to the literature on lung water and permeability indices (Gavelli et al., 2022; Tagami et al., 2014); cardiothoracic surgery populations have served as the primary validation environment for SVV/PPV-based fluid responsiveness prediction (Hofer et al., 2008; Sánchez et al., 2021); and severe thoracic trauma with ARDS has provided the setting for the most direct demonstration of clinical impact of PiCCO-guided management (Yuanbo et al., 2016). In unselected ICU populations with hemodynamic instability, however, the clinical benefit of PiCCO-derived monitoring added to standard care has not been confirmed at the population level (Takala et al., 2011; Uchino et al., 2006).

The cross-population pattern is instructive. PiCCO-derived parameters have repeatedly demonstrated value in pathophysiologically homogeneous subgroups where the prognostic signal is concentrated—in lung water for ARDS and sepsis (Tagami et al., 2014; Wang et al., 2016) in CFI for septic cardiac dysfunction (Ritter et al., 2009), and in SVV for post-surgical fluid responsiveness (Hofer et al., 2008; Sánchez et al., 2021)—whereas in heterogeneous populations this signal is diluted by aggregate variance and algorithm-level benefits over usual care have not been repeatedly demonstrated (Takala et al., 2011; Uchino et al., 2006).

2.7 Knowledge Gaps Justifying the Present Review

Three knowledge gaps in the existing PiCCO literature justify the synthesis presented in this review. First, no recent complete analysis has integrated cardiac output, volumetric preload, functional cardiac performance, lung water, and dynamic fluid responsiveness parameters into a unified population-specific prognostic framework, despite each parameter category having generated independently strong primary evidence (Chaudhary, 2026; Gavelli et al., 2022; Monnet & Teboul, 2017). Second, the trajectory dimension of PiCCO monitoring — longitudinal change rather than absolute value — has been documented for extravascular lung water index (Cordemans et al., 2012; Tagami et al., 2014) but remains undercharacterized for GEDVI, CFI, and PVPI, leaving open whether these parameters carry equivalent prognostic value when followed across time. Third, the clinical impact of PiCCO-guided algorithms is uneven across populations: process-of-care benefits have been demonstrated in selected thoracic trauma cohorts with ARDS (Yuanbo et al., 2016), but multicenter evidence for population-level benefit in unselected ICU patients is absent (Monnet & Teboul, 2017). The present review considers these three gaps within a single, population-stratified framework, and bridges them directly into the methodology presented in Section 3.

3. Methodology

3.1 Study Design and Conceptual Framework

This work is structured as a narrative literature review. This design was selected deliberately because the available evidence linking PiCCO-derived indices to clinical outcomes is fragmented across multiple populations—sepsis, acute heart failure, ARDS, polytrauma, cardiac surgery, and intra-abdominal hypertension—and spans a wide spectrum of methodological designs, from large prospective cohorts to small single-center physiologic validation studies (Monnet & Teboul, 2017; Muzaffar et al., 2023). Unlike a systematic review or meta-analysis, a narrative review permits broader conceptual synthesis across heterogeneous study designs while preserving interpretive judgment in weighting evidence of variable quality—an approach judged more appropriate than a uniform meta-analytic framework, which would be unreliable across such methodologically diverse inputs (Huygh et al., 2016; Monnet & Teboul, 2017).

The review was structured around a central research question: *What is the prognostic value of PiCCO-derived hemodynamic parameters for short- and medium-term clinical outcomes—including 28-day mortality, ICU length of stay, progression of organ failure, and fluid responsiveness—in adult critically ill patients?* Three subordinate questions addressed comparative performance relative to alternative technologies, the populations in which prognostic performance has been most rigorously evaluated, and the methodological boundaries constraining broader clinical extrapolation (Chaudhary, 2026; Monnet & Teboul, 2017).

3.2 Literature Search Strategy

The literature search was conducted across three principal biomedical databases—PubMed/MEDLINE, Scopus, and Web of Science Core Collection—supplemented by manual cross-checking of reference lists from key articles and pertinent narrative reviews. Search terms combined Medical Subject Heading terms with free-text keywords across three conceptual blocks: the technology (PiCCO, pulse contour cardiac output, transpulmonary thermodilution, PiCCO2, VolumeView); the population (critically ill, intensive care, sepsis, septic shock, acute heart failure, ARDS, polytrauma, cardiac surgery); and the outcomes (mortality, prognosis, fluid responsiveness, extravascular lung water, cardiac function index). Articles published between January 2000 and December 2025 were considered eligible; no language restriction was imposed at the search stage, but only articles published in English—or accompanied by English-language abstracts providing sufficient methodological detail—were retained for full-text review (Huygh et al., 2016; Muzaffar et al., 2023).

3.3 Selection Criteria

Studies were eligible if they enrolled adult patients (≥ 18 years) treated in an intensive care setting, utilized PiCCO or a validated transpulmonary thermodilution-based platform for hemodynamic monitoring, and reported at least one PiCCO-derived parameter in conjunction with at least one predefined clinical outcome (mortality, organ dysfunction, fluid responsiveness, or length of stay) (Litton & Morgan, 2012; Monnet & Teboul, 2017). Exclusion criteria comprised pediatric populations, intraoperative-only applications without postoperative ICU follow-up, animal or in vitro experimental studies, conference abstracts without companion full texts, and physiologic validation studies lacking clinical outcome data (Huygh et al., 2016; Kiefer et al., 2012). Retrieved articles were filtered sequentially by title and abstract screening, then by full-text review.

3.4 Data Extraction and Quality Assessment

For each retained study, information was recorded in a standardized extraction matrix covering study design and setting, population and sample size, PiCCO parameters evaluated, clinical outcomes, threshold values and associated prognostic metrics (sensitivity, specificity, AUROC, odds ratios, hazard ratios), and recognized methodological boundaries (Monnet & Teboul, 2017; Ritter et al., 2009). Given the methodological heterogeneity of the available evidence, formal risk-of-bias scoring using tools such as the Newcastle–Ottawa Scale or the Cochrane Risk of Bias instrument was not uniformly applicable; each study was therefore appraised qualitatively along six dimensions: sample size and statistical power, clarity of inclusion and exclusion criteria, standardization of PiCCO calibration protocols, blinding of outcome assessors, completeness of follow-up, and adjustment for established confounders including age, comorbidities, and severity-of-illness scores (Monnet & Teboul, 2017; Muzaffar et al., 2023).

3.5 Narrative Synthesis

The extracted evidence was synthesized qualitatively, organized first by PiCCO parameter category (static volumetric, functional cardiac, capillary leak, and dynamic) and then by clinical population—allowing both parameter-specific and population-specific conclusions to emerge. Where multiple studies reported concordant findings, the consistency and strength of the evidence were emphasized; where findings diverged, the methodological sources of disagreement—differences in calibration technique, threshold selection, population case-mix, or outcome definition—were explicitly examined and discussed (Huygh et al., 2016; Monnet & Teboul, 2017).

4. Results

4.1 PiCCO Parameters and 28-Day Mortality

Across the studies reviewed, three PiCCO-derived indices emerged as the most consistently reported mortality-relevant parameters in adult critically ill patients: extravascular lung water index, global end-diastolic volume index, and cardiac function index. The strongest and most quantitatively reproducible signal originated from EVLWI. In a prospective cohort of 30 patients with septic shock monitored with PiCCO, non-survivors demonstrated significantly higher day-3 EVLWI values than survivors (13.7 ± 4.5 vs. 8.6 ± 2.6 mL/kg; $p = 0.001$), and an EVLWI cutoff of 11.5 mL/kg on day 3 yielded an area under the ROC curve of 0.868 ± 0.128 ($p = 0.001$) for hospital mortality, with sensitivity of 77% and specificity of 80%; this corresponded to a hospital mortality of 77% above the threshold versus 19% below it ($p = 0.02$) (S et al., 2008). Cordemans and colleagues extended this finding by demonstrating that, in 123 unselected ICU patients, the maximal change in EVLWI observed during the ICU stay reached an AUC of 0.822 for predicting 28-day mortality (Cordemans et al., 2012), positioning EVLWI as a dynamic rather than only static prognostic marker. Tagami and colleagues, focusing on ARDS patients, reported that Δ -EVLWI above a threshold of 2.8 was associated with worse 28-day survival (78.8% vs. 61.7%; $p = 0.01$), though the AUC in this population was more modest at 0.62 (95% CI 0.53–0.70, $p = 0.01$), with sensitivity of 70% and specificity of only 51% (Tagami et al., 2014). These primary findings are consistent with the systematic review and meta-analysis by Gavelli and colleagues, who synthesized 17 studies—10 of which reported maximal EVLW values across unselected ICU, ARDS, and septic shock populations—and concluded that elevated EVLW, whether measured at baseline or at peak, was significantly associated with ICU, in-hospital, or 28-day mortality across heterogeneous critically ill populations (Gavelli et al., 2022). Taken together, the evidence indicates that EVLWI—and particularly its trajectory during the ICU stay—is the PiCCO parameter with the most robust and reproducible association with 28-day mortality in adult ICU patients, especially in septic shock and ARDS.

By contrast, GEDVI and intrathoracic blood volume index showed a less consistent mortality signal. While reduced values have been linked to adverse outcomes in trauma populations, no single study identified in this review established a GEDVI threshold with sufficient prognostic accuracy to be clinically applicable for 28-day mortality in unselected ICU cohorts. The pulmonary vascular permeability index, although conceptually linked to pulmonary capillary leak severity, is associated with mortality in several categories of critically ill patients (Monnet & Teboul, 2017).

4.2 Cardiac Performance in Sepsis and Acute Heart Failure

The cardiac function index appeared as a parameter with population-specific prognostic value. In an observational study enrolling patients with severe sepsis or septic shock and a parallel cohort with acute heart failure, Ritter and colleagues demonstrated that CFI differed sharply between septic survivors and non-survivors (median 6.7 min^{-1} , IQR 6.0–7.4, vs. 3.5 min^{-1} , IQR 3.0–5.4; $p < 0.001$), indicating that impaired cardiac performance during sepsis was strongly associated with mortality (Ritter et al., 2009). Notably, in the same study, cardiac index itself did not differ between septic survivors and non-survivors (2.6 vs. 2.8 L/min/m^2 ; $p = 0.54$), suggesting that CFI carried prognostic information not supplied by traditional flow-based indices (Ritter et al., 2009). In the acute heart failure cohort, however, the prognostic signal of CFI disappeared: CFI was 2.6 (2.0 – 3.0) min^{-1} in survivors and 2.9 (2.3 – 3.2) min^{-1} in non-survivors ($p = 0.46$), and again cardiac index did not differ between groups ($p = 0.54$) (Ritter et al., 2009). Pulmonary artery occlusion pressure, right atrial pressure, and GEDVI likewise did not differ between survivors and non-survivors in either cohort, indicating that CFI was the sole hemodynamic variable in this dataset carrying prognostic discrimination (Ritter et al., 2009). This evidence was congruent with the wider narrative that PiCCO-derived cardiac performance parameters are most informative when the underlying pathophysiology combines cardiac and distributive components—as in sepsis—whereas in isolated cardiogenic shock their prognostic contribution is attenuated (Monnet & Teboul, 2017). Cardiac index remained the most widely reported parameter across studies, but its prognostic accuracy was consistently inferior to that of CFI in septic populations, and no unified mortality-relevant cutoff was reported (Ritter et al., 2009).

4.3 Predictive Value of Fluid Responsiveness Parameters

Fluid responsiveness prediction appeared as a domain in which PiCCO demonstrated clear advantages in comparison to static pressure variables but similar accuracy to other dynamic indices. In a head-to-head comparison of stroke volume variation measured by PiCCOplus against uncalibrated SVV measured by the FloTrac/Vigileo system in 76 mechanically ventilated patients, Hofer and colleagues determined that the two systems exhibited comparable predictive performances for fluid responsiveness, but with systematically different optimal thresholds: 9.6% for SVVFloTrac (sensitivity 91%, specificity 83%) and 12.1% for SVVPiCCO (sensitivity 87%, specificity 76%), with no significant difference between the areas under the respective ROC curves (Hofer et al., 2008). The 12.1% threshold observed for the calibrated PiCCO system is consistent with the broader literature, which suggests that calibration to an absolute stroke-volume reference shifts the operating point of dynamic indices relative to uncalibrated pulse-contour monitors (Alhashemi et al., 2011; Monnet & Teboul, 2017).

A subsequent systematic review and meta-analysis by Alvarado Sánchez and colleagues confirmed that the predictive performance of SVV depends markedly on patient population: in post-cardiovascular surgery patients (diagnostic odds ratio (DOR) 95.67; $p = 0.03$) and septic shock patients (DOR 21.23; $p < 0.01$), SVV performance was substantially better than in post-high-risk non-cardiac surgery patients (DOR 6.70; $p = 0.13$) (Sánchez et al., 2021). The same meta-analysis identified that operating performance for responder classification was lower when transpulmonary thermodilution rather than conventional bolus thermodilution was used as the reference method—the apparent accuracy of SVV thus depending in part on the accuracy of the gold standard against which it is benchmarked (Sánchez et al., 2021). Static volumetric parameters continued to be used as alternative preload indicators, but their predictive value for fluid responsiveness remained inferior to that of dynamic indices (Alhashemi et al., 2011; Monnet & Teboul, 2017). Across the reviewed evidence, the operating characteristics of PiCCO SVV/PPV were robust enough to support threshold-guided fluid administration in the populations in which the metric had been formally validated—predominantly post-cardiac surgery and septic shock—while extrapolating the same thresholds to other populations was not supported by the available data (Sánchez et al., 2021).

4.4 Clinical Impact of PiCCO-Guided Therapeutic Algorithms

The clinical consequence of PiCCO-guided management has been evaluated in both trauma-ARDS-specific and general ICU populations, with mixed although informative results. In a controlled study of patients with severe thoracic trauma and acute respiratory distress syndrome randomized to PiCCO-guided versus central venous pressure-guided management, Zhong and colleagues reported no significant difference in 28-day mortality (3.2% versus 3.6%; $p = 0.841$), but a significantly shorter duration of mechanical ventilation (median 3 versus 5 days; $p = 0.002$) and shorter ICU length of stay (median 6 versus 11 days; $p = 0.004$), with lower treatment costs in the PiCCO group and a significantly faster improvement in the $\text{PaO}_2/\text{FiO}_2$ ratio over

time (Yuanbo et al., 2016). This study provided the clearest indication that PiCCO-guided algorithms could deliver measurable benefits in the process of care and the use of resources in selected populations, even when mortality remained unchanged.

A significantly different signal emerged from the multi-center randomized controlled trial by Takala and colleagues, which evaluated early minimally invasive cardiac output monitoring (predominantly PiCCO-based) added to usual care in hemodynamically unstable ICU patients. In that trial, hospital mortality was 26% in the monitoring group versus 21% in controls ($p = 0.34$), and median ICU length of stay was 2.0 days (IQR 1.2–4.6) versus 2.5 days (IQR 1.1–5.0; $p = 0.38$), leading the authors to conclude that minimally invasive monitoring added to usual care neither facilitated earlier hemodynamic stabilization nor altered outcomes (Takala et al., 2011). Although the Lopes pilot RCT of goal-directed fluid management based on pulse pressure variation monitoring reported feasibility of the approach and hypothesized a 35% reduction in postoperative hospital stay with a planned sample of 33 patients per arm, it stopped short of establishing a PiCCO-specific outcome benefit at the population level (Lopes et al., 2007).

This interpretation was reinforced by the historical benchmark of Connors and colleagues, whose prospective cohort of 5,735 critically ill adults across five US teaching hospitals demonstrated that right-heart catheterization during the first 24 hours was associated with increased 30-day mortality (OR 1.24; 95% CI 1.03–1.49), increased hospital costs (mean \$49,300 vs. \$35,700), and prolonged ICU stay (mean 14.8 vs. 13.0 days), without any subgroup showing benefit (Connors, 1996). The earlier Gattinoni trial of supranormal cardiac index and mixed venous oxygen saturation targets had similarly concluded that goal-oriented hemodynamic therapy failed to reduce morbidity or mortality in critically ill patients (Gattinoni et al., 1995). The aggregate results indicate that simply providing more hemodynamic data is insufficient—algorithms must be population-specific, threshold-anchored, and aligned with the underlying pathophysiology to translate into an outcome benefit.

4.5 Comparison with Alternative Hemodynamic Monitoring Technologies

When benchmarked against alternative technologies at the measurement level, PiCCO provides broad interchangeability within the transpulmonary thermodilution class: the newer VolumeView/EV1000™ platform was validated against PiCCO2™ with mean percentage errors of 9.7% for cardiac output, 11.5% for global end-diastolic volume, and 12.2% for extravascular lung water (Kiefer et al., 2012), values that fall within the ± 20 –30% accuracy band accepted for clinical-grade cardiac output monitors. Against uncalibrated pulse-contour devices, PiCCO retained the structural advantage of an intermittent intrathoracic thermodilution anchor, which preserves measurement accuracy amid abrupt changes in vasomotor tone, severe vasoplegia, or arrhythmia (Alhashemi et al., 2011; Monnet & Teboul, 2017); in head-to-head fluid responsiveness prediction, stroke volume variation thresholds were 12.1% for calibrated PiCCOplus versus 9.6% for the uncalibrated FloTrac/Vigileo, with comparable areas under the respective receiver operating characteristic curves (Hofer et al., 2008). Against the pulmonary artery catheter, PiCCO offered comparable physiologic information at a substantially lower procedural risk profile (Monnet & Teboul, 2017; Uchino et al., 2006), a profile that, taken together with the historical 30-day mortality risk associated with early PAC use (OR 1.24; 95% CI 1.03–1.49) (Connors, 1996), positioned PiCCO as the preferred minimally invasive alternative in contemporary practice. The device-by-device interpretation of these comparisons is developed further in Section 5.3.

5. Discussion

5.1 Main Findings and Strengths for Prognostic Stratification

The principal strength of PiCCO for prognostic stratification is its capacity to integrate—at a single arterial interface—several physiologically distinct but mutually reinforcing dimensions of cardiovascular status: cardiac preload (GEDVI/ITBVI), cardiac performance (CFI, dP/dt_{max}), pulmonary edema burden, capillary permeability, and dynamic fluid-responsiveness predictors. This multidimensional profile contrasts strikingly with legacy pressure-based variables: neither central venous pressure nor pulmonary artery occlusion pressure has been demonstrated to be a true predictor of fluid responsiveness in the critically ill (Alhashemi et al., 2011), and their prognostic value for 28-day mortality in unselected ICU cohorts is, at best, marginal.

Among individual parameters, extravascular lung water index has emerged as a solid prognostic marker. The supporting body of evidence is now structurally substantial—encompassing individual prospective cohorts stratifying EVLWI against hospital and ICU mortality (Cordemans et al., 2012), ARDS-specific analyses in which early-phase Δ -EVLWI tracked 28-day survival (78.8% vs 61.7%; $p = 0.01$) (Tagami et al., 2014), and a systematic review and meta-analysis synthesizing 17 studies, 10 of which directly examined maximal EVLW values across heterogeneous ICU populations (Gavelli et al., 2022). Cardiac function index provides complementary, population-specific prognostic information: CFI discriminated septic survivors from non-survivors (median 6.7 vs 3.5 min^{-1} ; $p < 0.001$) while cardiac index itself did not (2.6 vs 2.8 L/min/m^2 ; $p = 0.54$), demonstrating that CFI captures cardiac dysfunction masked by conventional flow-based parameters (Ritter et al., 2009). The same CFI signal disappears in isolated acute heart failure (2.6 vs 2.9 min^{-1} ; $p = 0.46$) (Ritter et al., 2009).

A third methodological advantage is the dual architecture of PiCCO—intermittent transpulmonary thermodilution providing calibrated absolute references plus beat-to-beat pulse-contour tracking of stroke volume and its derivatives (Monnet & Teboul, 2017). This structure preserves measurement integrity regardless of abrupt vasomotor changes, when uncalibrated pulse-contour systems drift, and supports trend monitoring over hours to days—an essential property when the prognostic signal lies in the parameter trajectory rather than a single value (Cordemans et al., 2012; Monnet & Teboul, 2017).

5.2 Limitations and Technical Challenges

EVLWI, PVPI, and GEDVI measurements are influenced by patient positioning and intrathoracic mechanics: transitioning from supine to prone position produces a measurable decrease in EVLW and PVPI, with the change being more pronounced after shorter supine equilibration (Sakka et al., 2009). EVLWI is also affected by intra-abdominal hypertension, which can overestimate EVLW and confound cumulative fluid-balance assessments (Cordemans et al., 2012). These constraints are particularly relevant in surgical and trauma populations, where PiCCO monitoring is most often deployed.

Pulse-contour analysis requires recalibration after major hemodynamic events, and its accuracy depends on adequate arterial signal quality, stable body habitus, regular cardiac rhythm, and tidal volume sufficient to generate physiologically meaningful respiratory variation (Monnet & Teboul, 2017; Sánchez et al., 2021). The operating performance of SVV as a fluid-responsiveness predictor is markedly weaker when transpulmonary thermodilution—rather than conventional bolus thermodilution—is the reference method, demonstrating that apparent predictive accuracy is itself contingent on the calibration anchor (Monnet & Teboul, 2017; Sánchez et al., 2021).

The prognostic performance of CFI is demonstrably population-specific: whereas CFI was significantly lower in non-survivors than survivors in sepsis, the discriminatory signal disappeared entirely in acute heart failure (Ritter et al., 2009), indicating that CFI should not be promoted as a general-purpose mortality predictor in unselected populations. Finally, PiCCO requires central venous and femoral arterial access, both of which carry non-trivial procedural risk, although contemporary use has not been associated with the magnitude of harm historically attributed to pulmonary artery catheterization (Takala et al., 2011; Uchino et al., 2006).

5.3 Comparison with Alternative Hemodynamic Technologies

Within the transpulmonary thermodilution class, PiCCO2 and VolumeView/EV1000 have demonstrated broad interchangeability, with mean percentage errors of 9.7% for cardiac output, 11.5% for GEDV, and 12.2% for EVLW (Kiefer et al., 2012), all within the ± 20 –30% accuracy band accepted for clinical-grade CO monitors. In contrast to uncalibrated pulse-contour devices, PiCCO retains the structural advantage of an intermittent intrathoracic thermodilution anchor, which preserves measurement accuracy during abrupt vasomotor changes, severe vasoplegia, or arrhythmia (Alhashemi et al., 2011; Monnet & Teboul, 2017). In head-to-head fluid-responsiveness prediction, PiCCOplus and FloTrac/Vigileo had comparable AUCs but distinct optimal thresholds — 12.1% versus 9.6%, respectively — indicating that calibration to an absolute stroke-volume reference systematically alters the operating point of dynamic indices (Alhashemi et al., 2011; Hofer et al., 2008; Monnet & Teboul, 2017).

In contrast to the pulmonary artery catheter, the contemporary case for PiCCO rests on three converging lines of evidence. First, epidemiological data suggest that PAC use per se does not improve outcomes: right-heart catheterization during the first 24 hours of ICU admission was associated with significantly increased 30-day mortality (OR 1.24; 95% CI 1.03–1.49), prolonged ICU stay, and higher costs (Connors, 1996). Second, minimally invasive technologies have not shown comparable risk signals: in the multi-center RCT of early minimally invasive CO monitoring, hospital mortality was 26% versus 21% in controls ($p = 0.34$) with no increase in resource utilization (Takala et al., 2011). Third, transpulmonary thermodilution platforms have shown acceptable agreement with PAC thermodilution as the reference (Kiefer et al., 2012). Taken together, the accumulated evidence is consistent with the conclusion that PiCCO provides a comparable level of hemodynamic insight with a substantially lower procedural risk profile (Uchino et al., 2006).

5.4 Clinical Implications and Practical Recommendations

For parameter interpretation: In patients with sepsis or clinically suspected pulmonary edema, day-3 EVLWI above 11 mL/kg and a persistent upward EVLWI trajectory throughout the first 72 hours should be interpreted as carrying elevated mortality risk (hospital mortality 77% above threshold vs 19% below; $p = 0.02$) and should prompt aggressive de-resuscitation strategies where feasible (Cordemans et al., 2012; S et al., 2008). In ARDS, an early-phase Δ -EVLWI above 2.8 mL/kg is associated with significantly worse 28-day survival (Tagami et al., 2014). CFI values below approximately 4 min⁻¹ in septic populations should be interpreted as carrying elevated mortality risk independent of cardiac index (Ritter et al., 2009); in acute heart failure, however, CFI should not be used as a solitary prognostic marker, as the discriminatory signal is lost (Ritter et al., 2009).

For fluid management: In mechanically ventilated patients in sinus rhythm with tidal volumes ≥ 8 mL/kg, SVV via calibrated PiCCO above 12.1% (sensitivity 87%, specificity 76%) indicates fluid responsiveness, while uncalibrated systems such as FloTrac/Vigileo should be interpreted against a 9.6% threshold (sensitivity 91%, specificity 83%) (Hofer et al., 2008). Population-specific extrapolation should be avoided: the available evidence supports fluid-responsiveness interpretation principally in post-cardiovascular surgery (DOR 95.67; $p = 0.03$) and septic shock populations (DOR 21.23; $p < 0.01$), and its diagnostic utility drops substantially in other post-surgical populations (DOR 6.70; $p = 0.13$) (Sánchez et al., 2021).

For management algorithms: PiCCO-derived data should not, on their own, drive resuscitation decisions without explicit threshold-based algorithms and clearly defined population targets (Monnet & Teboul, 2017; Takala et al., 2011). Pooled evidence from the ARDS subpopulation, however, is more encouraging. A 2022 meta-analysis of nine RCTs in 747 ARDS patients demonstrated that PiCCO-guided monitoring reduced 28-day mortality (RR 0.53; 95% CI 0.39–0.73; $P = 0.0001$), shortened mechanical ventilation by 3.91 days (95% CI –4.91 to –2.92; $P < 0.00001$), and reduced ICU length of stay by 5.23 days (95% CI –6.64 to –3.82; $P < 0.00001$) relative to conventional hemodynamic monitoring (Huang et al., 2022). This mortality signal in ARDS contrasts more sharply with the multicenter randomized evidence in unselected hemodynamically unstable ICU patients, where PiCCO- or comparable minimally invasive CO-guided management produced neither earlier hemodynamic stabilization nor improved hospital mortality (26% vs 21%; $P = 0.34$) (Takala et al., 2011), and with broader meta-analytic evidence across heterogeneous hemodynamic intervention strategies (8 RCTs, 5 323 patients; OR 0.96; 95% CI 0.82–1.11; $P = 0.95$) (Bateman et al., 2016). Process-of-care benefits in narrower severity strata have also been demonstrated—in severe thoracic trauma with ARDS, PiCCO-guided management shortened mechanical ventilation (median 3 vs 5 days; $P = 0.002$) and ICU length of stay (median 6 vs 11 days; $P = 0.004$) without altering 28-day mortality (3.2% vs 3.6%; $P = 0.841$) (Yuanbo et al., 2016). The convergence of these three evidence tiers suggests that PiCCO-guided management should be

regarded as *population-conditional* rather than *population-neutral*: benefit can be reasonably expected in ARDS specifically, but cannot be presumed in unselected hemodynamically unstable ICU populations.

For monitoring selection: PiCCO should be considered the preferred minimally invasive hemodynamic technology for adult ICU patients in whom multiple parameter domains—volumetric preload, cardiac performance, and pulmonary edema burden—must be evaluated from a single platform, particularly when invasive right-heart catheterization is not strictly indicated (Monnet & Teboul, 2017; Uchino et al., 2006). The interchangeability of PiCCO2 and VolumeView/EV1000 (Kiefer et al., 2012) allows technology selection to be driven by local availability rather than accuracy considerations.

5.5 Limitations of This Review

Four limitations should be acknowledged. First, the narrative review design, while suited to the heterogeneous body of evidence, does not permit quantitative meta-analytic synthesis and is more vulnerable than a systematic review to author-level selection and interpretation bias (Monnet & Teboul, 2017; Muzaffar et al., 2023); conclusions should therefore be read as consensus statements about the direction and consistency of the evidence, not as point estimates of effect. Second, the included studies span nearly two decades of evolving PiCCO technology and critical-care practice—lung-protective ventilation, sepsis bundles, fluid-conservative strategies—introducing temporal confounding that no individual study can fully control (Monnet & Teboul, 2017; Muzaffar et al., 2023). Third, the evidence over-represents single-center, post-cardiac-surgery, ARDS, and sepsis cohorts, while obstetrics, neurocritical care, burns, and pediatric ICU populations remain comparatively sparse—limiting external validity beyond the populations generating the original data (Muzaffar et al., 2023; Ritter et al., 2009). Fourth, much of the published work correlates PiCCO indices with mortality or ICU length of stay within a univariable rather than multivariable framework, with limited adjustment for age, severity-of-illness scores, and timing of PiCCO deployment (Monnet & Teboul, 2017; Ritter et al., 2009).

5.6 Directions for Future Research

Four research priorities emerge. First, multicenter prospective validation of day-3 EVLWI (11.5 mL/kg) and Δ -EVLWI (2.8 mL/kg) thresholds is needed within contemporary sepsis and ARDS populations, where benchmarks for sepsis management and ventilation have shifted (Tagami et al., 2014). Second, population-specific resuscitation algorithms incorporating calibrated PiCCO parameters as decision nodes should be tested in multicenter randomized designs. The ARDS subpopulation represents the most promising target for mortality-level benefit: a 2022 meta-analysis of nine RCTs in 747 ARDS patients reported a pooled 28-day mortality RR of 0.53 (95% CI 0.39–0.73; $P = 0.0001$) and a mean mechanical-ventilation reduction of 3.91 days in favor of PiCCO-guided management (Huang et al., 2022). The principal outstanding questions are no longer whether PiCCO monitoring changes ARDS outcomes, but rather which ARDS phenotypes (early vs established; mild vs severe Berlin strata; concomitant vasopressor burden) drive the heterogeneity observed across the constituent RCTs, and whether the 28-day mortality benefit extends to longer-horizon outcomes such as 60-day and 90-day survival. Conversely, the multicenter randomized evidence in unselected hemodynamically unstable ICU patients has not demonstrated comparable population-level benefit (Takala et al., 2011), and broader meta-analytic evidence across heterogeneous hemodynamic intervention strategies remains neutral (8 RCTs, 5 323 patients; OR 0.96; 95% CI 0.82–1.11; $P = 0.95$) (Bateman et al., 2016). Third, integration of PiCCO-derived trajectories—rather than single-point values—into patient-level prediction frameworks is methodologically promising, particularly for lung water (Cordemans et al., 2012; Tagami et al., 2014) and for CFI where absolute-value discrimination has proven population-dependent (Ritter et al., 2009). Fourth, deployment of PiCCO in underrepresented populations—obstetric critical care, neurocritical care, major burns, pediatric septic shock—would meaningfully extend external validity (Muzaffar et al., 2023). All four priorities are constrained by the absence of a recent multicenter calibration study harmonizing transpulmonary thermodilution measurement across PiCCO2, VolumeView/EV1000, and emerging platforms (Kiefer et al., 2012; Monnet & Teboul, 2017; Sakka et al., 2009).

6. Conclusions

6.1 Balance of Prognostic Value and Clinical Utility

The interpretation of PiCCO as a prognostic technology rests on a genuine balance between clinically meaningful advantages and recognized limitations. On the side of value, PiCCO offers an integrated, multidimensional view of the hemodynamic state—volumetric preload indices supplant underperforming pressure-based surrogates (Alhashemi et al., 2011; Monnet & Teboul, 2017), calibrated cardiac output measurement preserves accuracy under varying vasoactive conditions, and quantitative EVLWI is a recognized PiCCO-based mortality signal (Gavelli et al., 2022). The trajectory-based information provided by Δ -EVLWI adds an additional dynamic layer not available from any static monitoring modality (Cordemans et al., 2012; Tagami et al., 2014). Validated head-to-head comparisons demonstrate that PiCCO functions as a clinically accurate platform, comparable to direct pulmonary artery catheter measurement (Kiefer et al., 2012), while avoiding the procedural risks historically associated with right-heart catheterization (Connors, 1996; Uchino et al., 2006).

On the side of limitations, the prognostic performance of PiCCO-derived indices is population-specific in ways that constrain generalization. EVLWI measurements are subject to technical influences including patient positioning (Sakka et al., 2009), intra-abdominal pressure (Cordemans et al., 2012), and the integrity of the thermodilution calibration (Monnet & Teboul, 2017). CFI's prognostic discrimination has been most convincingly documented in septic populations, in which it captures cardiac dysfunction masked by conventional flow-based indices; the same signal does not extend to isolated acute heart failure, where CFI values have not been shown to differ between survivors and non-survivors (Ritter et al., 2009). Dynamic indices such as SVV perform poorly in patient populations in which they have not been specifically validated (Sánchez et al., 2021). The multicenter evidence for any PiCCO-specific mortality benefit at the population level does not currently exist in unselected ICU populations—early non-invasive CO monitoring in hemodynamically unstable ICU patients produced hospital mortality of 26% vs 21% in controls ($P = 0.34$) (Takala et al., 2011), and broader meta-analytic evidence across heterogeneous hemodynamic intervention strategies remains neutral (8 RCTs, 5 323 patients; mortality OR 0.96; 95% CI 0.82–1.11; $P = 0.95$) (Bateman et al., 2016). However, recent meta-analytic evidence in the ARDS subpopulation is more encouraging: a 2022 synthesis of nine RCTs in 747 ARDS patients reported a pooled 28-day mortality risk ratio of 0.53 (95% CI 0.39–0.73; $P = 0.0001$) for PiCCO-guided versus conventional hemodynamic monitoring, alongside reductions in mechanical ventilation duration of 3.91 days and ICU stay of 5.23 days (Huang et al., 2022). Process-of-care improvements have additionally been demonstrated in narrower severity strata of thoracic trauma with ARDS (Yuanbo et al., 2016), but it remains unclear how far this process-level benefit generalizes within the broader ARDS severity spectrum. The distinction is critical: PiCCO-specific mortality benefit should be framed as demonstrated in ARDS specifically, absent in unselected ICU populations, and untested in most intermediate clinical strata.

Two conclusions follow. First, PiCCO is a clinically meaningful tool for hemodynamic profiling in the ICU but is not, by itself, sufficient to alter mortality outcomes (Monnet & Teboul, 2017; Takala et al., 2011). Second, the prognostic value and clinical utility of PiCCO-derived data are distinct quantities: future implementation work must concentrate on the latter rather than the former, and the operational target is rigorous, population-tailored resuscitation algorithms rather than additional monitoring capacity.

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