The role of thoracic ultrasound in fluid management in critical care: a narrative review

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Contributions: (I) Conception and design: R da Hora Passos; (II) Administrative support: None; (III) Provision of study materials or patients: None; (IV) Collection and assembly of data: All authors; (V) Data analysis and interpretation: None; (VI) Manuscript writing: All authors; (VII) Final approval of manuscript: All authors.

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Background and Objective: Fluid management remains central to critical care, requiring a careful balance between early resuscitation and the prevention or reversal of pulmonary and systemic congestion. Thoracic ultrasound (TUS) offers real-time, organ-specific assessment of extravascular lung water (EVLW) and pleural effusion, helping clinicians recognize both fluid responsiveness and fluid intolerance—an increasingly relevant distinction in acute respiratory distress syndrome (ARDS), acute heart failure, kidney replacement therapy, and shock. This review synthesizes current evidence on TUS-guided fluid administration and removal and introduces the Fluid Responsiveness & Tolerance, Lung Congestion, Ultrafiltration Optimization, Individualized Therapy, Differentiating Shock (FLUID) framework as a practical bedside reasoning tool emphasizing repeated reassessment rather than prescriptive thresholds.

Methods: Narrative review of PubMed, Scopus, and Embase (January 2015 to January 2025), supplemented by landmark earlier articles when clinically relevant. Eligible studies included adult human research, systematic reviews, randomized trials, and consensus statements. Editorials, pediatric, and veterinary studies were excluded. Selection and full-text appraisal were performed independently by two reviewers.

Key Content and Findings: TUS provides bedside visualization of pulmonary congestion through B-lines, lung ultrasound scoring, and effusion monitoring, improving detection of EVLW compared with physical examination or central venous pressure. Integrated with focused cardiac and venous Doppler evaluation, TUS supports decisions regarding resuscitation, diuretic escalation, ultrafiltration, or fluid removal in ARDS, heart failure, and shock. Evidence suggests TUS-guided strategies may reduce cumulative fluid balance and rehospitalization in heart failure and may facilitate ventilator liberation, though definitive outcome effects remain under investigation. The FLUID framework structures iterative bedside reasoning without functioning as a prescriptive protocol.

Conclusions: TUS is a practical and repeatable tool that enhances individualized fluid management by identifying evolving pulmonary congestion and estimating fluid tolerance. The FLUID framework supports structured clinical integration of ultrasound findings but requires further prospective validation. Future trials

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and artificial intelligence (AI)-assisted quantification tools may help standardize practice and clarify outcome benefits.

Keywords: Thoracic ultrasound (TUS); fluid management; lung ultrasound; critical care; hemodynamic assessment

Submitted Jun 10, 2025. Accepted for publication Nov 25, 2025. Published online Jan 26, 2026.
doi: 10.21037/jtd-2025-1103
View this article at: https://dx.doi.org/10.21037/jtd-2025-1103

Introduction

Fluid management remains a defining element of critical care decision-making. Early fluid resuscitation can restore perfusion and prevent organ injury, but persistent positive fluid balance contributes to pulmonary edema, impaired gas exchange, prolonged mechanical ventilation, and higher mortality, with fluid overload affecting a substantial proportion of critically ill patients (1). This has led to the concept of fluid stewardship, which emphasizes not only when to administer fluids, but also when to refrain or actively remove them as clinical conditions evolve (2). The challenge lies in accurately assessing the consequences of fluid therapy at the bedside, where conventional tools such as central venous pressure or physical examination often lack reliability (3).

Thoracic ultrasound (TUS) provides a repeatable, organ-specific evaluation of pulmonary congestion and pleural effusion by visualizing aeration patterns and B-lines as markers of extravascular lung water (EVLW) (4). When integrated with cardiac and venous ultrasound, TUS supports the clinical balance between fluid responsiveness and fluid tolerance, informing both resuscitation and deresuscitation decisions (5). Recent evidence suggests that TUS-guided fluid management may reduce cumulative fluid balance across heterogeneous ICU populations (6), and the ongoing CONFIDENCE trial is evaluating its impact on ventilator duration in invasively ventilated patients (7).

The objective of this review is therefore focused: to synthesize current evidence on the use of TUS to guide fluid administration and removal across syndromes such as acute respiratory distress syndrome (ARDS) (8,9), acute heart failure (10), kidney replacement therapy (KRT) (11), and shock (12), and to introduce the FLUID framework as a practical bedside approach. We present this article in accordance with the Narrative Review reporting checklist (available at https://jtd.amegroups.com/article/view/10.21037/jtd-2025-1103/rc).

Highlight box

Key findings

- Thoracic ultrasound (TUS) provides a real-time, bedside assessment of pulmonary aeration, allowing clinicians to detect and monitor extravascular lung water, pulmonary congestion, and pleural effusion with higher sensitivity than physical examination.
- Integrating TUS with focused cardiac evaluation and venous congestion assessment enhances the ability to distinguish fluid responsiveness from fluid intolerance, improving decisions on fluid administration, diuretic therapy, and ultrafiltration.
- The Fluid Responsiveness and Tolerance, Lung Congestion, Ultrafiltration Optimization, Individualized Therapy, and Differentiating Shock (FLUID) framework offers a practical structure for repeated reassessment during fluid management.

What is known and what is new?

- It is known that excessive positive fluid balance worsens pulmonary and systemic congestion, contributing to impaired gas exchange, prolonged mechanical ventilation, and organ dysfunction. TUS has been widely recognized as a sensitive tool for identifying pulmonary edema through B-lines and loss of aeration.
- This manuscript synthesizes emerging evidence across acute respiratory distress syndrome, heart failure, kidney replacement therapy, and shock, and introduces the FLUID framework as a structured bedside reasoning tool. The review emphasizes the distinction between fluid responsiveness and fluid tolerance, a concept increasingly relevant in modern fluid stewardship.

What is the implication, and what should change now?

- Clinicians should adopt a more dynamic, physiology-based approach to fluid management using serial TUS integrated with cardiac and venous findings.
- Practice should shift from fixed fluid targets toward individualized decisions that prioritize congestion assessment and fluid tolerance.
- Future implementation requires standardized training, consistent reporting of lung ultrasound findings, and prospective validation of ultrasound-guided fluid strategies.

Methods

This narrative review was conducted to explore the role

Table 1 The search strategy summary

Items	Specification
Date of search	January 5, 2025
Databases	PubMed, Scopus, and Embase
Search terms used	"Thoracic Ultrasound", "Lung Ultrasound", "Fluid Management", "Volume Status", "Critical Care", "ARDS", "Heart Failure", and "Shock"
Timeframe	January 2015 to January 2025
Inclusion and exclusion criteria	Inclusion: human studies, English language, adults, reviews and original research
	Exclusion: pediatric studies, veterinary applications, editorials
Selection process	Articles were selected by two independent reviewers (R.H.P. and R.H.M.). Disagreements were resolved by discussion and consensus
Additional considerations	Priority was given to articles with high citation index, recent systematic reviews, and original contributions in major journals

of TUS in fluid management of critically ill patients. The literature search was performed in January 2025, using three electronic databases: PubMed, Scopus, and Embase. The search strategy combined MeSH terms and free-text keywords, including: "Thoracic Ultrasound", "Lung Ultrasound", "Fluid Management", "Volume Status", "Critical Care", "ARDS", "Heart Failure", and "Shock". A detailed search strategy for PubMed is provided in Table S1.

The search focused on articles published within the last 10 years (from January 1, 2015, to January 31, 2025). However, additional studies published before this time frame were included when deemed clinically relevant and frequently cited in key publications or consensus documents. Only studies involving adult human populations and published in English were considered. Eligible articles included original research, randomized controlled trials, systematic reviews, narrative reviews, and expert consensus guidelines. Editorials, case reports, pediatric studies, and veterinary literature were excluded.

Two reviewers (R.H.P. and R.H.M.) independently screened all titles and abstracts. Selected full-text articles were then evaluated based on relevance to the central topic and contribution to the development or validation of protocols involving TUS in fluid assessment. Discrepancies were resolved through discussion and mutual agreement.

As this is a narrative review, no formal risk-of-bias assessment or meta-analysis was conducted. Instead, the goal was to provide an integrative, evidence-informed synthesis to support clinical decision-making and introduce the Fluid Responsiveness & Tolerance, Lung Congestion, Ultrafiltration Optimization, Individualized Therapy, Differentiate Shock (FLUID) mnemonic—as an educational framework to support personalized, evidence-based fluid management. This concept complements, rather than replaces, existing strategies, and requires further prospective validation. *Table 1* summarizes the search strategy.

Technical aspects of TUS relevant to fluid management

TUS allows bedside evaluation of pleural and subpleural lung aeration, providing dynamic insight into pulmonary fluid content (13,14). Although image interpretation is operator-dependent, brief structured training has proven sufficient to achieve reproducible competency, supporting broader use in critical care (15,16). The pleural line and lung sliding help confirm pleural apposition, with M-mode distinguishing normal sliding ("sea-shore") from patterns suggestive of pneumothorax ("barcode/stratosphere") (17,18). A-lines indicate preserved aeration (19), while B-lines—vertical artifacts arising from the pleura and erasing A-lines—signal interstitial–alveolar edema and increased EVLW; quantifying them across lung zones enables serial monitoring of congestion (20,21). The Lung Ultrasound Score (LUS) provides a standardized approach to track aeration changes and guide decisions regarding diuretics or ultrafiltration in evolving cardiopulmonary instability (22,23). TUS is also highly sensitive in detecting pleural effusion and in monitoring its progression, informing when thoracentesis may be beneficial (17). However, TUS does not independently differentiate cardiogenic from non-cardiogenic edema and cannot exclude pulmonary embolism; therefore, findings must be integrated with hemodynamic assessment, biomarkers, and focused echocardiography for accurate clinical interpretation (23-25). *Figure 1* illustrates key lung ultrasound findings, along with interpretation tips and their correlation with associated pathologies.

TUS in ARDS management

ARDS is defined by acute hypoxemia and diffuse inflammatory lung injury with heterogeneous alveolar collapse, commonly accompanied by increased EVLW (16). Because this edema is primarily non-hydrostatic, minimizing fluid accumulation is essential to preserve alveolar recruitment and gas exchange (26). TUS enables real-time bedside assessment of aeration and pulmonary congestion, supporting dynamic, physiology-guided fluid management (27,28).

The 2023–2024 international ARDS consensus acknowledges TUS as an acceptable bedside modality to detect reduced aeration and interstitial-alveolar edema, reflected by bilateral B-lines and/or subpleural consolidations, particularly when radiography or computed tomography (CT) are not readily available. These findings are considered supportive but not diagnostic in isolation; interpretation requires integration with clinical context and echocardiography to distinguish noncardiogenic from hydrostatic pulmonary edema. Within this framework, TUS contributes to ongoing assessment of pulmonary edema severity and its response to treatment (29). In addition to ruling out alternative diagnoses, TUS can also be used to classify ARDS into subphenotypes. Clinical trials are currently underway to analyze if this approach improves patient outcomes (30).

Fluid management is central in ARDS, as excessive intravascular volume increases EVLW and compromises gas exchange; thus, conservative and deresuscitative strategies are generally preferred (31). TUS supports fluid decision-making in ARDS by enabling serial bedside assessment of lung aeration and EVLW. An increase in B-line burden or new subpleural consolidations indicates reduced fluid tolerance and a higher risk of worsening pulmonary edema. When integrated with focused echocardiography and venous Doppler evaluation (e.g., VExUS), these findings help determine whether further fluid administration is likely to be beneficial or harmful, guiding the transition toward conservative or deresuscitative strategies as physiology evolves (32). TUS also detects pleural effusions that may impair ventilation and guides drainage when appropriate (33).

TUS in heart failure management

TUS is a key bedside tool for assessing pulmonary congestion in acute decompensated heart failure, where clinical examination, natriuretic peptides, and chest radiography often lack sensitivity or timely responsiveness (34,35). B-lines directly reflect EVLW and correlate with congestion severity and outcomes, with ≥3 B-lines per intercostal space providing greater diagnostic accuracy for pulmonary edema than auscultation or radiography (36). Because congestion fluctuates over time, serial TUS allows monitoring of decongestive response: reduction in B-lines after diuresis is associated with symptomatic improvement, whereas persistence suggests elevated filling pressures or venous congestion and may prompt escalation of diuretic strategies, vasodilators, or ultrafiltration in selected patients (37,38). TUS-guided decongestion has been associated with fewer readmissions and shorter hospital stay, with meta-analytic data similarly showing reduced exacerbations and rehospitalizations, though mortality effects remain inconsistent (39).

Fluid responsiveness does not necessarily equate to fluid tolerance; stroke volume may transiently rise following fluid administration even as congestion simultaneously worsens, rendering additional fluid potentially harmful (40). These two states—responsiveness and intolerance—can coexist, underscoring the complexity of hemodynamic management in critical illness (41). In this context, B-lines represent an actionable marker of fluid intolerance. Integrating TUS with focused echocardiography and venous congestion assessment [e.g., inferior vena cava (IVC) dynamics or VExUS grading] yields a comprehensive hemodynamic profile that supports individualized decongestive and resuscitative strategies. Further studies should evaluate the clinical implications of this integrative approach and its potential to refine fluid resuscitation and monitoring practices in diverse critical care settings (42). Emerging automated B-line quantification may enhance reproducibility and facilitate broader clinical implementation (43).

TUS during KRT and ultrafiltration

Fluid overload is highly prevalent among critically ill patients requiring KRT, and the safety of ultrafiltration

Finding	Tip	Associated pathologies	Image
Pleural line and lung sliding	Use a high frequency linear probe for optimal resolution. Look for the ‘ants marching’ artifact to confirm normal lung sliding.	Normal lung function; Pneumothorax (if absent)	
A-lines	A-lines indicate normal lung aeration but do not exclude all lung pathologies. Check for lung sliding to rule out pneumothorax.	Normal lung aeration	
B-lines	Scan multiple lung zones (anterior, lateral, posterior). A finding of ≥3 B lines per zone suggests significant pulmonary congestion.	Pulmonary edema, ARDS, interstitial alveolar syndromes	
Pleural effusion (simple)	Use a curvilinear or phased-array probe to assess pleural effusions. Apply gentle pressure to check if the fluid is free flowing or loculated.	Heart failure, hypervolemia (transudative effusions)	
Pleural effusion (complicated)	Look for septations and internal echoes, which suggest exudative effusion, often due to infection or malignancy.	Infections, malignancies (exudative effusions)	

Figure 1 Summary of key lung ultrasound findings, their imaging characteristics, and associated pathologies. ARDS, acute respiratory distress syndrome.

hinges not only on the absolute volume removed but on the patient's hemodynamic capacity to tolerate fluid shifts (44-46). TUS provides a direct, bedside quantification of EVLW, allowing clinicians to determine whether ongoing ultrafiltration is effectively reducing pulmonary congestion or whether lung water remains elevated despite fluid removal, implying persistent elevations in pulmonary capillary pressure and impaired lymphatic clearance. However, lung ultrasound alone cannot define the limits of fluid tolerance, as pulmonary and systemic compartments may evolve discordantly (44,47).

The capacity to sustain ultrafiltration is determined principally by venous return pressure and right ventricular adaptation to increased afterload. The VExUS score integrates Doppler evaluation of hepatic, portal, and renal venous flow to quantify systemic venous hypertension, which reflects the degree to which rising right-sided filling pressures are transmitted to organ microcirculations. High-grade venous congestion is strongly associated with ultrafiltration-induced hypotension, renal tubular injury, and delayed renal recovery, even when pulmonary congestion is present. When combined with IVC dynamics and focused cardiac ultrasound to assess right ventricular size, function, and interventricular dependence, a more complete picture of the hemodynamic tolerance threshold emerges (48,49).

Growing observational and interventional evidence suggests that integrating TUS with venous Doppler and cardiac imaging improves the accuracy of congestion assessment, supports earlier and more targeted deresuscitation, and may facilitate ventilator liberation in selected patients, although definitive randomized trials are ongoing (50-55). In this context, ultrasound does not function as an isolated diagnostic modality but as the core of a dynamic, physiology-guided framework for fluid management (56).

TUS in shock management

Circulatory shock—whether distributive, cardiogenic, hypovolemic, or obstructive—poses a unique challenge in fluid management, where the timely use of multi-organ point-of-care ultrasound (MOPOCUS) can aid in rapid diagnosis and guide clinical decision-making for more effective treatment (57). In septic shock, ultrasound can help differentiate between fluid responsiveness and fluid overload, allowing for timely adjustments to therapy to prevent pulmonary edema and improve hemodynamic stability (58). In hypovolemic or early distributive shock, the lung is typically characterized by an A-line pattern. When B-lines emerge during resuscitation, this may indicate decreasing fluid tolerance, even in patients who remain fluid responsive by dynamic preload indices (57). In cardiogenic shock, TUS often reveals more diffuse or coalescent B-lines, sometimes accompanied by pleural effusions. The integration of these findings with echocardiographic assessment of ventricular function and filling pressures can help guide whether therapy should prioritize preload reduction, afterload modification, or inotropic support, although the optimal ultrasound-guided strategy continues to be refined (59). In obstructive shock, particularly pulmonary embolism, lung ultrasound findings are variable, and normal or near-normal aeration does not exclude PE. Thus, when PE is suspected, TUS should be complemented by echocardiography and confirmatory imaging (60,61).

FLUID: a conceptual framework to support ultrasound-informed fluid management

The Rescue, Optimize, Stabilize, Evacuate (ROSE) model has long served as a conceptual scaffold for fluid resuscitation in shock, delineating four sequential phases that guide clinicians from the restoration of perfusion to the eventual removal of excess fluid. Its structured simplicity has made it a cornerstone of intensive care education and practice (62,63). Nonetheless, recent evidence has underscored key limitations: ROSE assumes a linear trajectory of care and provides limited direction for dynamic reassessment, particularly during the critical transition from fluid responsiveness to venous congestion. Moreover, it does not explicitly incorporate the evaluation of venous congestion—a central determinant of organ dysfunction that often eludes detection by static or pressure-based metrics (64).

In contrast, the FLUID construct is conceived not as a prescriptive protocol but as a cognitive model to guide iterative, bedside re-evaluation throughout the course of critical illness. Rather than replacing the temporal logic of the ROSE model, it complements it by emphasizing how ultrasound-derived findings can be assimilated into evolving hemodynamic reasoning. Through this lens, FLUID promotes a cyclical, physiology-based approach to fluid management—anchoring decision-making in continuous reassessment, particularly in patients whose circulatory status fluctuates rapidly under critical conditions.

- ❖ F: fluid responsiveness and fluid tolerance. Evaluation of whether cardiac output is likely to increase with fluid administration remains important. However, recent literature emphasizes the parallel assessment of fluid tolerance—the capacity to receive fluid without worsening pulmonary or systemic congestion. Tools such as hepatic, portal, and renal venous Doppler patterns, incorporated into venous congestion grading systems, may help estimate tolerance when interpreted with echocardiographic and clinical findings (65).

- ❖ L: lung congestion. Lung ultrasound can identify and track early interstitial edema through the presence, distribution, and evolution of B-lines. Because congestion can change quickly during resuscitation or decongestion, serial assessment may assist in adjusting fluids, diuretics, or vasodilators, although optimal thresholds and clinical triggers remain under investigation (23,66).
- ❖ U: ultrafiltration optimization. In patients receiving KRT, monitoring EVLW via B-line burden and assessing venous congestion may help individualize the rate and intensity of ultrafiltration, aiming to relieve dyspnea and congestion while avoiding hypotension or reduced organ perfusion. Evidence is still emerging and largely observational (44).
- ❖ I: individualized therapy. Fluid therapy should adapt to dynamic physiology rather than fixed targets. Goals such as “dry weight” or “neutral balance” may not be appropriate during early shock, evolving cardiac dysfunction, or recovery phases. Repeated reassessment, rather than a predetermined endpoint, is central to individualized fluid care (1).
- ❖ D: differentiating shock phenotypes. Combined thoracic, cardiac, and vascular ultrasound may help clarify hemodynamic profiles—for example, distinguishing cardiogenic from distributive or obstructive shock—supporting decisions on whether fluids are likely to be beneficial or potentially harmful. However, ultrasound findings must be interpreted with clinical context and are not sufficient alone for definitive etiologic classification (57).

Overall, FLUID is intended as a structured mental framework that supports bedside reasoning and interdisciplinary communication (*Figure 2*). It does not prescribe numeric thresholds or specific therapeutic actions. Current evidence suggests that ultrasound-integrated fluid assessment may improve congestion trajectories and guide more physiologic therapy, but definitive outcome benefits remain uncertain, as reflected in recent systematic reviews (7,65).

Future perspectives

The next stage in ultrasound-informed fluid management will likely emphasize integrated, multimodal assessment rather than reliance on TUS alone. The combined use of lung ultrasound, focused echocardiography, and venous congestion evaluation (e.g., VExUS) offers a more complete understanding of both fluid responsiveness and fluid tolerance, reinforcing that TUS is most effective when embedded within a broader hemodynamic reasoning strategy (67,68).

Technological developments may strengthen this approach. Automated B-line quantification, artificial intelligence (AI)-assisted image acquisition, and decision-support algorithms could reduce operator variability and expand the utility of TUS among less experienced users. These innovations are promising, but their clinical relevance remains to be established, and implementation will require careful evaluation in different care environments (69,70).

To date, the evidence base supporting ultrasound-guided fluid management consists largely of observational studies and relatively small interventional trials. While some analyses suggest improvements in cumulative fluid balance and reduced heart failure readmissions, conclusive effects on outcomes such as mortality, renal recovery, or duration of mechanical ventilation have not yet been demonstrated (7,65). Future research will benefit from prospective multicenter trials that incorporate standardized ultrasound acquisition, reporting frameworks, and predefined intervention thresholds. Such studies are essential to determine whether ultrasound-integrated fluid strategies can reliably influence clinical outcomes and become part of routine critical care practice.

Conclusions

TUS provides a practical, repeatable bedside method to assess pulmonary congestion and fluid tolerance in critically ill patients. When interpreted alongside focused cardiac evaluation and clinical context, it can support more precise titration of both fluid administration and fluid removal, helping clinicians adapt therapy to evolving physiology.

The FLUID framework offers a structured way to organize this reasoning. It is not a protocol, but a conceptual guide that integrates lung aeration, venous congestion, ultrafiltration considerations, and shock phenotype into

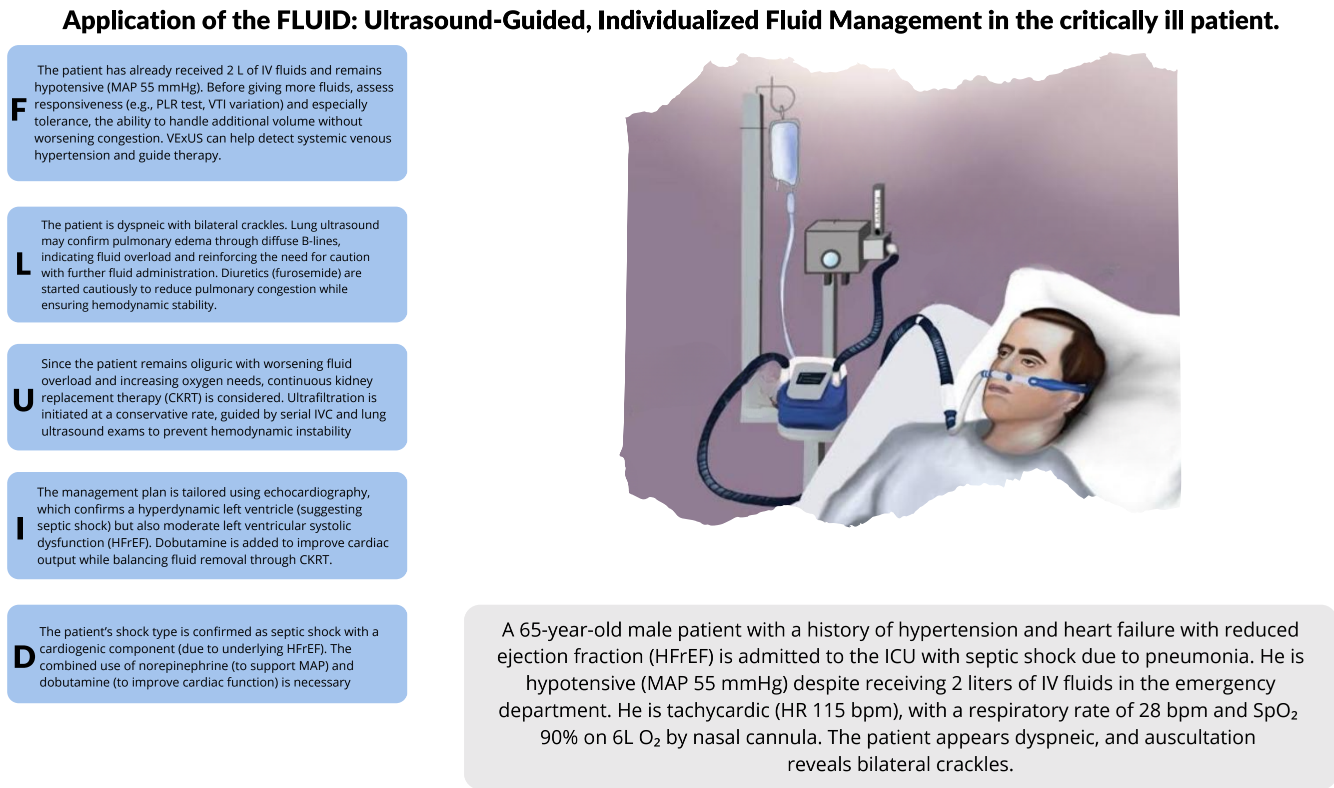

Figure 2 Case scenario applying the FLUID framework. FLUID, Fluid Responsiveness & Tolerance, Lung Congestion, Ultrafiltration Optimization, Individualized Therapy, Differentiate Shock Types, Continuous Monitoring, Avoid Complications, Real-Time Decision-Making; ICU, intensive care unit; IV, intravenous; IVC, inferior vena cava; MAP, mean arterial pressure.

ongoing bedside reassessment.

Evidence to date suggests improved congestion management, though definitive effects on major outcomes remain uncertain. Future multicenter trials with standardized ultrasound approaches will be essential to determine clinical impact. Meanwhile, TUS can help clinicians make more thoughtful, patient-centered fluid decisions—where timing, context, and balance are key.

Acknowledgments

None.

Footnote

Reporting Checklist: The authors have completed the Narrative Review reporting checklist. Available at https://jtd.amegroups.com/article/view/10.21037/jtd-2025-1103/rc

Peer Review File: Available at https://jtd.amegroups.com/article/view/10.21037/jtd-2025-1103/prf

Funding: None.

Conflicts of Interest: All authors have completed the ICMJE uniform disclosure form (available at https://jtd.amegroups.com/article/view/10.21037/jtd-2025-1103/coif). The authors have no conflicts of interest to declare.

Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

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Cite this article as: da Hora Passos R, Andari LVWBU, de Almeida Lopes M, Galindo VB, Flato UAP, Narciso RC, Pellegrino CM, Midega TD, de Almeida RS, Coelho FO, Zawadzki B, Melo RH, de Arruda Bravim B. The role of thoracic ultrasound in fluid management in critical care: a narrative review. J Thorac Dis 2026;18(1):40. doi: 10.21037/jtd-2025-1103