



Review

Role of Bioimpedance Spectroscopy, Lung Ultrasound, and Inferior Vena Cava Diameter in Assessing Dry Weight in Hemodialysis Patients: A Narrative Review

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Abstract

Accurate dry weight assessment is crucial for hemodialysis (HD) fluid management, yet traditional clinical methods often lack precision. A significant scientific gap exists in the availability of a standardized multimodal framework for integrating objective tools, leaving clinicians without clear guidance on combining results from multiple devices. To address this gap, this narrative review provides a qualitative clinical synthesis of bioimpedance spectroscopy (BIS), lung ultrasound (LUS), and inferior vena cava diameter (IVCD). A structured literature search was conducted across PubMed, Scopus, and CINAHL for English-language studies published between 2012 and 2024. Studies focusing on dry weight assessment using these tools in adult HD patients were included, and findings from 22 core studies were synthesized narratively. BIS and LUS are valuable tools for identifying fluid overload. BIS assesses systemic fluid distribution across compartments, whereas LUS allows non-invasive detection of extravascular lung water. In contrast, IVCD primarily reflects intravascular volume status. While the integrated use of these tools shows potential clinical utility, individual methods, particularly IVCD, require further validation owing to interpatient variability. A multimodal approach that integrates these objective methods with clinical judgment offers a comprehensive evaluation of dry weight. Integrating these assessment strategies may improve outcomes and decision-making in nephrology care.

Keywords: hemodialysis; dry weight; bioimpedance spectroscopy; lung ultrasound; inferior vena cava diameter; hydration status



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1. Introduction

A multinational study conducted by the International Society of Nephrology–Global Kidney Health Atlas (ISN-GKHA) in 2023 revealed that chronic kidney disease (CKD) affects almost 850 million people worldwide, representing more than 10% of the global population. The aging populations in developing countries, such as China and India, collectively account for 69.1% of adults with CKD in the region [1]. Currently, diabetes and hypertension are the major causes of kidney failure. Dialysis treatment requires careful

fluid management, which remains a significant clinical challenge [2]. Clinical nephrologists face challenges in maintaining adequate hydration and accurately assessing fluid status in dialysis patients [2].

Both hypervolemia and hypovolemia can occur in hemodialysis (HD) patients and may negatively affect their quality of life, potentially leading to cardiovascular complications over time during maintenance hemodialysis (MHD) [3]. Chronic fluid overload is associated with systemic hypertension, left ventricular hypertrophy, and higher rates of cardiovascular mortality [4]. Fluid depletion, however, is also a risk factor for a reduced quality of life and damage to vital organs, such as cardiac stunning and loss of residual renal function [5]. Approximately one-third of patients experience an inadequately managed fluid balance [5]. Even slight deviations from the optimal fluid status can impact survival [5]. Managing fluid overload and hypertension has remained a top priority since HD emerged as a promising treatment for patients with end-stage kidney disease (ESKD) [6].

The concept of dry weight was introduced to guide ultrafiltration (UF) during HD and to achieve normal hydration levels after each session [6]. Dry weight is a clinically determined weight that typically represents the lowest post-dialysis body weight a patient can safely maintain without experiencing hypotension or intradialytic symptoms such as dizziness and cramps [6]. This ensures that there is no evidence of fluid overload and helps maintain reasonable blood pressure control [6]. Determining dry weight accurately is essential. Each HD session aims to achieve optimal fluid and solute removal while ensuring patient comfort and minimizing adverse effects such as hypotension, cramps, and dizziness [6]. Identifying the correct dry weight is crucial for improving dialysis efficiency, minimizing cardiovascular strain, and increasing survival rates among dialysis patients [7]. Increasing evidence suggests that the hydration status and blood pressure of chronic HD patients are crucial indicators and predictors of patient outcomes [8]. Overestimating dry weight is a major risk factor contributing to hypertension, left ventricular hypertrophy, and cardiovascular disease, and ultimately impacts the mortality risk of HD patients [7]. Underestimating dry weight can lead to hypovolemia, causing hypotension, muscle cramps, and dizziness [7].

The gold standard for absolute blood volume assessment is the radioisotope indicator dilution technique [9]. Recognized as the reference method by the International Council for Standardization in Hematology (ICSH), this technique is time-consuming, with a full assessment requiring an average of 3.5 h for tracer labeling, equilibration, and sampling [9]. These practical limitations make the method difficult to implement in routine clinical practice, particularly in high-volume environments such as HD units. Various other techniques used to evaluate fluid overload in HD patients include clinical methods, bioimpedance spectroscopy (BIS), lung ultrasound (LUS), inferior vena cava diameter (IVCD) via ultrasound, B-type natriuretic peptide, relative plasma volume, and carotid artery-corrected flow time. Artificial intelligence, increasingly applied for pattern recognition and predictive modeling of dialysis outcomes, serves as a powerful tool for the secondary analysis of data derived from other diagnostic modalities. Invasive techniques, such as pulmonary artery catheterization, transesophageal aortic flow measurement, and hydrodensitometry, have also been described [10]. However, a significant scientific gap exists: a lack of a standardized multimodal framework that integrates these objective tools, leaving clinicians without a standard guide for interpreting them.

In this narrative review, we provide a qualitative clinical synthesis of the literature and evidence on the assessment of dry weight in HD patients using three emerging methods: BIS with a body composition monitor (BCM), LUS, and IVCD measurements. Rather than an exhaustive systematic mapping, this work offers an expert perspective on the clinical utility of a combined approach that incorporates objective methods alongside traditional

clinical methods. This review supports Sustainable Development Goal 3 (Good Health and Well-being), which is part of the United Nations 2030 Agenda and aims to ensure healthy lives and promote well-being for all at all ages. This goal includes specific targets, such as reducing premature mortality from non-communicable diseases and promoting mental health. By contributing to improved fluid management and optimized dry weight assessment, this research aligns with global efforts to reduce cardiovascular mortality and enhance the quality of life for HD patients. The techniques and interpretation of hydration status using these methods are summarized in Table 1, and the advantages, limitations, and clinical applications of these tools are presented in Table 2.

Table 1. Overview of methods used to assess fluid status in HD patients.

Methods Used to Assess Fluid Status	Procedure	Equipment Required	Fluid Compartment Assessed	Hydration Status
Clinical method	Fluid status is assessed based on clinical parameters such as edema, blood pressure, interdialytic weight gain, cramps, ultrafiltration rate, the patient's signs and symptoms, and intradialytic hemodynamic instability [10,11].	The nephrologist sets the dry weight based on these clinical parameters.	Assesses extracellular fluid (ECF) and total body water (TBW).	Based on the results obtained by evaluating clinical parameters, patients are classified as underhydrated, normally hydrated, or overhydrated.
Bioimpedance spectroscopy with BCM	Hydration status and body composition are evaluated using a portable BIS device (BCM). This involves placing electrodes on the patient's non-fistula forearm and ankle while the patient lies supine. The device analyzes resistance and reactance to the applied electric current. It operates at 50 frequencies to measure impedance spectroscopy [10,12].	Requires a BCM device with disposable electrodes.	Assesses ECF, intracellular fluid (ICF), TBW, and overhydration.	If the absolute fluid overload is between -1.1 and $+1.1$ L, it indicates normohydration. Over- or underhydration is defined as a volume above or below this range, respectively [12].
Lung ultrasonography	LUS is performed using a curvilinear (convex) probe (2–5 MHz) [13,14]. Scanning protocols vary—most commonly, the 28-zone protocol involves scanning 16 sites on the right hemithorax and 12 on the left [13,14]. The 12-zone protocol focuses on 12 specific lung areas: six on anterior axillary lines, three on mid-axillary lines, and three on mid-clavicular lines [15], while the 8-zone protocol includes two anterior and two lateral zones on each side to shorten examination time while maintaining good correlation with the 28-zone protocol [14,16]. The analysis focuses on sonographic artifacts known as B-lines to assess lung fluid accumulation [14,17].	Requires an ultrasound machine with a curvilinear or convex probe.	LUS evaluates extravascular lung water (EVLW).	≥ 4 B-lines at any site on an 8-zone scan indicate a positive region [14]. In a 12-zone scan, if total B-lines < 7 = none/mild, 8–16 = moderate, ≥ 16 = severe overhydration [15]. TLUS < 15 = none/mild, 16–30 = moderate, ≥ 30 = severe overhydration in the 28-zone protocol [15].

Table 1. Cont.

Methods Used to Assess Fluid Status	Procedure	Equipment Required	Fluid Compartment Assessed	Hydration Status
IVC ultrasonography	The examination is usually performed with a 3–5 MHz convex probe. IVCD is explored in the subxiphoid window during expiration (IVCDmax) and inspiration (IVCDmin) within 2.5 cm of the confluence of the IVC and the right atrium. IVCD is indexed to body surface area (IVCDi). The IVC-CI is calculated as $(IVCDmax - IVCDmin) / IVCDmax \times 100$ [18,19].	Ultrasound machine with a convex probe.	Assesses the IVCD and collapsibility index.	Patients are categorized as underhydrated if IVCDmax is $<8 \text{ mm/m}^2$, normohydrated if IVCDmax is $8\text{--}11.5 \text{ mm/m}^2$, and overhydrated if IVCDmax is $>11.5 \text{ mm/m}^2$ [18,19]. IVC-CI (%): Hypovolemia if $>75\%$, euvolemia $40\text{--}75\%$, hypervolemia $<40\%$ [19].

Note: These hydration status assessment thresholds are representative benchmarks; values may vary based on individual patient characteristics, study design, and clinical context. ECF—Extracellular fluid, TBW—Total body water, ICF—Intracellular fluid, BIS—Bioimpedance spectroscopy, BCM—Body composition monitor, LUS—Lung ultrasound, EVLW—Extravascular lung water, IVCD—Inferior vena cava diameter, TLUS—Total Lung ultrasound score, IVCDmax—Maximum Inferior Vena Cava diameter indexed to body surface area (mm/m^2), IVC-CI—Inferior vena cava collapsibility index.

Table 2. Pros, cons, and clinical value of fluid status assessment tools in HD.

Features	Bioimpedance Spectroscopy	Lung Ultrasonography	Inferior Vena Cava Ultrasonography
Specific marker	Electrical impedance–derived body water compartments	B-line count	IVC diameter and collapsibility
Pros	Highly objective and reproducible. Non-invasive, rapid, bedside tool. Provides body composition data and reflects nutritional status. Widely studied for dry weight assessment in HD. Detects subclinical fluid overload and dehydration.	Non-invasive, bedside tool. Can detect early fluid overload. Direct visualization of pulmonary congestion. Useful for guiding ultrafiltration and preventing pulmonary edema.	Non-invasive, bedside tool. Reflects acute intravascular volume changes. Useful for dynamic assessment (pre- and post-dialysis).
Cons	Lacks compartmental resolution—unable to distinguish pulmonary congestion from peripheral edema. Requires expensive equipment. Limited availability in resource-limited settings. Results may be influenced by comorbidities (obesity, implants, amputations).	Operator-dependent. B-lines can be false positives (may occur in other lung diseases). Requires ultrasound expertise. Less informative about total body volume.	Operator-dependent with high inter-observer variability. Influenced by respiratory effort, intra-abdominal pressure, and cardiac dysfunction. Less reliable in chronic HD patients with vascular changes.
Clinical value	Guides dry weight prescription. Useful for setting long-term volume management and reflects nutritional status.	Detects early pulmonary congestion before clinical signs (crackles, dyspnea) manifest. Guides ultrafiltration.	Best suited for acute intravascular volume assessment and monitoring the immediate response to ultrafiltration.

HD—Hemodialysis, IVC—Inferior vena cava.

2. Literature Search Strategy and Selection Criteria

This narrative review provides a qualitative clinical synthesis of current evidence regarding dry weight assessment in HD patients. To ensure transparency and academic rigor, a structured search was conducted with a primary emphasis on the BIS, LUS, and IVCD. The literature search prioritized English-language research published between 2012 and 2024 to reflect the modern era of standardized BIS and the widespread clinical implementa-

tion of LUS protocols, ensuring that the review aligns with contemporary benchmarks in fluid assessment and HD care. The search process and the selection of the 22 core studies are summarized in the simplified search flow diagram (Figure 1). The selection process primarily included studies involving adult HD populations that evaluated hydration status and strategies to optimize dry weight. Pediatric populations were excluded from this synthesis to ensure clinical homogeneity, as fluid assessment in children involves distinct growth-related physiological factors and may utilize different validation standards and reference ranges for objective tools. The selection intentionally focused on prospective observational studies, cross-sectional analyses, and diagnostic accuracy studies to evaluate clinical feasibility, practical integration, and correlations. Therefore, a formal systematic risk-of-bias assessment of interventional outcomes was not performed. Relevant retrospective cohort studies assessing the BIS, LUS, or IVCD were also considered when they provided objective measurements and clearly defined fluid status outcomes. Although randomized controlled trials (RCTs) were not the primary focus of the search strategy, key RCTs relevant to dry weight assessment were identified separately through targeted screening and were discussed to contextualize and complement the observational and diagnostic evidence. Findings from the identified literature, including core studies and relevant secondary references, were synthesized narratively. Data were categorized by assessment method to facilitate a detailed clinical comparison of the strengths, limitations, and practical applications of each modality, alongside traditional clinical methods used in routine nephrology care.

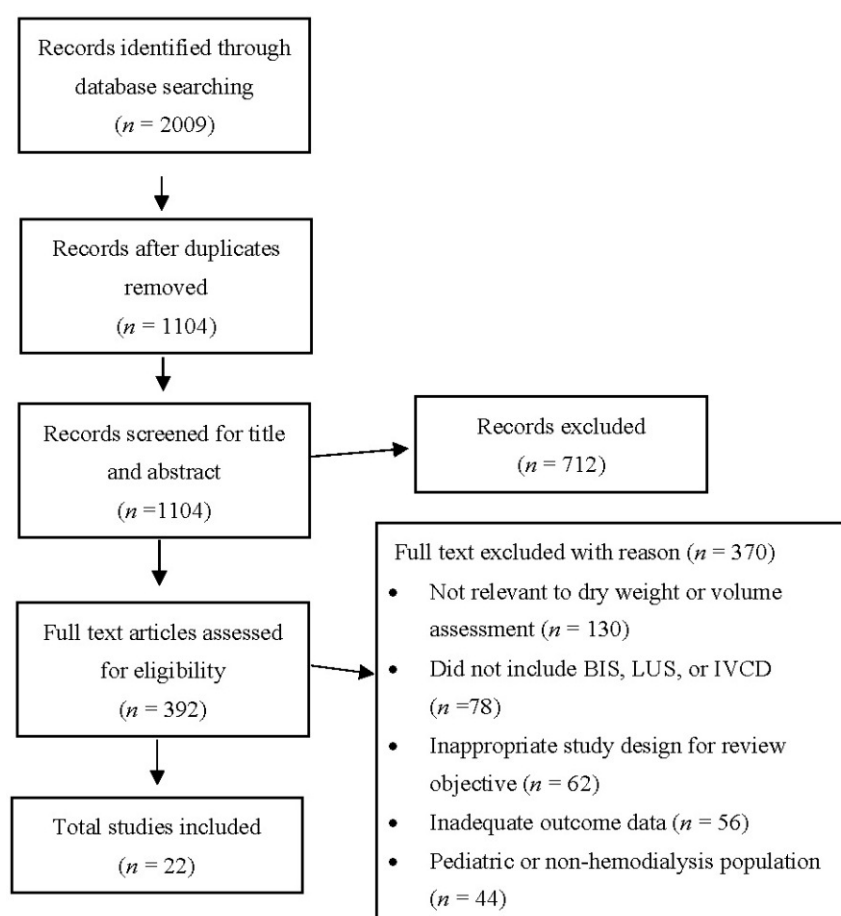


Figure 1. Simplified search flow diagram.

3. Discussion

3.1. Role of Clinical Method in Dry Weight Estimation

Currently, most HD centers use the clinical method as the standard technique for assessing dry weight because of its feasibility and cost-effectiveness; the results may be observer-dependent and unreliable [20]. In clinical practice, nephrologists assess dry weight before initiating HD using clinical criteria, considering various factors, as mentioned in Table 1 [10]. However, most overhydration symptoms occur mainly in cases of severe overhydration and are not always caused by fluids, limiting their reliability for accurate assessment [21]. This method evaluates TBW, including ECF and ICF, and relies heavily on blood pressure as a key parameter [10,22]. Elevated blood pressure before dialysis is closely linked to greater interdialytic weight gain [23]. Moreover, in the ESKD population, excess fluid is often regarded as the main pathogenic cause of hypertension [21]. According to a study, patients with chronic fluid overload had higher systolic blood pressure than those whose volume was managed intermittently [24].

Another study reported that clinical assessment underestimated the degree of overhydration. The dry weights derived from the clinical assessment were slightly but significantly higher than those obtained using BCM, highlighting the limitations of relying solely on clinical estimation [21]. Because this estimate is obtained through trial and error, it is inherently prone to inaccuracy [25]. The gap between the clinically assessed fluid status and the actual volume status is mainly due to the subjectivity of the clinical assessment [14,20]. Nephrologists often deliberately aim for a slightly higher target dry weight to minimize the risk of fluid overload while avoiding adverse effects such as intradialytic hypotension (IDH) and muscle cramps, which may further contribute to persistent volume overload [21]. Furthermore, patients frequently remain fluid overloaded even after dialysis because clinical methods cannot consistently quantify excess volume. This persistent overhydration not only limits the effectiveness of dialysis but also exacerbates pre-existing hypertension and increases the risk of overt pulmonary edema [21].

3.2. Role of the BIS Using BCM in Dry Weight Estimation

The most popular non-invasive technique for assessing fluid distributions across body compartments is BIS via the BCM, which applies an electric current to distant electrodes on the body surface to determine the body's resistance and reactance [10,26]. This method requires a BCM machine that operates at 50 frequencies to analyze various tissue properties, such as fluid overload, lean tissue mass under normal hydration conditions, and adipose tissue mass under normal hydration conditions [27]. According to BCM development and validation studies, normohydration is defined as an absolute fluid overload within -1.1 to $+1.1$ L. Over- or underhydration is defined as when the volume is above or below this range [12]. At present, BIS is thought to be the most promising technical solution for fluid control in dialysis [28]. BIS measurements of ICF, ECF, and TBW have been verified against isotopic techniques, which are considered the gold standard [12,29]. These findings emphasize the importance of the BCM in evaluating a patient's fluid status and predicting survival. This tool holds substantial promise for enhancing daily clinical practice [30]. The BCM helps improve the consistency of fluid status assessment when used alongside clinical observations [22,28,30]. In one study, the BCM technique improved evaluations of arterial stiffness, overall fluid overload, and blood pressure management [31]. A comprehensive, multicenter validation study including 152 subjects showed good agreement between the TBW measured by body composition spectroscopy and that measured by gold standard methods [32]. In a study comparing BCM with nephrologist-assessed dry weight, although the two correlated significantly ($r = 0.987$, $p < 0.001$), BCM detected a greater prevalence

of overhydration, suggesting that clinical assessments alone may underestimate fluid burden [21]. BCM has also been shown to improve clinical outcomes.

In a prospective study, BCM-guided target weight adjustment led to a significant decrease in intradialytic hypertension events (from 2.37 to 1.82 events/session, $p = 0.01$) and a decrease in systolic and diastolic blood pressure (by 5.7 mmHg and 2.9 mmHg, respectively), suggesting improved cardiovascular control [12]. Additionally, BCM-determined overhydration status was associated with increased cardiovascular mortality and remained undetectable by conventional methods in a subset of clinically euvolemic patients [12]. Another study demonstrated that even moderate fluid overload (>2.5 L) measured by BCM was substantially linked with increased all-cause mortality (Cox regression HR was significant), further supporting its prognostic value [30]. BCM is a rapid and practical tool that can support dry weight adjustment between nephrologist reviews and may support the titration of antihypertensive medication through improved fluid management [21]. The BCM is a valuable tool for assessing hydration status, and treatment decisions are not based solely on its values. Instead, BCM serves as a complement to clinical judgment, particularly in patients with multiple comorbidities, such as diabetes and hypertension [21]. The studies on the use of BCM to assess dry weight in HD patients are summarized in Table 3.

Table 3. Studies evaluating fluid status using BCM in HD patients.

Author	Sample Size	Type of Study	Volume Parameter Used	Quantitative Results	Outcomes (Fluid Status)	Key Limitations
Mathilakath et al., [12]	110	Prospective observational	BCM: OH/ECW ratio > 1.1 to define overhydration	Overhydration prevalence: 27.2%. Clinically undetected: 33%. ↓ Intradialytic hypertension ($p = 0.017$). ↓ SBP/DBP ($p \geq 0.05$).	BCM identified hidden overhydration; guided dry weight adjustment reduced intradialytic hypertension episodes.	Lack of strict implementation of salt and fluid intake restrictions. Achievement of the target dry weight was delayed, requiring a mean of 20 weeks instead of the intended 12.
Mamat et al., [21]	80	Prospective cross-sectional	BCM: ECW, ICW, TBW	$r = 0.987, p < 0.001$ (BCM vs. nephrologist DW). Pre- vs. post-dialysis ECF/TBW/ICF reductions ($p < 0.001$). SBP reduction ($p = 0.015$).	BCM measurements significantly correlated with nephrologist-assessed dry weights, and BCM detected higher pre- and post-HD overhydration compared to clinical estimates.	The study lacked follow-up and did not assess long-term outcomes.
Kim, C.R. et al., [24]	142	Retrospective longitudinal	ECW/TBW Ratio	HR 4.7 (95% CI 1.4–16.1, $p < 0.05$): all-cause mortality (independent). HR 2.4 (95% CI 1.2–5.1, $p < 0.05$): Cardiovascular events (univariate only; Adjusted HR 1.7, NS).	Chronic volume overload independently predicted all-cause mortality.	The study was retrospective, limiting control over confounding factors, and volume assessment was performed within 30 min of dialysis initiation rather than the recommended pre-dialysis or post-dialysis timing.

Table 3. Cont.

Author	Sample Size	Type of Study	Volume Parameter Used	Quantitative Results	Outcomes (Fluid Status)	Key Limitations
Passauer et al., [28]	370	Cross-sectional	FO via BCM	Non diabetics: Pre FO vs. SBP: $r^2 = 0.046, p < 0.005$. Post FO vs. SBP: $r^2 = 0.078, p < 0.001$ FO vs. antihypertensives: Pre $r^2 = 0.044, p < 0.005$; Post $r^2 = 0.029, p < 0.05$ Diabetics: all correlations NS.	Bioimpedance analysis showed that 26% of patients assessed clinically for dry weight did not achieve normal fluid balance.	Measurement was performed only pre-dialysis, with post-dialysis of FO calculated indirectly.
Keber et al., [30]	92	Retrospective Cohort	FO via BCM	FO > 2.5 L: poorer survival ($p = 0.039$); independent predictor of death ($p = 0.044$).	FO > 2.5 L was linked to increased mortality.	Conditions such as congestive heart failure, liver cirrhosis, and patient medications were not included, although they can strongly influence fluid status and outcomes.
Watanabe et al., [33]	78	Cross-sectional observational	ECW/TBW Ratio (>45%)	ECF/TBW correlated with hANP ($p = 0.001$) and CTR ($p = 0.003$); ECW/TBW cut-off 45% for hANP ≥ 50 pg/mL.	ECW/TBW > 45% was associated with hANP ≥ 50 pg/mL and higher BP/CTR, identifying overhydration.	Medication use for hypertension and vasopressor support may have confounded blood pressure and CTR, making it difficult to distinguish actual FO from drug effects.
Moissl, U. et al., [34]	170	Cross-sectional	BCM: FO, FO/ECW ratio	Pre-HD FO correlated with SBP ($r = 0.39, p < 0.01$); 43% overloaded pre-HD, 12% post-HD; just 48% of overloaded patients were hypertensive.	Pre-HD FO was strongly associated with SBP; BP alone was not reliable for fluid status.	Post-HD fluid status was estimated indirectly from weight loss rather than measured directly, which may introduce error in detecting actual depletion or residual overload.
Lazarevic et al., [35]	45	Cross-sectional observational	BCM: TBW, ECF, ICF, OH, ECF/ICF ratio	Before HD: NT-proBNP vs. ECF/ICF ratio $r = 0.499, p < 0.0005$; post HD: $r = 0.425, p = 0.004$. BIS parameters (ECF, TBW, OH) significantly decreased post-HD ($p < 0.0005$).	BCM was useful for volume assessment; post-HD decreases in ECF, TBW, and OH confirmed correction of overhydration.	The absence of follow-up and long-term outcome assessment limits the ability to draw prognostic conclusions.
Zoccali et al., [36]	39,566	Large multinational observational cohort	BCM: FO (absolute FO, FO%)	Baseline FO predicted mortality across BP groups (HR 1.25–1.51), and cumulative FO exposure further increased mortality risk (HR 1.51–1.94, $p < 0.001$).	Chronic FO measured via BCM strongly predicted mortality.	Despite adjustment for many confounders, unmeasured or imprecisely measured risk factors could still influence the FO-mortality association, potentially affecting the stability of the risk estimates.

Table 3. Cont.

Author	Sample Size	Type of Study	Volume Parameter Used	Quantitative Results	Outcomes (Fluid Status)	Key Limitations
Siriopol et al., [37]	173	Prospective observational cohort study	BCM: Relative Fluid Overload (RFO)	BCM-derived fluid overload improved mortality prediction ($\Delta C = 0.058$, 95% CI 0.003–0.114), and an RFO > 6.88% was associated with higher mortality risk (Sensitivity 74.2%, Specificity 52.1%).	BCM-driven fluid assessment (RFO) was independently associated with mortality.	Could not determine the exact cause of death.

BCM—Body composition monitor, OH—Overhydration, ECW—Extracellular water, SBP—Systolic blood pressure, DBP—Diastolic blood pressure, DW—Dry weight, ICW—Intracellular water, TBW—Total body water, HD—Hemodialysis, ECF—Extracellular fluid, HR—Hazard ratio, CI—Confidence interval, NS—Not significant, FO—Fluid overload, r^2 —Coefficient of determination, CTR—Cardiothoracic ratio, hANP—Human atrial natriuretic peptide, BP—Blood pressure, NT-proBNP—N-terminal pro-B-type natriuretic peptide, BIS—Bioimpedance spectroscopy, r —Correlation coefficient, p — p -value, RFO—Relative fluid overload, $\downarrow$ —Decrease.

In addition to observational findings, several randomized controlled trials have evaluated the impact of BCM-guided management on fluid status and clinical outcomes. In a multicenter study of 189 HD patients, centers using BCM achieved a greater reduction in excess fluid, lowering the proportion of severely overhydrated patients to 52.5% compared with 65.9% in the control group after 12 months [38]. In the ABISAD III randomized trial (298 patients), BCM-guided weight adjustment reduced complications during fluid removal from 31% to 12%. Compared with clinical judgment alone, BCM-guided management reduced the risk of severe fluid overload or cardiovascular events by half [39]. The same trial also reported fewer IDH episodes (approximately 6% vs. 7%) in the BCM group [39]. The BOCOMO randomized trial (445 patients) revealed a trend toward improved survival in the BCM group, although this trend did not reach statistical significance at 1 year [40]. Additionally, a single-center randomized trial (131 patients) that used BCM exclusively to set dry weight over 2.5 years reported ~90% lower all-cause mortality (hazard ratio 0.10) and greater improvements in arterial stiffness and fluid overload than clinical care [41]. A randomized study of 135 patients also revealed that bioelectrical impedance analysis-guided ultrafiltration improved cardiovascular parameters, lowering systolic blood pressure (144.6 $\rightarrow$ 135.3 mmHg) and arterial stiffness (pulse wave velocity 8.2 $\rightarrow$ 6.9 m/s) compared with those reported in clinical assessment [42]. An Indian randomized study (50 patients) revealed that BIS-guided ultrafiltration increased normal hydration from 20% to 88%, reduced IDH by ~40% (2.8 vs. 4.8 episodes per patient over 6 months), and reduced the antihypertensive pill burden by ~35% [6]. Overall, these studies suggest that using BCM alongside routine assessment improves fluid management, reduces treatment-related complications, and may support better long-term outcomes for HD patients.

3.3. Role of LUS in Dry Weight Estimation

LUS has recently drawn interest as a dry weight estimation technique, as it measures extravascular lung water (EVLW), which provides an assessment of lung congestion [13,14,43–45]. It is a non-invasive, inexpensive technique. Additional training is required to perform this procedure; it does not consider the intravascular fluid compartment, and the results may be observer-dependent [46]. LUS exploits fundamental ultrasonography principles. Elevated lung water within thickened subpleural interlobular septa reflects the ultrasound (US) beam, creating highly echogenic structures called US B-lines. These hyperechoic reverberation artifacts exist between the subpleural interlobular

septa and the pleura above [46,47]. Ideally, 28 intercostal scans (28-rib interspace technique) are needed to detect B-lines [14].

Scanning four locations along the midclavicular and mid-axillary lines on each side of the hemithorax, including the upper and lower anterior chest, is also acceptable [14]. Four or more B-lines in any hemithorax are defined as lung congestion [14]. Incorporating ultrasound-based dry weight estimation into routine patient care is feasible. The technique is rapid, straightforward, cost-effective, and widely available, even in secondary health centers. Only an ultrasound machine with a convex probe is needed [48]. Lung congestion is a major risk factor for cardiovascular and all-cause mortality, even in patients with minimal or no symptoms [16]. The use of LUS B-lines to predict fluid overload showed a moderate correlation with clinical examination [16].

A prospective observational study of 107 patients demonstrated that pre-dialysis B-lines quantification was a reliable predictor of IDH risk. Using a 28-position scanning method, pre-dialysis B-lines < 8 predicted IDH (AUC 0.736), >15 indicated fluid overload, and post-dialysis B-lines < 5 helped identify IDH due to dehydration or overestimation of dry weight. This provided a safer metric than clinical examination for volume management [49].

An eight-point LUS using a portable handheld ultrasound device (HHUSD) with artificial intelligence-based B-line detection provided clinically useful information on hydration status and the diagnosis of fluid overload in dialysis patients [16]. B-lines offered real-time assessments of interstitial water content [14]. In a cross-sectional study of lung water using ultrasound-guided therapy, LUS outperformed clinical criteria in identifying and tracking excess volume in HD patients [43]. LUS-guided volume assessment was useful for assessing fluid-related symptoms and helped optimize blood pressure control in HD patients [15]. Over time, reductions in the total LUS score (TLUS) were associated with lower pre- and post-dialysis blood pressure and a decreased cardiothoracic ratio. These findings suggested that TLUS could guide adequate volume and cardiovascular management [15]. Even in asymptomatic or mildly symptomatic patients (New York Heart Association [NYHA] Class I–II), moderate-to-severe pulmonary congestion detected by LUS is common, highlighting its ability to detect subclinical fluid overload [13,15].

LUS's real-time ability to detect changes in pulmonary water content after dialysis, as evidenced by reductions in B-lines, provides a dynamic, responsive method for evaluating ultrafiltration adequacy [45]. Importantly, LUS-based classifications of congestion levels (e.g., mild, moderate, severe, based on B-lines thresholds) were shown to predict survival outcomes. Patients with ≥ 30 B-lines had significantly lower one-year survival rates, highlighting the prognostic value of LUS in identifying patients at high risk for cardiovascular events and death [44]. Furthermore, the incorporation of artificial intelligence-driven LUS using handheld devices enabled standardization and broader applicability by minimizing operator dependency, potentially making LUS viable in resource-limited dialysis units [16]. The studies on the role of LUS as a tool for assessing dry weight in HD patients are summarized in Table 4.

Table 4. Studies evaluating fluid status using LUS in HD patients.

Author	Sample Size	Type of Study	Volume Parameter Used	Quantitative Results	Outcomes (Fluid Status)	Key Limitations
Ngoh et al., [13]	50	Cross-sectional	LUS-BLS	Median BLS 46.5 (IQR 22.5–77.0); 88% moderate/severe congestion; pre-dialysis BCM-derived AHS correlated with LUS BLS ($r = 0.46$, $p < 0.001$).	LUS detected subclinical pulmonary congestion in 61% of patients classified as normohydrated by BCM.	The study excluded patients with severe heart failure, active cardiac disease, and BMI > 40 kg/m ² —groups that often present challenges in fluid management, limiting generalizability to high-risk populations.
Trirattanapikul et al., [15]	20	Prospective cohort	LUS-BLS	TLUS–WG $r = 0.38$; TLUS–ECF $r = 0.35$; TLUS–OH $r = 0.39$; FO (L): ≤ 15 BLS = 2.18, 16–24 = 2.74, 25–33 = 3.13, 34–38 = 3.81, $\geq 39 = 5.03$; SBP $\downarrow$ 10 mmHg.	TLUS was positively correlated with weight gain and ECF, aiding in dry weight adjustments and blood pressure control.	The study focused only on HD patients with NYHA Class I–II, excluding those with advanced cardiac disease.
Vitturi et al., [25]	71	Prospective observational	LUS-BLS	BLS pre vs. post dialysis: $3.13 \pm 3.4 \rightarrow 1.41 \pm 2.47$, $p < 0.001$; correlation pre vs. post BLS: $r = 0.829$, $p < 0.005$; B-lines reduction vs. weight loss: $\beta = 0.36$, $p = 0.007$.	Weight loss during dialysis was significantly associated with a decrease in BLS.	Measurements were limited to pre- and post-dialysis, without assessing interdialytic changes or long-term outcomes.
Zheng et al., [44]	98	Cross-sectional observational	LUS-BLS	Pre vs. Post dialysis: BLS $\downarrow$ from median 15 to 5 ($p < 0.001$); Severe group had lower survival vs. mild ($\chi^2 = 10.05$, $p = 0.002$).	The BLS decreased significantly after dialysis, and a higher BLS count was associated with lower survival.	Patients underwent LUS only once; a single LUS measurement may not reflect average fluid status over weeks or months.
Jiang et al., [45]	17	Observational	LUS-BLS	BLS vs. weight: $r = 0.40$, $p < 0.05$; BLS vs. UF: $r = 0.33$, $p < 0.05$.	Reduction in BLS correlated with fluid removal, improving dry weight determination.	The study was limited by its small sample size, and although dialysis prescriptions were blinded to the sonographer, other clinical decision-making factors may have introduced bias.
Ivanov et al., [48]	83	Cross-sectional	LUS-BLS	Mean BLS $\downarrow$ 18.9 $\rightarrow$ 7.3 ($p < 0.0001$); correlated with BNP pre-HD ($\rho = 0.49$, $p < 0.001$) and post-HD ($\rho = 0.42$, $p < 0.001$).	BLS significantly decreased post-HD, reflecting improvement in volume status, and could be used to evaluate patients' volume status on chronic HD.	The study focused on assessing volume status via the B-line score and its correlation with other methods, without evaluating clinical outcomes or long-term prognosis.

Table 4. Cont.

Author	Sample Size	Type of Study	Volume Parameter Used	Quantitative Results	Outcomes (Fluid Status)	Key Limitations
Pardala et al., [50]	54	Cross-sectional	LUS-BLS	BLS positively correlated with IVCD ($r = 0.221$, $p = 0.025$) and with NT-proBNP ($r = 0.455$, $p < 0.001$); inversely with LVEF ($r = -0.443$, $p < 0.001$); positively with mitral gradient ($r = 0.326$, $p = 0.001$).	BLS reflected both overhydration and left ventricular dysfunction.	BLS occurrence was influenced by factors such as left ventricular dysfunction and pulmonary hypertension, reducing its utility as a standalone hydration marker.
Cui et al., [51]	88	Prospective observational	LUS-BLS	Pre-dialysis BLS OH 24.8, post-dialysis OH 7.5 ($p < 0.001$); ROC AUC 0.841, cut-off 13, sensitivity 66%, specificity 95%. Mortality: KM $p = 0.048$, Cox OR = 3.9 ($p = 0.048$).	LUS detected FO in HD patients, and higher lung congestion was associated with increased mortality.	Not all patients completed every assessment; for instance, only 74 of 88 underwent echocardiography.

LUS—Lung ultrasound, BCM—Body composition monitor, AHS—Absolute hydration status, r —Pearson correlation coefficient, p — p -value, TLUS—Total lung ultrasound score, WG—Weight gain, ECF—Extracellular fluid, OH—Overhydration, SBP—Systolic blood pressure, HD—Hemodialysis, NYHA—New York Heart Association, χ^2 —chi-square test statistic, UF—Ultrafiltration, β —regression coefficient, BLS—B-line score, BNP—B-type natriuretic peptide, ρ —Spearman correlation coefficient, IVCD—Inferior vena cava diameter, NT-proBNP—N-terminal pro-B-type natriuretic peptide, FO—Fluid overload, LVEF—Left ventricular ejection fraction, ROC—Receiver operating characteristic, AUC—Area under the curve, KM—Kaplan–Meier, Cox OR—Cox regression Odds Ratio, BMI—Body mass index, ↓—Decrease.

In addition to observational findings, several randomized controlled trials have evaluated the impact of LUS-guided management on fluid status and clinical outcomes. Compared with standard care, LUS-guided dry weight reduction produced measurable cardiac structural improvements over 12 months in hypertensive HD patients, including reductions in left atrial volume (-3.22 ± 11.82 mL/m² vs. $+4.76 \pm 12.83$ mL/m²) and left ventricular end diastolic volume (-0.94 ± 11.45 vs. $+6.58 \pm 13.92$ mL/m²) [52]. In the BUST trial, the use of LUS (combined with BIS) lowered the rate of pre-dialytic dyspnea by 19% (rate ratio 0.81, 95% CI 0.68–0.96) [53]. In a 12-month RCT, LUS-guided care reduced 48 h ambulatory BP (SBP $136.19 \pm 14.78 \rightarrow 130.31 \pm 13.57$ mmHg; DBP $80.72 \pm 9.83 \rightarrow 76.82 \pm 8.97$ mmHg) and lowered intradialytic BP (SBP $136.94 \rightarrow 129.88$ mmHg; DBP $83.77 \rightarrow 79.72$ mmHg) within the intervention arm [54]. In an 8-week randomized substudy, LUS-guided dry weight reduction produced greater ambulatory BP reductions than clinical care (SBP -6.61 ± 9.57 vs. -0.67 ± 13.07 mmHg; DBP -3.85 ± 6.34 vs. -0.55 ± 8.28 mmHg) [55]. Together, these trials demonstrate that LUS helps identify fluid excess and enables targeted ultrafiltration, improving cardiac chamber volumes, reducing dyspnea, and achieving better BP control in HD patients.

3.4. Inferior Vena Cava Diameter Measurement

Ultrasonographic measurement of the inferior vena cava (IVC) is a reliable, non-invasive, and cost-effective method for assessing intravascular volume status [14]. Performing this measurement requires additional training because it does not account for extravascular fluid, and the results may vary between observers [18,19]. This procedure is usually performed via a 3–5 MHz convex probe [18]. The IVCD is measured in the subxiphoid window during expiration (IVCDmax) and inspiration (IVCDmin) within 2.5 cm of the IVC–right atrial junction [18]. The indexed IVC size (IVCDi) is calculated by dividing

IVCDmax and IVCDmin by the body surface area (square meters) [18]. The IVC collapsibility index (IVC-CI) is calculated using the formula $[(IVCD_{\max} - IVCD_{\min}) / IVCD_{\max} \times 100]$. Patients are categorized as overhydrated if the maximum IVC diameter indexed to body surface area (IVCD_{max}) is $>11.5 \text{ mm/m}^2$ [18,19] or if the IVC-CI is $<40\%$ [19]. These thresholds should be viewed as clinical guides rather than fixed diagnostic cutoffs, as individual factors such as age and cardiac comorbidities influence IVC variability. Furthermore, these values are specifically calibrated for the HD population; clinicians should avoid extrapolating standard intensive care unit (ICU) thresholds to the dialysis setting, as chronic cardiac remodeling and altered vascular compliance in ESKD necessitate these specialized benchmarks.

Ultrasound evaluation of the IVC assesses parameters such as vessel diameter and the collapse index, which reflect the interactions among central venous pressure, right atrial pressure, intrathoracic pressure, and intra-abdominal pressure [25]. A collapsed IVC can help estimate dry weight, as studies have shown that overhydration in adult HD patients is associated with IVC dilatation [56]. Although it reflects central venous pressure, the IVC alone is not a reliable indicator of hydration status because it can be influenced by changes in intrathoracic or abdominal pressure, right heart activity, and respiration [57]. However, in individuals with right-sided heart failure, IVCD is not reliable because of its significant correlation with right atrial pressure [58]. Patients with a low pre-dialysis IVC-CI had a considerably higher incidence of hypotensive events [19]. Furthermore, the utility of the measurement in the clinical context is limited by the requirement for timing accuracy [58,59].

A study reported that IVCD_{max} and IVCD_{min} significantly decreased after HD, demonstrating that IVCD reflects fluid removal. Additionally, they reported a significant correlation between IVCD_{max} and the BIS before dialysis, confirming the usefulness of the BIS in assessing fluid status. However, they noted that the IVC-CI, the collapsibility index derived from IVCD, did not significantly change post-dialysis ($p = 0.13$), suggesting a potential limitation in its ability to reflect volume changes compared with the BIS or LUS methods [18]. A substantial decrease in IVCD after HD supports its role in reflecting intravascular fluid changes, further evidenced by the strong correlation between IVCD changes and post-dialysis weight [60,61]. IVCD was positively correlated with lung B-lines, indicating its utility in evaluating both intravascular and pulmonary fluid status [61].

The authors noted drawbacks, including underestimation due to the cylinder-tangent effect and variability in probe angulation, which can affect measurement consistency. Despite these limitations, redefining dry weight via IVCD improved symptoms in HD patients, particularly reducing orthostatic giddiness and breathlessness [14]. Hypovolemia was detected in 39% of patients by IVCD measurement using hand-carried ultrasound, and differences in interpretation were associated with variation in adverse intradialytic events. This highlights the necessity of uniform training and standardization of ultrasound-based fluid assessment procedures [19].

The present evidence is summarized in Table 5, and IVCD can be used as a complementary technique alongside other methods in routine practice for assessing dry weight in HD patients. While some evidence for IVCD assessment in this review is derived from regional journals, the consistency of findings across geographically diverse cohorts—including those from India, Italy, and Egypt—highlights the reproducible nature of these metrics. These findings suggest that IVCD may serve as an accessible, economical bedside adjunct for fluid assessment across various clinical environments.

Table 5. Studies evaluating fluid status using IVCD in HD patients.

Author	Sample Size	Type of Study	Volume Parameter Used	Quantitative Results	Outcomes (Fluid Status)	Key Limitations
Arun Thomas et al., [14]	74	Open-label interventional	IVC-CI (50–75%)	IVC-CI improved significantly from 0.23 ± 0.09 to 0.53 ± 0.16 , $p < 0.001$. Breathlessness: $p = 0.003$ (24 h post-HD), $p < 0.001$ (pre-HD day); Orthostatic giddiness: $p = 0.147$; B-lines reduction: $p < 0.001$.	Redefining dry weight via USG significantly improved intravascular volume status and pulmonary congestion symptoms (breathlessness, B-lines).	The study had only a short 2-week follow-up, limiting evaluation of sustained benefits or harms. Long-term outcomes were not assessed.
Basso et al., [18]	30	Cross-sectional	IVCD during inspiration/expiration	Reduction post-HD: BIS, LUS, IVCD ($p < 0.001$); IVC-CI ($p = 0.13$).	IVCD correlated with BIS before HD, but was less correlated after HD; IVC-CI showed no significant post-HD change.	IVCD showed only modest changes post-dialysis, and delayed fluid re-equilibration makes the optimal timing for assessment uncertain.
Hafiz et al., [60]	30	Controlled cross-sectional	IVCD, IVC-CI	IVCD (expiration) vs. weight loss: $p < 0.001$. IVC-CI increased post-HD: $p < 0.001$.	IVCD and IVC-CI were strongly correlated with ultrafiltration, reflecting post-dialysis fluid changes.	Measurements were taken before and after a single dialysis session, without longitudinal follow-up, to assess prognostic value.
Trivedi et al. [62]	60	Prospective observational study	IVCD, IVC-CI	CVP vs. IVCD: $r = 0.23$, $p = 0.08$. CVP vs. IVC-CI: $r = 0.14$, $p = 0.30$.	No linear correlation was found between CVP and IVCD or IVC-CI.	Measurements were not performed during routine dialysis sessions.

IVC-CI—Inferior vena cava collapsibility index, p — p -value, HD—Hemodialysis, USG—Ultrasonography, BIS—Bioimpedance spectroscopy, LUS—Lung ultrasound, IVCD—Inferior vena cava diameter, r —Pearson correlation coefficient, CVP—Central venous pressure.

3.5. Comparison Among the Three Techniques

BIS was more consistent than clinical assessment and IVCD in detecting overhydration [63]. Similarly, LUS identified pulmonary congestion more frequently than BCM and IVCD [13]. Additionally, LUS detected congestion even in patients judged normohydrated by BCM and clinical examination, and revealed observable B-line changes in response to fluid removal [13]. While IVCD was an objective method, studies reported that IVCD identified congestion less frequently than LUS did, and its correlation with hydration parameters appeared less consistent than that with BCM and LUS [13,18,25]. In contrast to LUS, which reflected pulmonary congestion, BIS estimated total body water, whereas IVCD/IVC-CI primarily reflected intravascular volume [13]. The clinical assessment was least consistent with objective methods, frequently underestimating volume overload and showing a weak correlation with both the BIS and LUS findings [13–15]. Combining the BIS and LUS offered a more comprehensive and objective evaluation of dry weight status than clinical examination or IVCD alone, making this integrated approach preferable for fluid management in HD patients [13,15,44].

In ICU patients undergoing dialysis, combined pre-dialysis LUS and IVC assessment provided real-time cardiopulmonary profiling, with IVC collapsibility independently associated with IDH beyond clinical variables [64]. The IVC-CI also predicted ultrafiltration

feasibility more reliably than clinical examination or static pressure measures, with lower collapsibility values associated with successful achievement of planned net ultrafiltration in critically ill dialysis patients [65].

In pediatric hemodialysis patients, bedside sonographic assessment of both extravascular and intravascular volume added clinically relevant information beyond traditional clinical parameters alone [66]. Clinical criteria alone were insufficient for precise fluid status assessment, and LUS, IVC parameters, and BIS provided complementary insights, with LUS identifying subclinical volume overload not evident on clinical or other objective assessments [67].

3.6. Clinical Implementation

While the Kidney Disease Outcomes Quality Initiative (KDOQI) and Kidney Disease Improving Global Outcomes (KDIGO) guidelines establish the clinical foundation for dry weight assessment, they primarily rely on clinical signs such as edema and blood pressure changes and have yet to incorporate objective methods into standard care. A significant implementation gap persists in the standardized use of objective technologies, and our review addresses this gap by proposing a multimodal framework in which the BIS, LUS, and IVCD serve as adjunctive, data-driven complements to traditional assessment. This integrated approach enables the detection of subclinical congestion before overt symptoms appear. Although large randomized controlled trials are still needed for definitive validation, current evidence suggests that multimodal assessment provides a more objective baseline for dry weight titration than clinical evaluation alone.

Based on the available evidence, we propose establishing a baseline target dry weight using BCM in conjunction with clinical assessment, complemented by LUS, to identify subclinical pulmonary edema and allow for further weight adjustment in asymptomatic patients, with IVCD serving as a hemodynamic safety check to ensure adequate intravascular filling and mitigate the risk of IDH. Incorporating these objective modalities alongside clinical methods may strengthen dry weight determination and improve patient outcomes.

3.7. Strengths and Limitations

This review synthesizes the clinical utility of multimodal fluid assessment, yet limitations exist. Most evidence comes from observational and cross-sectional studies, which carry a higher risk of bias than randomized trials. Furthermore, methodological variations—including inconsistent BIS thresholds, differing LUS protocols, and varying sample sizes—make direct numerical comparisons challenging. While indicator dilution techniques offer precise measurements, their complexity precludes routine use, leaving the field without a practical gold standard. Despite these limitations, the consistent correlation between the discussed parameters and weight changes underscores the practical utility and reproducibility of an integrated multimodal approach in routine nephrology.

4. Future Perspectives

The transition from traditional clinical assessment to objective fluid management marks a significant shift in nephrology. However, several hurdles remain before these tools can be fully integrated into a universal gold standard. Future research should move beyond isolated snapshot measurements and prioritize large-scale randomized controlled trials (RCTs). Such trials are essential for validating a standardized, multimodal framework that uses BIS, LUS, and IVCD in tandem rather than as competing alternatives. Furthermore, the practical future of these technologies lies in automation and continuous monitoring to reduce operator dependency. This includes a move toward artificial intelligence-enhanced handheld ultrasound devices and wearable sensors for real-time monitoring. Ultimately,

the goal is to validate an integrated, automated, and patient-centered framework that allows for precise, personalized dry weight optimization, thereby minimizing cardiovascular risk and improving long-term survival.

5. Conclusions

As nephrology care advances, precision in fluid management has emerged as a critical cornerstone of effective dialysis practices. This review addresses the current scientific gap by highlighting that the future of dialysis care lies within a standardized multimodal framework. While the BIS and LUS are clinically useful for identifying fluid overload, and IVCD allows non-invasive monitoring, their utility may improve when used in combination. By integrating these objective methods, clinicians may overcome the limitations of traditional clinical assessment. This approach provides a framework for comparing and combining results, offering a pathway toward more reliable and individualized fluid management. However, the formal establishment of standardized clinical guidelines will depend on further large-scale randomized trials to fully validate this integrated multimodal strategy.

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Abbreviations

The following abbreviations are used in this manuscript:

BIS	Bioimpedance Spectroscopy
IVCD	Inferior Vena Cava Diameter
LUS	Lung Ultrasound
CKD	Chronic Kidney Disease
HD	Hemodialysis
MHD	Maintenance Hemodialysis
ESKD	End-Stage Kidney Disease
BCM	Body Composition Monitor
ECW/ECF	Extracellular Water/ Extracellular Fluid
ICW/ICF	Intracellular Water/ Intracellular Fluid

TBW	Total Body Water
EVLW	Extravascular Lung Water
FO	Fluid Overload
SBP	Systolic Blood Pressure
DBP	Diastolic Blood Pressure
TLUS	Total Lung Ultrasound Score
IVC	Inferior Vena Cava
IVC-CI	Inferior Vena Cava Collapsibility Index
IVCDimax	Maximum Inferior Vena Cava Diameter indexed to Body Surface Area
BP	Blood Pressure
NYHA	New York Heart Association
IDH	Intradialytic Hypotension
KDOQI	Kidney Disease Outcomes Quality Initiative
KDIGO	Kidney Disease Improving Global Outcomes

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