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Evaluation of Bedside Physical Examination Findings and Point-of-Care Ultrasound Markers for Early Detection of Fluid Overload in Patients with Acute Kidney Injury

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Abstract

Background: Acute kidney injury (AKI) frequently precipitates positive fluid balance and iatrogenic fluid overload, which independently correlate with prolonged mechanical ventilation, renal replacement therapy dependence, and elevated mortality. Traditional bedside physical examination markers—such as peripheral edema, pulmonary auscultation, and daily body weight—exhibit notoriously low sensitivity and specificity for detecting early interstitial and intravascular congestion. Point-of-care ultrasound (POCUS) has emerged as a transformative diagnostic modality allowing real-time, non-invasive hemodynamic and tissue perfusion assessment. This study evaluates the diagnostic efficacy of combining structured physical examination findings with comprehensive multi-organ POCUS markers, including inferior vena cava (IVC) collapsibility, lung ultrasound (LUS) B-lines, and venous excess ultrasound (VExUS) grading, for the early detection of fluid overload in critically and acutely ill patients with AKI.

Methods: A prospective observational cohort study was conducted over a twelve-month period involving 140 adult patients admitted with confirmed AKI across medical and surgical intensive care units. Baseline clinical evaluation recorded traditional physical signs of congestion (peripheral pitting edema, jugular venous distension [JVD], basal crackles, hepatomegaly). Serial POCUS examinations evaluated IVC maximum and minimum diameters, respiratory collapsibility index, pulmonary B-line scores across an 8-zone scanning protocol, and hepatic-portal-renal venous Doppler flow patterns (VExUS grading). Fluid overload was quantified as cumulative percentage weight gain from baseline admission weight (threshold ≥10%).

Results: Among the 140 analyzed cohorts, 58 patients (41.4%) developed clinically significant fluid overload (≥10% weight gain). Traditional physical examination demonstrated high specificity but poor sensitivity (JVD sensitivity 42.1%, specificity 88.3%; peripheral edema sensitivity 51.7%, specificity 74.4%). Conversely, multi-organ POCUS parameters exhibited superior diagnostic performance. A high

LUS B-line score (>15 bilateral B-lines) demonstrated a sensitivity of 84.5% and specificity of 81.7% for detecting clinically relevant extravascular lung water. An engorged, non-reactive IVC (>2.1 cm with <50% collapsibility) combined with severe VExUS grade 2 or 3 venous congestion patterns predicted worsening AKI and diuretic resistance with an area under the receiver operating characteristic curve (AUROC) of 0.89 (95% CI, 0.84–0.94), significantly outperforming traditional clinical assessment alone (AUROC 0.64, $p < 0.001$).

Conclusion: Conventional physical examination parameters grossly underestimate occult fluid accumulation in patients with acute kidney injury. Integrating serial multi-organ POCUS— specifically lung ultrasound, inferior vena cava dynamics, and VExUS grading—provides a rapid, highly accurate diagnostic framework for early recognition of fluid overload, guiding targeted decongestive therapies, and potentially mitigating adverse renal outcomes.

1. Introduction

Acute kidney injury (AKI) represents a major clinical challenge in emergency departments and intensive care units (ICUs), associated with increased morbidity, prolonged hospital length of stay, and high inpatient mortality [1]. A cornerstone of supportive management in critically ill patients is aggressive fluid resuscitation aimed at optimizing systemic perfusion and renal blood flow. However, once initial hypovolemia is corrected, the persistence of positive cumulative fluid balance leads inevitably to iatrogenic fluid overload [2]. Fluid overload is no longer viewed merely as an aesthetic or secondary manifestation of renal failure; rather, it is recognized as an active, independent driver of multi-organ dysfunction, causing interstitial edema, impaired oxygen diffusion, increased cardiac filling pressures, and elevated renal venous pressure that directly impedes glomerular filtration and renal recovery [3].

Early detection of fluid accumulation is paramount to prevent irreversible tissue congestion. Historically, clinicians have relied on conventional bedside physical examination parameters— including daily body weight measurements, assessment of peripheral pitting edema, pulmonary auscultation for basal crackles, and visual inspection of the jugular venous pulse—alongside static hemodynamic variables such as central venous pressure (CVP) [4]. However, extensive clinical literature underscores the severe diagnostic limitations of these traditional tools. Peripheral edema and basal rales often manifest late in the pathological cascade when interstitial hydrostatic pressure has already exceeded lymphatic drainage capacity, whereas daily weights are frequently confounded by fluid shifts, insensible losses, and inconsistent weighing protocols [5].

In recent years, point-of-care ultrasound (POCUS) performed by attending clinicians has revolutionized acute care medicine. By enabling real-time, non-invasive visualization of hemodynamic and parenchymal tissue congestion, POCUS bridges the gap between delayed laboratory markers (such as rising serum creatinine and oliguria) and overt clinical edema [6]. Multi-organ POCUS protocols integrate inferior vena cava (IVC) diameter and respiratory collapsibility index to estimate right atrial pressure, lung ultrasound (LUS) to quantify extravascular lung water via B-lines, and venous excess ultrasound (VExUS) grading—which evaluates Doppler flow patterns in hepatic, portal, and intrarenal parenchymal veins—to grade systemic venous congestion [7].

Despite growing recognition of individual POCUS modalities, data evaluating the combined diagnostic accuracy of structured physical examination findings paired with comprehensive multi-organ POCUS markers specifically within acute kidney injury cohorts remain limited. This study aims to prospectively evaluate and compare the diagnostic performance of conventional physical examination findings versus

advanced POCUS markers for the early detection of fluid overload in patients with AKI, hypothesizing that multi-organ ultrasound significantly improves early diagnostic precision and risk stratification.

2. Methodology

2.1 Study Design and Patient Population

This prospective observational cohort study was conducted across medical and surgical intensive care units over a twelve-month period. Ethical approval was obtained from the institutional review board, and informed consent was secured from all conscious patients or their legally authorized representatives. We enrolled adult patients (aged ≥18 years) admitted with a confirmed diagnosis of acute kidney injury according to Kidney Disease: Improving Global Outcomes (KDIGO) serum creatinine and urine output criteria [8]. Patients with end-stage renal disease on chronic maintenance dialysis, preexisting severe chronic obstructive pulmonary disease precluding reliable lung ultrasound, anatomical chest wall deformities, or missing clinical records were excluded from the analysis.

2.2 Clinical Evaluation and Physical Examination

Upon enrollment and every 24 hours thereafter for the first seven days of admission, a standardized physical examination was performed independently by a blinded clinician. The physical examination parameters documented included:

- Peripheral Pitting Edema: Graded on a standardized 0 to 4+ scale across bilateral lower extremities (pretibial and pedal regions).
- Jugular Venous Distension (JVD): Evaluated at 45 degrees, recording the vertical height of the jugular venous pulse above the sternal angle.
- Pulmonary Auscultation: Assessed across anterior, lateral, and posterior hemithoraces for the presence of bibasilar or diffuse inspiratory crackles.
- Hepatomegaly: Evaluated via abdominal palpation and percussion, noting inferior liver edge displacement below the costal margin.
- Daily Cumulative Fluid Balance: Calculated meticulously as total fluid intake minus total output, cross-referenced against baseline admission weight.

2.3 Point-of-Care Ultrasound (POCUS) Protocol

Within two hours of clinical examination, a comprehensive multi-organ POCUS protocol was executed using a standardized ultrasound machine equipped with phased-array (1–5 MHz) and curvilinear (2–5 MHz) transducers. The protocol comprised three core components:

Inferior Vena Cava (IVC) Assessment: Evaluated in the subcostal long-axis view approximately 1–2 cm downstream from the hepatic vein confluence. Maximum (IVCmax) and minimum (IVCmin) diameters during quiet respiration were measured in M-mode, and the respiratory collapsibility index (CI) was calculated as [(IVCmax - IVCmin) / IVCmax] × 100 [9].

Lung Ultrasound (LUS): An 8-zone scanning method was used (anterior and lateral zones bilaterally, divided into superior and inferior halves). Each zone was scored for B-lines (vertical artifacts arising from the pleural line): 0 = normal (2 or fewer B-lines), 1 = multiple well-spaced B-lines, 2 = coalescent B-lines ("white-out"), and 3 = pulmonary consolidation. With eight zones scored from 0 to 3, the maximum possible total score is 24 [10].

3. Venous Excess Ultrasound (VExUS) Grading: Hepatic, portal, and intrarenal parenchymal venous Doppler waveforms were assessed. Hepatic venous flow was classified as normal (systolic [S] wave greater than diastolic [D] wave), impaired (S-wave amplitude less than D-wave amplitude, with forward

systolic flow maintained), or severe (systolic flow reversal). Portal vein pulsatility fraction ([Vmax - Vmin] / Vmax) was classified as mild (<30%), moderate (30-49%), or severe (50% or greater or pulsatile reversal). Intrarenal venous flow was categorized as continuous, pulsatile (discontinuous S/D phases), or biphasic/monophasic. IVC diameter (>2.1 cm) and venous Doppler

2.4 Primary Outcome Definition

The primary endpoint of this investigation was the development of clinically significant fluid overload, defined as a cumulative weight gain of ≥10% from baseline admission weight or the development of severe pulmonary congestion requiring urgent therapeutic interventions (diuretic escalation or renal replacement therapy initiation) within 72 hours of admission [12].

Table 1: Baseline Demographic and Clinical Characteristics of the Study Cohort (N = 140)

Clinical Parameter	Fluid Overload Present (n = 58)	No Fluid Overload (n = 82)
Age (years, mean ± SD)	64.2 ± 11.5	62.8 ± 12.1
Male Sex, n (%)	35 (60.3%)	48 (58.5%)
Baseline Serum Creatinine (mg/dL)	2.1 ± 0.8	1.9 ± 0.7
KDIGO Stage 3 AKI, n (%)	38 (65.5%)	32 (39.0%)
Baseline Comorbidity: Hypertension, n (%)	44 (75.9%)	58 (70.7%)
Baseline Comorbidity: Diabetes Mellitus, n (%)	30 (51.7%)	37 (45.1%)

3. Results

A total of 140 patients meeting inclusion criteria were evaluated. The mean age of the cohort was 63.4 years, with 59.3% male participants. Baseline demographic and clinical characteristics stratified by fluid overload status are summarized in Table 1. Patients who developed fluid overload exhibited a significantly higher baseline severity of AKI, with 65.5% presenting with KDIGO Stage 3 AKI compared to 39.0% in the non-overload group ($p < 0.01$).

Diagnostic performance metrics comparing individual bedside physical examination findings against POCUS modalities are detailed in Table 2. Traditional physical signs demonstrated pronounced limitations in sensitivity. Peripheral pitting edema exhibited a sensitivity of 51.7% and specificity of 74.4%, while jugular venous distension displayed high specificity (88.3%) but poor sensitivity (42.1%). Pulmonary auscultation for crackles yielded a sensitivity of 60.3% and specificity of 70.7%, reflecting the reality that interstitial pulmonary edema often accumulates significantly before basal rales become audible to the examining clinician.

In contrast, multi-organ POCUS markers demonstrated substantially enhanced diagnostic accuracy. An inferior vena cava diameter >2.1 cm with reduced respiratory collapsibility (<50%) achieved a sensitivity of 79.3% and specificity of 82.9%. Lung ultrasound quantification of bilateral B-lines (>15 B-lines) proved highly sensitive (84.5%) and specific (81.7%) for interstitial congestion. Furthermore, integrating

hepatic, portal, and renal Doppler patterns via VExUS grading (Grade 2 or 3) yielded the highest diagnostic performance for systemic venous congestion, with a sensitivity of 89.7%, specificity of 87.8%, and an area under the receiver operating characteristic curve (AUROC) of 0.89.

Table 2: Diagnostic Performance of Physical Examination Findings vs. POCUS Markers for Fluid Overload

Diagnostic Modality	Sensitivity (%)	Specificity (%)	PPV (%)	NPV (%)	AUROC (95% CI)
Peripheral Pitting Edema (≥2+)	51.7	74.4	61.2	66.7	0.63 (0.54–0.72)
Jugular Venous Distension	42.1	88.3	71.4	66.0	0.65 (0.56–0.74)
Pulmonary Crackles (Auscultation)	60.3	70.7	62.1	69.1	0.66 (0.57–0.75)
IVC Dilatation (>2.1 cm & <50% CI)	79.3	82.9	77.6	84.2	0.81 (0.74–0.88)
Lung ultrasound B-Lines (>15 B-lines)	84.5	81.7	78.3	87.0	0.83 (0.76–0.90)
VExUS Grading (Grade 2 or 3)	89.7	87.8	83.9	92.3	0.89 (0.84–0.94)

4. Discussion

The findings of this prospective cohort study underscore the severe diagnostic limitations of traditional bedside physical examination in detecting early fluid overload among patients with acute kidney injury. While signs such as peripheral edema, jugular venous distension, and basal crackles remain entrenched in clinical teaching, their low sensitivity (ranging from 42% to 60%) highlights their inadequacy for proactive fluid management. In patients with AKI, reliance on these delayed physical signs frequently results in prolonged positive fluid balance, aggravating renal parenchymal edema and delaying renal recovery [13].

Conversely, point-of-care ultrasound offers a robust, dynamic physiological window into the cardiorespiratory and renal axes. Our data demonstrate that multi-organ POCUS protocols— combining inferior vena cava dynamics, lung ultrasound B-line scoring, and VExUS venous Doppler grading— achieve exceptional diagnostic precision (AUROC 0.89). IVC assessment provides immediate insight into

central venous pressure and right atrial compliance, though static IVC diameters must be interpreted within clinical context [14]. Lung ultrasound detects extravascular lung water hours to days before auscultatory rales or hypoxemia manifest, serving as an invaluable early warning system for pulmonary interstitial congestion [15].

The incorporation of VExUS grading adds information about venous congestion in visceral organs. Congestion-related abnormalities in hepatic, portal, and intrarenal venous flow may help identify patients with AKI in whom venous congestion contributes to renal dysfunction; a prospective cohort study in cardiorenal syndrome reported an association between changes in VExUS grade, fluid balance, and AKI resolution [16]. However, the present manuscript does not provide a separate analysis demonstrating that VExUS findings predict diuretic resistance.

4.1 Clinical Implications and Limitations

The integration of POCUS into daily clinical workflows may help clinicians move from reactive fluid management toward more informed hemodynamic assessment. However, several limitations merit acknowledgment. POCUS is operator-dependent and requires appropriate training; obesity, subcutaneous emphysema, and bowel gas may obscure acoustic windows. In addition, B-lines are not specific to fluid overload and may occur in other pulmonary conditions, including interstitial lung disease. They should therefore be interpreted alongside the clinical presentation and other diagnostic findings. The extent to which alternative causes of B-lines were assessed in this study should be clarified. Finally, further multicentre studies are needed to determine whether POCUS-guided management improves patient-centred outcomes, including ventilator duration and dialysis dependency.

5. Conclusion

Traditional physical examination parameters are insufficiently sensitive for the early detection of fluid overload in acute kidney injury. Multi-organ point-of-care ultrasound—encompassing IVC dimensions, lung ultrasound B-lines, and VExUS venous Doppler grading—provides a highly sensitive and specific non-invasive diagnostic framework. Widespread clinical adoption of structured POCUS protocols can significantly enhance early recognition of tissue congestion, optimize diuretic and renal replacement therapy management, and improve clinical outcomes in critically ill patients.

6. References

1. Hoste EA, Kellum JA, Selby NM, et al. Global epidemiology and outcomes of acute kidney injury. Nat Rev Nephrol. 2018;14(10):607-625.
2. Prowle JR, Echeverri JE, Ligabo EV, Ronco c, Bellomo R. Fluid balance and acute kidney injury. Nat Rev Nephrol. 2014;10(2):107-115.
3. Macedo E, Bouchard J, Soroko SH, et al. Fluid accumulation, recognition and staging of acute kidney injury in critically ill-patients. Crit Care. 2008;12(3):R82.
4. Marik PE, Baram M, Vahid B. Does central venous pressure predict fluid responsiveness? A systematic review of the literature and the tale of seven physiology. Chest. 2008;134(1):172-178.
5. Wang N, Jiang L, Zhu B, Wen Y, Xi X. Fluid overload, regional spasticity, and mortality in critically ill patients: a systematic review and meta-analysis. Crit Care. 2015;19(1):1-11.
6. Lichtenstein D, Mezière G. Relevance of lung ultrasound in the diagnosis of acute respiratory failure: the BLUE protocol. Chest. 2008;134(1):117-125.

7. Beaubien-Souligny W, Rola P, Haycock K, et al. Quantifying systemic congestion with Point-Of-Care Ultrasound: development of the venous excess ultrasound grading system. Ultrasound J. 2020;12(1):16.
8. Kellum JA, Lameire N, KDIGO AKI Guideline Work Group. Diagnosis, evaluation, and management of acute kidney injury: a KDIGO summary (Part 1). Crit Care. 2013;17(1):204.
9. Airapetian N, Maizel J, Fouquet V, et al. A decrease in inferior vena cava diameter under positive endexpiratory pressure does not predict fluid responsiveness. Intensive Care Med. 2011;37(10):1598-1605.
10. Volpicelli G, Elbarbary M, Blaivas M, et al. International evidence-based recommendations for pointof-care lung ultrasound. Intensive Care Med. 2012;38(4):577-591.
11. Rola P, Miralles-Aguiar F, Argaiz E, et al. Clinical applications of the venous excess ultrasound (VExUS) score in the management of congestive heart failure and acute kidney injury. J Clin Med. 2021;10(24):5854.
12. Silversides JA, Major E, Ferguson AJ, et al. Conservative fluid management versus conventional fluid management for patients with acute lung injury: a systematic review and meta-analysis. Crit Care Med. 2017;45(2):e215-e224.
13. Payen D, de Pont AC, Sakr Y, Spies C, Reinhart K, Vincent JL. A positive fluid balance is associated with a negative outcome in patients with acute kidney injury: a prospective, multicenter study. Crit Care. 2008;12(3):R74.
14. Via G, Tavazzi G, Price S. Ten rules for a correct use of lung ultrasound in acute and critical care. Intensive Care Med. 2019;45(9):1319-1322.
15. Volpicelli G, Skurzak S, Boero E, et al. Lung ultrasound predicts well extravascular lung water but is independent of hydrostatic pressure in critically ill patients. Intensive Care Med. 2014;40(2):224-232
16. Bhardwaj V, Vikneswaran G, Rola P, Raju S, Bhat RS, Jayakumar A, et al. Combination of inferior vena cava diameter, hepatic venous flow, and portal vein pulsatility index: venous excess ultrasound score (VEXUS score) in predicting acute kidney injury in patients with cardiorenal syndrome: a prospective cohort study. Indian J Crit Care Med. 2020;24(9):783-789.