The Pediatric Tri-POCUS Approach: Conceptual Review and Case Series

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Abstract

Effective fluid management presents a significant challenge for pediatric intensivists. Enhanced ultrasound data that predict adverse outcomes, such as edema and venous congestion, can provide important information about optimal fluid management. The integration of bedside multiorgan ultrasound protocols (Multi-POCUS) mitigates the limitations of individual scoring systems, enabling more accurate fluid monitoring and management. The Tri-POCUS approach, described initially in adult patients, combines lung ultrasound, focused cardiac ultrasound, and venous excess ultrasound, and its application in the pediatric population is proposed. This study examines the Tri-POCUS approach from a pediatric perspective: we applied it to a cohort of critically ill pediatric patients with venous congestion admitted to a pediatric intensive care unit. Four cases are presented to demonstrate the bedside utility of the Tri-POCUS approach in critically ill children with the goal of monitoring venous congestion.

Keywords: Fluid overload, hepatic venous Doppler, inferior vena cava, intrarenal venous Doppler, pediatric intensive care unit, point of care ultrasound, portal venous Doppler, ultrasonography/heart, ultrasonography/lung, venous congestion, venous excess ultrasound, VExUS score

Introduction

Excessive fluid administration, although common, is not always effective and has been associated with adverse outcomes, including venous hypertension, multiorgan dysfunction, acute kidney injury (AKI), prolonged mechanical ventilation (MV), and increased mortality.[1] Proper fluid management is crucial in pediatric intensive care to avoid venous congestion. Therefore, it is essential to focus on detecting reliable methods to monitor venous congestion.

Beaubien-Souligny *et al*.[2] emphasized the utility of ultrasound to estimate the severity of venous congestion in adults with heart failure, validating the "venous excess ultrasound score (VExUS)" by assessing the diameter of the inferior vena cava (IVC) and Doppler patterns in the hepatic (HVD), portal (PVD), and intrarenal veins (IRVD) and correlating these findings with the severity of AKI.[3] The VExUS score has been recognized as a valuable tool for estimating venous congestion in adults[4] and has been suggested as an essential exam ("third eye") for intensivists.[5]

However, diagnosing and monitoring venous congestion in pediatrics is even more challenging, as there are currently very few references in the pediatric literature. Menéndez-Suso *et al*. validated the reliability and utility of VExUS to detect high central venous pressure (CVP) in critically ill children.[6] Another recent study indicated that in pediatric postoperative cardiac surgery patients with right ventricular dysfunction, venous congestion assessed by VExUS was associated with AKI.[7] In addition, a case series reported the application of VExUS by POCUS-trained pediatric intensivists in children with persistent or recurrent septic shock.[8]

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Received: 15-09-2024 **Revised:** 15-12-2024 **Accepted:** 06-01-2025 **Available Online:** 23-05-2025

Access this article online

Quick Response Code:

Website: https://journals.lww.com/jmut

DOI: 10.4103/jmu.JMU-D-24-00002

How to cite this article: Palanca Arias D, Clavero Adell M, Estabén Boldova V, Alonso Formento JE, Ayerza Casas A, Alonso Ojembarrena A. The pediatric Tri-POCUS approach: Conceptual review and case series. J Med Ultrasound 2025;33:154-61.

Abbreviations	
AKI	Acute kidney injury
MV	Mechanical ventilation
IVC	Inferior vena cava
HVD	Hepatic venous doppler
PVD	Portal venous doppler
IRVD	Intrarenal venous doppler
CVP	Central venous pressure
LUS	Lung ultrasound
FoCUS	Focused cardiac ultrasound
NIV	Noninvasive ventilation

In hemodynamically unstable situations, integrating individual scoring systems into clinical practice, such as lung ultrasound (LUS), focused cardiac ultrasound (FoCUS), and abdominal vein assessments, facilitates the exclusion of specific diagnoses before initiating fluid therapy or inotropic support. In recent years, multiorgan ultrasound approaches (Multi-POCUS)[9] have been proposed to overcome the limitations of individual scores by combining multiple modalities.[10-13] They advocate for incorporating POCUS into pediatric training and developing POCUS-guided management protocols for various clinical scenarios, including venous congestion.[14]

With the recent publication of international pediatric and neonatal POCUS guidelines[15] and the increasing demand for ultrasound in pediatric training,[16] this study proposes applying the Tri-POCUS approach in a series of critically ill pediatric patients.

Materials and Methods

During the months of January 2024–June 2024, the Tri-POCUS approach evaluation was performed on critically ill children admitted to the pediatric intensive care unit (PICU) with hemodynamic instability requiring intubation. Following initial stabilization, an ultrasound evaluation to rule out treatable causes by FoCUS and LUS was conducted. As these patients required multiple fluids, and due to the clinical suspicion of venous congestion, the VExUS score was added. Patients with aggressive MV parameters (positive end-expiratory pressure >10 cmH_2O), significant right ventricular dysfunction, or pulmonary hypertension were excluded from the study.

We selected those cases where the Tri-POCUS approach aided to monitor venous congestion. All images were obtained by the same senior staff physician with over 10 years of experience in pediatric intensive care and pediatric cardiology.

We used a "Canon Aplio a" ultrasound machine (Canon Medical Systems Switzerland). We described the ultrasonographic pattern in the lungs (interstitial, consolidation, or pleural effusion) without calculating a numerical score in anterior, lateral, and posterior fields using a high-frequency linear transducer. FoCUS described heart contractility, need for fluids, or tamponade using a sectorial transducer.

The IVC diameter was measured approximately 2 cm below the right atrial junction by placing the probe in the subxiphoid region [Figure 1]. Given the variability in IVC values according to age and the absence of studies with normal Z-score values for pediatrics, venous flows were assessed despite normal IVC values and rated according to measurements published by Kutty *et al*. for pediatric ages.[17]

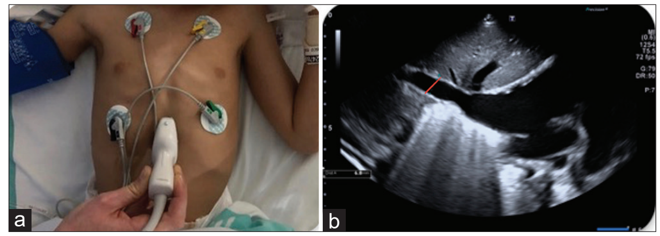

Figure 1: Subxiphoid window, (a) Inferior vena cava in 2D longitudinal axis, with its measurement approximately 2 cm below the right atrial junction (red) (b)

HVD, PVD, and IRVD evaluations followed the methodology described by Beaubien- Beaubien-Souligny *et al*.[2] Normal findings in venous ultrasound evaluation conducted on pediatric PICU patients are depicted in Figure 2. VExUS scored venous congestion (0–3 points) using a convex probe with simultaneous electrocardiogram tracing. Following the first VExUS assessment at admission, ultrasound exams were repeated after 72 h or before discharge to monitor changes in the patient's condition.

We gathered some clinical variables of the patients included at admission and after 72 h that are detailed in Table 1, as well as informed consent from all patients' parents. The paediatric the Tri-POCUS approach (LUS, FoCUS, VExUS) is detailed in Figure 3.

Case 1

An 8-month-old infant was admitted to the emergency department, presenting with poor general condition, tachycardia, tachypnea, hypotension, and poor peripheral perfusion. Physical examination revealed decreased breath sounds at the left base, drowsiness, a maculopapular rash on the trunk, and malar erythema. Laboratory tests showed elevated NT-proBNP (46,000 pg/mL), troponin I (350 ng/L), and procalcitonin (900 ng/mL). The patient initially received noninvasive ventilation (NIV) but required intubation due to hemodynamic instability for 5 days. Several fluid boluses (30 ml/kg), bicarbonate, adrenaline, milrinone, noradrenaline, and hydrocortisone were administered due to refractory shock. Bilateral pleural drainage was performed, and the infant developed ascites as well. In the context of streptococcal toxic shock syndrome by *Streptococcus pyogenes* (positive PCR in pleural fluid, rash, and septic shock), the patient was treated with antibiotics (cefotaxime, vancomycin, and clindamycin) and immunoglobulins. After improvement, inotropic support was discontinued within 72 h. The patient received a red blood cell transfusion and continuous furosemide infusion for the first 6 days of admission.

In Figure 4, we describe the evolution of the Tri-POCUS approach: therapy with diuretics and inotropes was titrated

Table 1: General characteristics of patients undergoing venous excess ultrasound evaluation

Case	Age	Acute condition	Documented fluid balance at T1 (mL)	VExUS score at T1 IVC diameter at T1 (ULN)	LUS findings at T1	FoCUS findings at T1	VExUS derived management	Documented fluid balance at T2 (mL)	VExUS score at T2 IVC diameter at T2 (ULN)	LUS findings at T2	FoCUS findings at T2
1	8 months	STTS	Day 1: +360	1 5.3 mm (7mm)	Pleural effusion Bilateral toracocentesis	MR Preserved EF	Furosemide 0.2 mg/kg/h	Day 1: −250 Day 2: −330 Day 3: −150	0 4.5 mm (7 mm)	No pleural effusion A-lines	No regurgitation Preserved EF
2	13 years	MODS	Day 1: +250 Day 2: +3010 Day 3: +1815	1 9.6 mm (16 mm)	Pleural effusion Bilateral toracocentesis Paracentesis	Moderate pericardial effusion Preserved EF	Furosemide 0.8 mg/kg/h CVVH	Day 1: −400	0 8 mm (16 mm)	Minimal pleural effusion Isolated B lines	No pericardial effusion Preserved EF
3	2 months	RSV bronchiolitis	Day 1: +172 Day 2: +372 Day 3: +313	1 5 mm (7 mm)	Multiple B-lines	Mild pericardial effusion	Furosemide 0.3 mg/kg/h	Day 1: −444 Day 2: −43 Day 3: −123	0 3 mm (7 mm)	A-lines	No pericardial effusion
4	3 years	STSS	Day 1: +2344	3 8.3 mm (11 mm)	Pleural effusion Right torachocentesis	MR Mild systolic dysfunction	Furosemide 0.3 mg/kg/h	Day 1: −802 Day 2: −506 Day 3: −415	0 5 mm (11 mm)	Minimal pleural effusion A-lines	No regurgitation Preserved EF

Fluid balance before (T1) and after VEXUS-guided treatment (T2). LUS and FoCUS assessments are also included. CVVH: Continuous veno-venous hemofiltration, EF: Ejection fraction, FoCUS: Focus cardiac ultrasound, IVC: Inferior vein cava, LUS: Lung ultrasound score, MODS: Multiple organ dysfunction syndrome, MR: Mitral regurgitation, RSV: Respiratory syncytial virus, T1: Timepoint at first ultrasound scan, T2: Timepoint 72 h after VExUS-guided management, ULN: Upper limit of normality, VEXUS: Venous excess ultrasound, STSS: Streptococcal toxic shock syndrome, FoCUS: Focused cardiac ultrasound

based on these findings, resulting in improved hemodynamic status. Ascites resolved after achieving a negative fluid balance. The IVC diameter decreased from 5 mm to 3 mm. Doppler profiles normalized: PVD decreased from 33% to 11%, HVD improved (sD to Sd), but there was persistent abnormal IRVD.

Case 2

A 13-year-old patient diagnosed with peripheral systemic T-cell lymphoma was admitted to the PICU. Following chemotherapy, the patient developed persistent febrile illness and polyserositis, worsening general condition, and progressive hypoxemia. Despite diuretic therapy, there was an increase in pleural effusion and ascites. NIV was initiated, and diuretic therapy intensified. The patient developed progressive hepatic and renal dysfunction, and he received broad-spectrum antibiotics and antifungals due to suspected typhlitis. The patient also required red blood cell and platelet transfusions. There was a progression toward a cardiac pulmonary arrest (CPA) with advanced resuscitation maneuvers and subsequent recovery. Marked metabolic acidosis and hemodynamic instability prompted the initiation of inotropic support (adrenaline and noradrenaline) and multiple volume expansions. Notable findings included hypoalbuminemia, bilateral pleural effusion, and significant ascites requiring paracentesis. Hemodiafiltration was initiated after 72 h due to a cumulative positive balance of five liters despite corticosteroid therapy and continuous furosemide infusion (0.8 mg/kg/h). The patient clinically deteriorated progressively, demonstrating severe and progressive hepatic failure. In light of severe multiorgan failure, a consensus decision was made to transition to palliative care after 96 h of admission, and the patient died that same day. The Tri-POCUS assessment [Figure 5] revealed at admission a normal IVC diameter (7.5 mm), normal cardiac systolic function, and pericardial and pleural effusion. The Doppler pattern indicated venous congestion, which improved after intensifying decongestive therapy (hemodiafiltration) for 12 h. Despite the hypervolemic condition, PVD remained unaffected, likely due to pressure attenuation from tumor infiltration in the hepatic and portal hilum, as described by other authors.[18]

Case 3

A 2-month-old infant was admitted to the PICU with bronchiolitis (positive for respiratory syncytial virus), requiring progressively increased respiratory support within the first 24 h. Due to a tension pneumothorax, the infant experienced a CPA with subsequent recovery after intubation and pneumothorax evacuation. The infant did not require inotropes. Progressive clinical improvement in respiratory status allowed extubation and initiation of rescue NIV 48 h later due to left lung atelectasis. Following prolonged fluid therapy, generalized edemas appeared, so the patient was assessed using the Tri-POCUS approach [Figure 6]: after a normal exam at admission (images not shown), at 72 h, the IVC diameter was still in the normal range (5.4 mm), as well as cardiac contractility; an interstitial lung pattern was noted, and VExUS score was 1. The infant subsequently received a

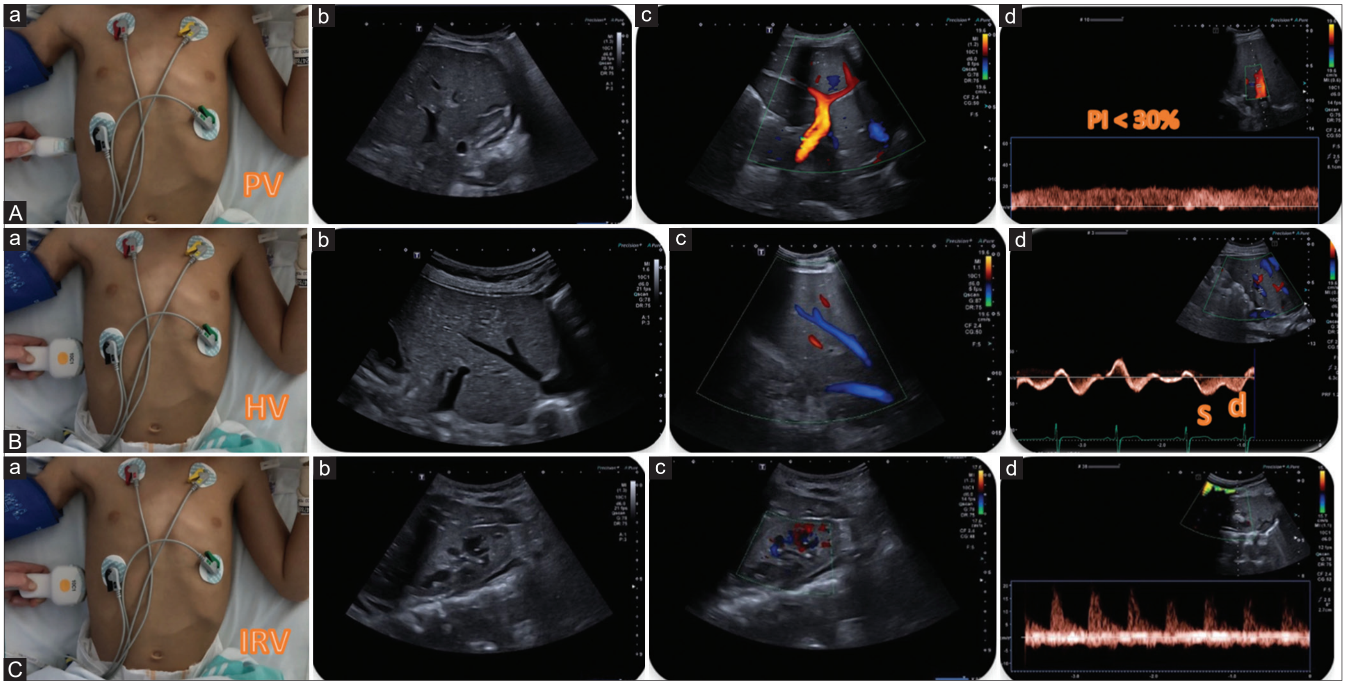

Figure 2: Systematic Doppler-ultrasound evaluation of the three abdominal veins and their normal and abnormal venous Doppler waveforms. Transverse right lateral portal approach, (A; a) Portal vein (2D), (A; b) Portal vein (color), (A; c) Normal portal vein pulsatility index (<30%), (A; d) Longitudinal right lateral suprahepatic approach, (B; a) Hepatic veins in 2D, (B; b) Hepatic Vein Doppler in color (B; c) Normal hepatic vein waveform (Sd), (B; d) Longitudinal right lateral renal approach (C; a). Kidney in 2D (C; b). Kidney in color (C; c). Normal intrarenal waveform (C; d)

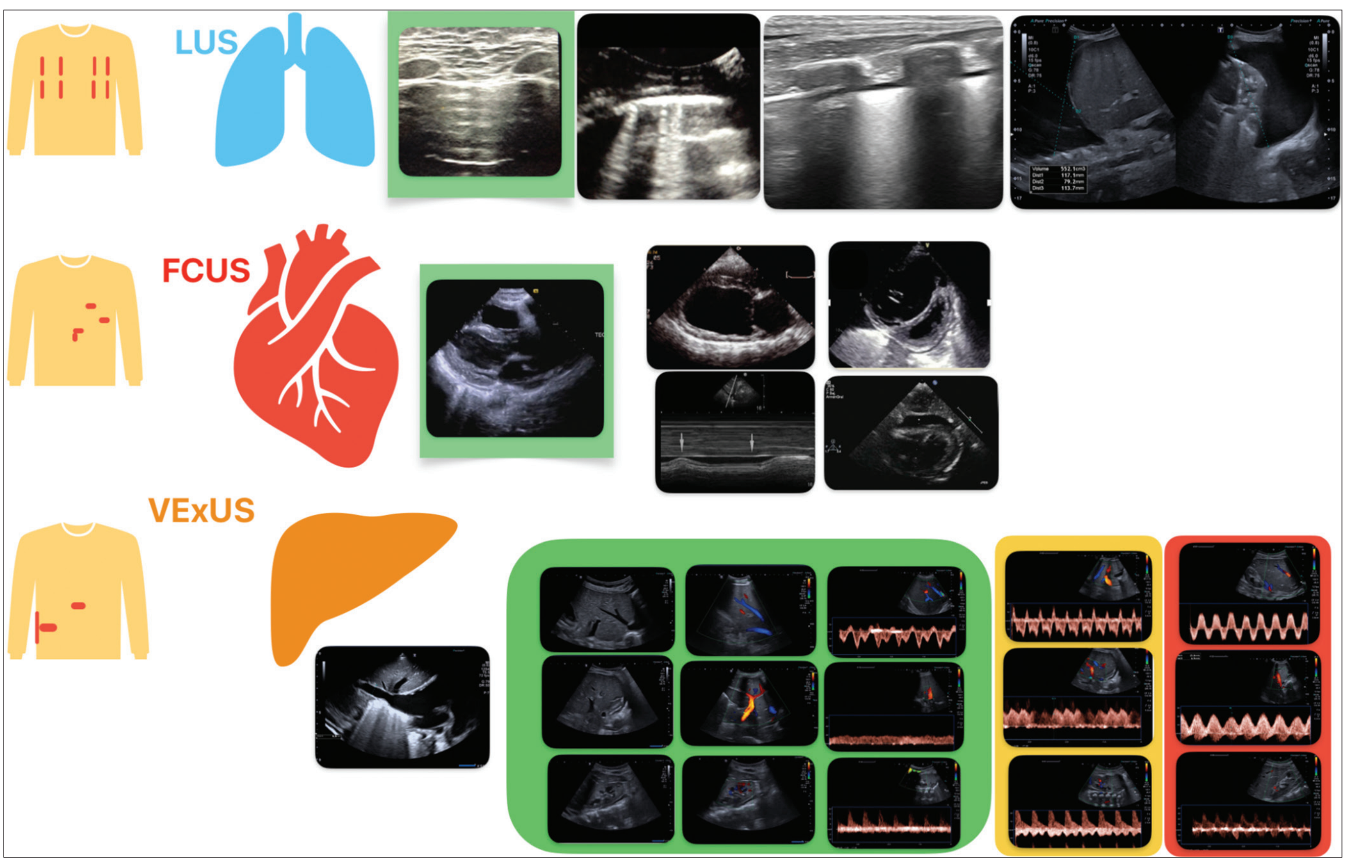

Figure 3: Tri-POCUS approach. Lung ultrasound: normal pattern, A-lines (green), more than 3 B-lines, confluent B-lines, pleural effusion. Focused cardiac ultrasound: normal long axis (green), any abnormality (left failure, right failure, hypovolemic shock, tamponade). VExUS: Inferior Vena Cava size. Hepatic venous Doppler, portal venous Doppler, intrarenal venous Doppler normal (green), mild to moderate (yellow), severe (red)

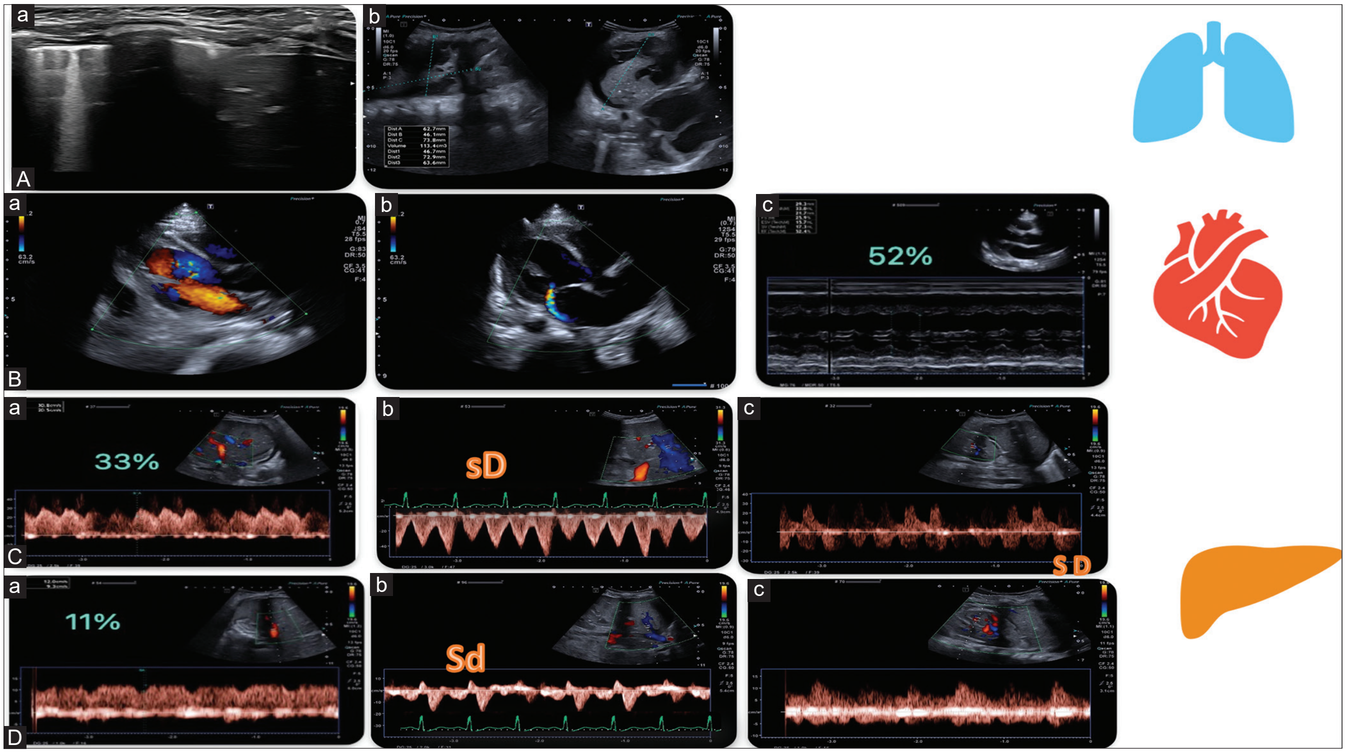

Figure 4: Case 1 - Lung ultrasound: B-lines (A; a) and pleural effusion (A; b). Focused cardiac ultrasound: Normal PLAX, no insufficiencies (B; a), and after 72 h: mild mitral regurgitation (B; b) and mild left dysfunction LVEF 52% (B; c). VExUS: Changes in Portal Venous Doppler (C and D; a), Hepatic Venous Doppler (C and D; b), and intrarenal venous Doppler (C and D; c) after 72 h. Inferior vena cava diameter decreased from 5 to 3mm

furosemide infusion for 72 h (0.3 mg/kg/h), resulting in the normalization of VExUS score across all patterns.

Case 4

A 3-year-old girl with a history of inflammatory bowel disease since the age of 9 months and suspected undiagnosed immunodeficiency presented to the emergency department with decompensated shock due to vomiting and diarrhea. Oxygen therapy and fluid boluses (40 ml/kg) were administered along with cefotaxime. Physical examination revealed fair overall condition, dry mucous membranes, scarlatiniform rash, subcostal retractions, tachypnea, tachycardia, paleness, delayed capillary refill, drowsiness, hypotension, and severe hypoxemia. The patient was admitted to the PICU due to suspected septic shock, requiring intubation for 6 days and pleural drainage 48 h after admission. Rapid streptococcal test and pharyngeal smear were positive for *S. pyogenes*, confirmed in pleural fluid. There was progressive improvement in hemodynamics, leading to discontinuation of inotropic support after 7 days of admission. The patient had a favorable outcome and was discharged.

In the Tri-POCUS assessment at admission [Figure 7], the IVC diameter was normal (8.3 mm), and mild systolic dysfunction with mild mitral regurgitation was observed. At 72 h, after furosemide infusion (0.25 mg/kg/h) resulted in negative fluid balances, normal cardiac systolic function, disappearance of mitral regurgitation, and change in VExUS score from 3 to 1. There was a significant improvement in PVD (30%), HVD (Sd), and less disturbed IRVD, with no change in IVC (8 mm). By day 6, IVC decreased to 3 mm, PVD improved (21%), there was a normal IRVD, as well as a disappearance of the free fluid and minimal pleural effusion.

Discussion

Managing hemodynamics in children has centered the use of fluids and catecholamines to maintain adequate cardiac output and arterial blood pressure. However, elevated venous pressures are often overlooked. Optimizing hemodynamics in critically ill patients is crucial for positive outcomes, and fluid overload can be harmful and impede organ oxygenation, causing peripheral and pulmonary edema. A recent pediatric study demonstrated an association between VExUS score and CVP elevation as a surrogate measure of systemic venous congestion.[6]

Bedside ultrasound has become the ideal tool for monitoring venous congestion and fluid overload (LUS and VExUS), and FoCUS is a noninvasive method to characterize hemodynamics and may improve outcomes in children with septic shock[19] providing crucial information including venous Doppler imaging.[8]

To the best of our knowledge, this is the first case series describing the Tri-POCUS approach in critically ill children. Conversely, there are limited studies applying the VExUS scoring system in pediatrics.[6,7] Natraj and Ranjit[8] describe VExUS as a logical extension of POCUS, emphasizing that with adequate training, pediatric intensivists proficient in

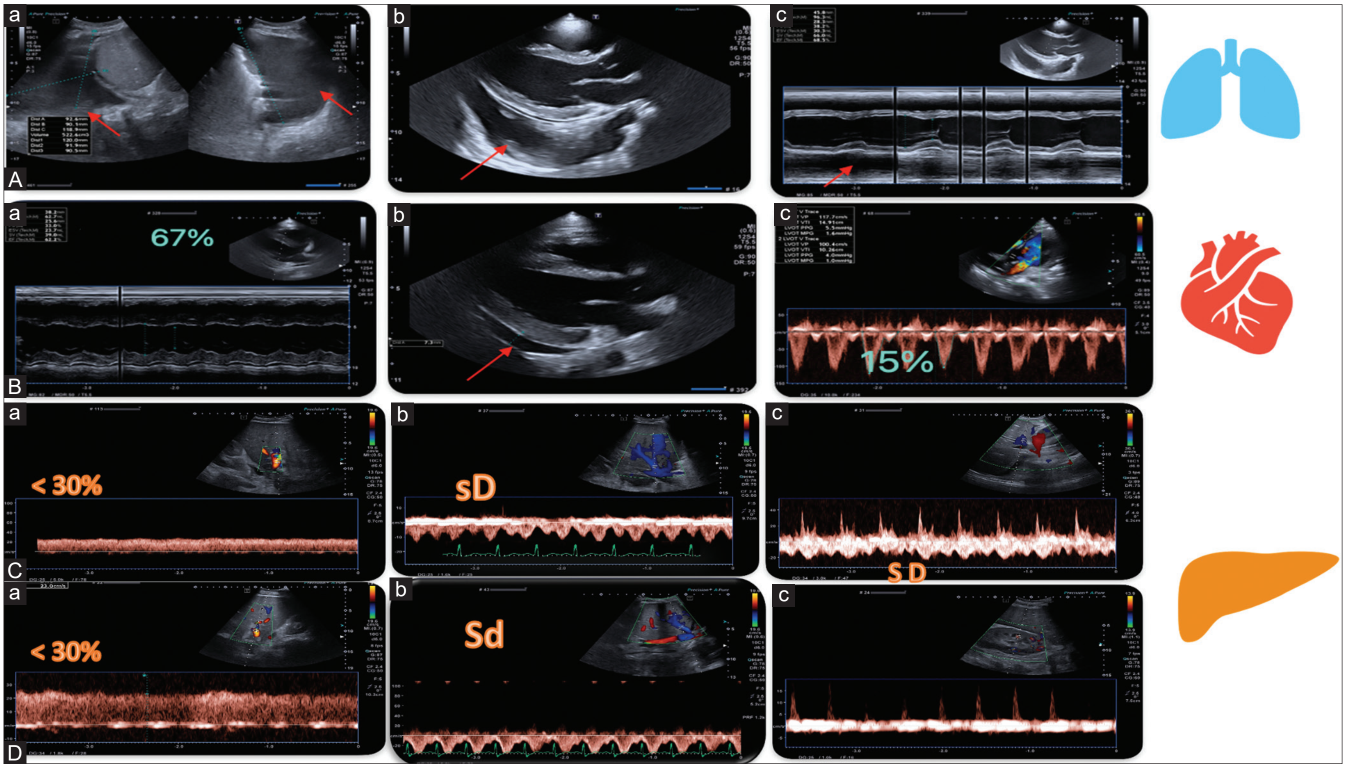

Figure 5: Case 2 - Lung ultrasound: Marked pleural effusion (A; a), visible even from PLAX (A; b) and M Mode (A; c). Focused cardiac ultrasound: preserved LVEF 67% (B; a), mild pericardial effusion (B; b), and aortic variability (>12%) (B; c). VExUS: at presentation alteration of the pattern in HVD (sD) (C; b) and IRVD (C; c). Note improved the hepatic venous Doppler (D; b) and Intrarenal venous Doppler (D; c) after optimizing the treatment at 12 h (C and D; b and c), except for the portal venous Doppler which did not show variability (<30%) (C and D; a). Normal inferior vena cava diameter (7,5mm) at admission

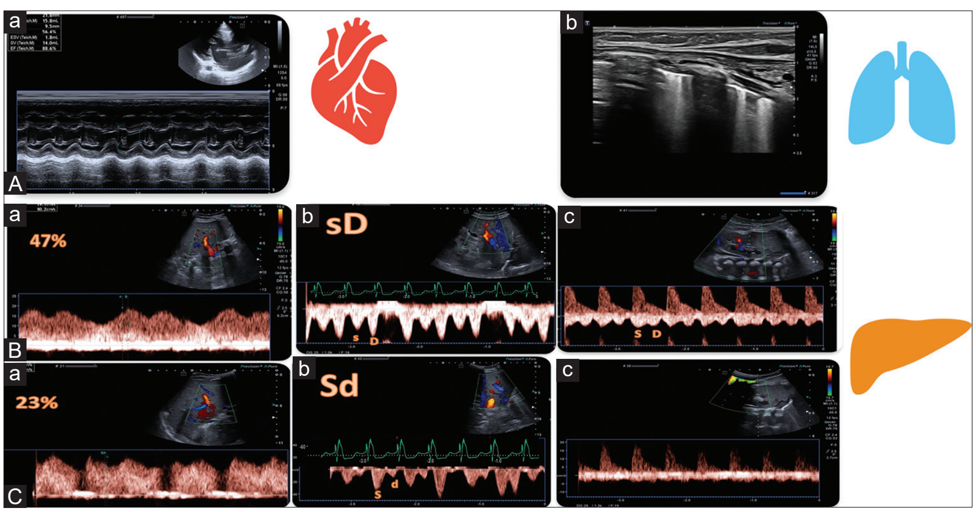

Figure 6: Case 3 - Focused cardiac ultrasound: preserved contractility (A; a). Lung ultrasound: B-lines (A; b). VExUS 1: Portal Venous Doppler (PVD) (30%–50%) at presentation (B; a). Hepatic venous Doppler (HVD) mildly abnormal (sD) (B; b). Intrarenal venous Doppler (IRVD) discontinuos with an s and D phase (B; c). After diuretic therapy and negative balance. VExUS 0. PVD < 30% (C; a). Normal HVD (C; b). Normal IRVD (C; c). Inferior vena cava diameter was still in the normal range (5,4mm)

POCUS can reasonably perform hepatic, portal, and renal Doppler to detect venous congestion, which may contribute to tissue hypoperfusion.

However, VExUS has not been validated in pediatrics to guide management, nor have VExUS scores been linked to outcomes in this population. This case series represents a valuable step in this emerging field. Integrating VExUS with LUS and FoCUS can provide more precise information regarding venous congestion when interpreted in the appropriate clinical context. We emphasize the utility of the comprehensive Tri-POCUS examination in evaluating hemodynamic status and volume

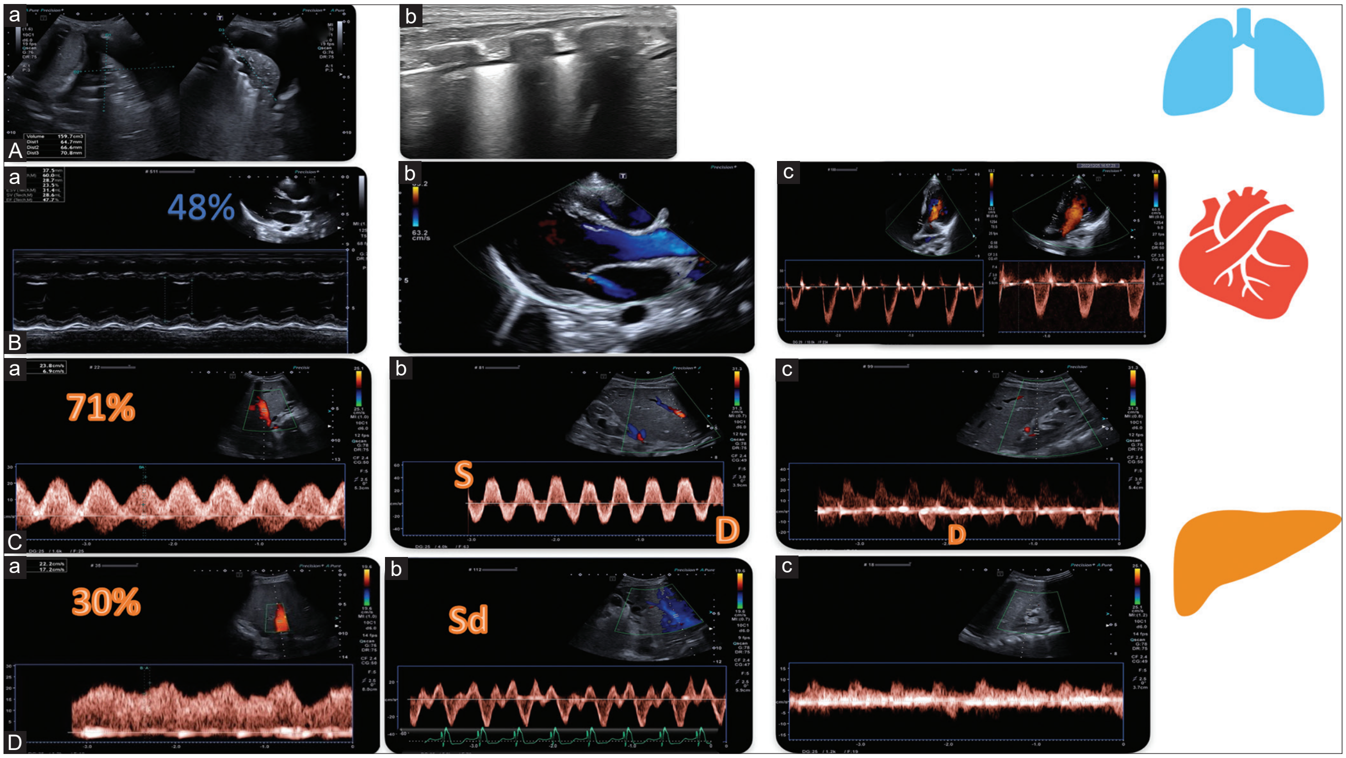

Figure 7: Case 4 - Lung ultrasound: Pleural effusion (A; a). Confluent B-lines (A; b). Focused cardiac ultrasound: LVEF 48%, poor contractility (B; a), mild MI (B; b), aortic flow variability with changes from the beginning when fluid resuscitation was required (left) and after progression without variability (right). VExUS score (3): Portal Venous Doppler showing 71% pulsatility (>50%) (C; a) and after improvement (23%) (D; a). Hepatic venous Doppler showing the D wave and reversal of the S wave (C; b) and after normalization (Sd) (D; b). Intrarenal venous Doppler discontinuos with only a diastolic phase (d) (C; c) and subsequent control (D; c). After improvement and subsequent control, the VExUS score was 1. Inferior vena cava diameter was normal (8,3mm) with no change at 72h and after 6 days decreased to 3mm

management through ultrasonographic monitoring aimed at achieving a more negative fluid balance.

FoCUS enabled to rule out treatable causes such as left heart failure, pericardial effusion, or mitral insufficiency, which normalized with resolution of the congestive state when present. Similarly, LUS tracked the evolution of tissue congestion through B-lines and the extent of pleural effusion.

Nevertheless, this study has several limitations. The series includes only a small number of cases with diverse pathologies, albeit all suggestive of venous congestion. Further research with larger, more homogeneous samples are warranted to explore the prognostic utility of the VExUS score and the Tri-POCUS approach in pediatric patients.

Given the increasing preference for noninvasive ultrasound parameters over invasive measures like CVP and the lack of consensus on IVC cutoffs for calculating the VExUS score in pediatric patients, investigating VExUS venous flows in cases with suspected venous congestion is crucial. Most literature currently defines IVC size relative to other structures in pediatrics; however, absolute IVC measurements pose significant interpretive challenges within pediatric VExUS. Age-specific cutoffs proposed by Kathuria *et al*.[20] appear promising and feasible but lack sufficient data for extrapolation to patients under 2 years old.

Despite using normal IVC values, we continued to apply this scoring system in pediatric cases, noting a reduction in both IVC diameter and marked improvement in Doppler patterns (VExUS) following interventions like diuretic-induced fluid depletion. VExUS offers greater objectivity in assessing fluid overload compared to clinical data alone. Rather than prescriptive fluid administration guidance, VExUS informs initial assessment and subsequent evaluation of diuretic efficacy or fluid restriction effectiveness.

Incorporating the VExUS score alongside standard PICU ultrasound assessments such as FoCUS and LUS to exclude treatable causes and evaluate tissue congestion may enhance objective data availability for monitoring venous congestion beyond isolated metrics such as IVC measurements.

Conclusion

These clinical cases demonstrate the feasibility of the Tri-POCUS examination and the subsequent changes in venous flows following fluid removal therapy. Establishing management protocols guided by POCUS across various clinical scenarios, including venous congestion, is essential for mitigating fluid overload. Integrating the Tri-POCUS approach as a bedside tool appears straightforward for initial assessment and monitoring of venous congestion in critically ill pediatric patients, offering crucial insights for fluid management. This approach can unveil novel findings in diverse clinical contexts and aid in averting fluid overload. The utility and feasibility of bedside VExUS measurements in PICUs provide an additional parameter for monitoring and guiding decisions regarding fluid management.

Ethics statement

This study was conducted in accordance with the ethical principles outlined in the Declaration of Helsinki and its amendments. The authors certify that they have obtained all appropriate patient consent forms. In the form, the patients have given their consent for their images and other clinical information to be reported in the journal. The patients understand that their names and initials will not be published and due efforts will be made to conceal their identity, but anonymity cannot be guaranteed.

Financial support and sponsorship

Nil.

Conflicts of interest

There are no conflicts of interest.

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