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The Use of the Venous Excess Ultrasound Score as a Bedside Tool to Predict Incidence of Acute Kidney Injury in Patients with Septic Shock: A Prospective Observational Study.

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Abstract

Background: Septic shock is a life-threatening condition in critically ill patients, and fluid therapy is one of the main pillars in its management. However, excessive fluid accumulation can lead to venous congestion, which adversely affects renal blood flow and function. **Objectives:** This study aims to determine the predictive value of the VExUS score for acute kidney injury (AKI) in patients with septic shock, based on the hypothesis that identifying venous congestion early may help predict AKI. **Methods:** An observational cohort study was conducted at Menoufia University Hospital. Daily VExUS examinations were performed on forty adult patients with septic shock for 7 days, and patients were monitored for AKI development. On day 7, we categorized patients into AKI and non-AKI groups, and based on changes in VExUS scores, we classified them into improving, unchanged, or worsening groups. We followed AKI

patients until they resolved or initiated renal replacement therapy. **Results:** Among the 40 patients, those who developed AKI exhibited higher VExUS scores compared to those without AKI. After one week, 50% of AKI patients had worsening VExUS scores, needed more dialysis, required longer mechanical ventilation, and had higher mortality. The diagnostic performance of VExUS ≥ 2 on admission for predicting AKI showed good specificity (83.3%). However, sensitivity was low (25%). **Conclusion:** The VExUS score may predict AKI in patients with septic shock.

Keywords:

Venous Excess Ultrasound Score, Acute Kidney Injury, Septic Shock, Bedside Ultrasound, Point of Care Ultrasound.

1. Introduction:

Septic shock is a life-threatening condition due to dysregulated response to infection with high mortality rates due to the complexity of inflammatory mediators, hemodynamic instability, and organ dysfunction [1,2]. Sepsis is one of the most common factors in acute kidney injury (AKI) of critical illness [3]. Previous studies noted that about 60% of patients with septic shock developed AKI and found a higher mortality and longer duration of hospital stay in patients with AKI compared to patients without AKI [4]. Fluid therapy is a critical component in septic shock management that needs adequate dose and duration to avoid fluid accumulation. Venous congestion may arise from compromised cardiac function, venous obstruction, and fluid overload. Increased venous pressure may cause renal venous congestion, reduced glomerular filtration rate (GFR), and AKI [5,6].

The proper identification of individuals at risk for developing AKI is essential for early management and better prognosis [7]. Accurate assessment of venous congestion is essential for early intervention and effective management of septic shock and associated AKI. Recently, we have been interested in using bedside ultrasonography to evaluate fluid status in critically ill patients. Venous excess ultrasound score (VExUS) provides a non-invasive method to evaluate venous congestion and predict AKI. By assessing inferior vena cava (IVC) size, portal, hepatic, and renal venous flow patterns [8,9].

VExUS predicts the development of AKI and adverse outcomes with higher accuracy than its components or central

venous pressure (CVP) [10]. However, using VExUS to predict AKI in septic shock needs more investigation. Our study suggests that VEXUS scores could be a predictive tool for the early detection of AKI in septic shock patients.

2. Methods:

Study Design and Population

This prospective cohort study involved 40 patients aged 18 to 80 diagnosed with septic shock according to the Third International Consensus Definitions for Sepsis and Septic Shock (Sepsis-3) criteria [1], admitted to the ICU at Menoufia University Hospitals within 24 hours of sepsis diagnosis. Ethical approval was obtained from the institutional review board (IRB) of Menoufia University, Shiben elkoom, Egypt (Approval No. 12/2022 ANES28) in 1.12.2022.

Clinical Trial Preregistration:

The study was registered in the Pan African Clinical Trials Registry: PACTR202409715853957, date:2/9/2024.

Exclusion Criteria

We excluded patients: was pregnant, discharged from the ICU within 7 days, undergone cardiopulmonary resuscitation (CPR), or had any of the following conditions: inferior vena cava (IVC) thrombus, conditions affecting portal Doppler assessment (e.g. cirrhosis or portal thrombosis), chronic kidney disease (CKD) with an estimated glomerular filtration rate (eGFR) < 60 mL/min/1.73 m^2, dialysis, moderate to severe tricuspid regurgitation, or impaired systolic function.

Outcomes

The primary objective of this study was to evaluate the VExUS score as a prognostic tool for patients with septic shock in the ICU. The primary outcome was to assess the relationship between serial VExUS scores and the incidence of acute kidney injury (AKI) in these patients. Secondary outcomes included the association between the VExUS score and various clinical parameters, such as fluid balance, clinical indicators of fluid overload, the onset of additional organ failure, length of ICU stay, duration of mechanical ventilation, and in-hospital mortality rates.

Data Collection

For included patients, we recorded demographic and clinical data. Including sex, age, weight, comorbidities, vital signs, laboratory results, and daily fluid balance. We evaluated Acute Physiology and Chronic Health Evaluation II (APACHE II) and Sequential Organ Failure Assessment (SOFA) scores on admission and reassessed SOFA after 7 days. We also evaluated Peripheral signs of volume

overload and clinical interventions, as mechanical ventilation and renal replacement therapy (RRT).

Patients underwent serial ultrasound examinations for VExUS scoring within the first 24 hours of ICU admission and then daily for the next 7 days. We monitored kidney function and urine output daily to identify AKI, according to the Kidney Disease Improving Global Outcomes (KDIGO) criteria for staging [11]. On day 7, Patients were categorized into improving, unchanged, or worsening groups based on changes in their VExUS score grades from baseline. A grade of 0 was referred to as VExUS 0, grade 1 as VExUS 1, grade 2 as VExUS 2, and grade 3 as VExUS 3 (Figure 2). Follow-up continued until AKI resolution or initiation of renal replacement therapy. Data of volume overload was collected and defined clinically by the presence of one or more of the following: peripheral edema, pulmonary crackles, or radiographic evidence of pulmonary congestion. These signs were assessed daily during the first 7 days of ICU admission in conjunction with VExUS scoring.

Steps of VExUS Assessment

VExUS is a four-step protocol for evaluating IVC diameter, hepatic vein, portal vein, and intra-renal vein Doppler flow patterns [12,13].

Preparation and Patient Positioning:

A bedside SonoScape ultrasound system (China) was used with a low-frequency curvilinear probe. The patient was supine, lowering the head of the bed to 0º and bent the legs. The operator is on the patient's right side. We used an abdominal preset with a color Doppler (CD) and pulse wave Doppler (PWD) to conduct the exam successfully.

The IVC was measured in a sub-xiphoid view, 1–2 cm below the hepatic vein confluence. A dilated IVC with minimal respiratory collapse suggests venous congestion. Hepatic Vein Assessment was done using Doppler modes. normal hepatic vein flow shows dominant S and D waves. A reduced S wave indicates mild congestion, while S wave reversal indicates severe congestion. The portal vein normally has continuous flow. Increased pulsatility reflects congestion. A pulsatility index >50% indicates severe congestion. Normal renal venous flow is monophasic. Biphasic flow suggests mild congestion, and loss of systolic flow indicates severe congestion, Figure 1.

The VExUS score grades

VExUS score ranges from grades 0-3. In grade 0, non-dilated IVC [< 2 cm] indicates no congestion. In grade I, dilated IVC with normal or mild abnormal flow patterns indicate mild

congestion. In grade 2, dilated IVC with one severe abnormal flow pattern indicates moderate congestion. In grade 3, a dilated IVC with two or more severe abnormal flow patterns indicates severe congestion, Figure 2 [8, 9].

Sample size calculation:

We calculated the sample size based on an expected effect size, using G*Power with 80% power and a critical t-value of 1.6. We estimated the sample size using the formula $N=\frac{Z2.p.q}{d2}$. Z represents the standardized value for a 95% confidence level (1.96), p is the estimated proportion of the target population with the characteristic (0.03), q is 1 minus p, and d is the margin of error set at (0.05). Using these parameters, the required sample size was calculated to be 40 patients. The sample size was estimated using a proportion-based formula due to limited prior data on VExUS-related group differences in AKI or mortality in similar populations. While this method does not directly incorporate the expected change in primary outcome, it provided a feasible estimate for initial study planning.

Statistical Analysis

We analyzed data using SPSS version 26.0. We reported descriptive statistics for qualitative variables as frequencies and percentages and for quantitative variables as mean ± standard deviation (SD) for normally distributed data or median and interquartile range (IQR) for non-normally distributed data based on the results of the Shapiro-Wilk normality test. We used The Chi-squared test to assess relations between qualitative variables, One-way ANOVA to compare more than two samples with normally distributed data, while the Kruskal-Wallis test for non-normally distributed data. The normality of quantitative data was evaluated using the Shapiro-Wilk test. A P-value < 0.05 was considered statistically significant. To assess the diagnostic performance of the VExUS score $\geq$ 2 in predicting AKI development, the following metrics were calculated: sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), and diagnostic accuracy. Diagnostic accuracy was determined as the proportion of true positives and true negatives out of the total number of patients. Sensitivity was defined as the proportion of AKI patients correctly identified by the VExUS score ≥ 2, while specificity was the proportion of non-AKI patients correctly identified. The PPV and NPV were calculated to assess the likelihood that a positive or negative VExUS score accurately predicted AKI development. Statistical significance for these parameters was assessed using

appropriate tests, with 95% confidence intervals calculated for each estimate.

3. Results:

Baseline characteristics of the study subjects

The baseline demographic, comorbidities, clinical, and laboratory data were similar across the three groups: worsening, improving, and unchanged VExUS scores (Table 1). On admission, no significant differences were observed in APACHE II scores, SOFA scores, or serum creatinine levels across the VExUS groups. However, by Day 7, significant differences emerged. The "Worsening" VExUS group had higher SOFA scores (median 9, IQR: 5–13, P=0.01) and elevated serum creatinine levels (median 2.6 mg/dL, IQR: 1.2–3.5, P=0.039), reflecting worsening clinical status and renal function. These findings indicate that a worsening VExUS score is associated with the incidence of AKI.

VExUS score frequencies at different timelines and AKI development

Table 2 shows the relation between VExUS scores and AKI onset over seven days. On Day 1, most patients had VExUS 0 (37.5%) or VExUS 1 (42.5%), with no patients classified as VExUS 3. From Day 2 to Day 4, significant increases in VExUS scores were noted, particularly in AKI patients. By Day 3, 31.2% of AKI patients had VExUS 3 (P = 0.013). VExUS 1 predominated on Day 5, but the differences between AKI and non-AKI groups were no longer significant (P = 0.101). Elevated VExUS scores (VExUS 2 and 3) remained more common in AKI patients on Days 6 and 7. The findings underscore a strong association between higher VExUS scores and AKI, particularly in the early stages of septic shock. Furthermore, 50% of AKI-improving patients showed VExUS score improvement, while no improvement was seen in the AKI-worsening group (P = 0.036, Figure 2). While a higher proportion of patients with VExUS 3 scores were observed in the AKI group on Day 3, statistical evaluation of all VExUS categories across groups did not include pairwise comparisons.

Diagnostic Performance of VExUS ≥ 2 on admission for Predicting AKI

A VExUS score ≥ 2 on admission showed high specificity (83.3%) but low sensitivity (25%) for predicting AKI, with a PPV of 50%, NPV of 62.5%, and overall diagnostic accuracy of 60%. Although its sensitivity is limited, the score's specificity supports its utility in ruling out AKI and informing early clinical decisions in septic shock management.

Association of VExUS Scores with Volume Overload, Hemodynamic Parameters, and Clinical Outcomes

A worsening VExUS score was significantly associated with indicators of volume overload, higher CVP readings, greater cumulative fluid balance, and worse clinical outcomes. Patients in the worsening group had a higher prevalence of volume overload signs (e.g., pulmonary edema, pedal edema, ascites), elevated CVP particularly by Days 5 and 7, and significantly greater fluid accumulation. This group also showed higher rates of renal replacement therapy, longer durations of mechanical ventilation, and increased mortality, highlighting the clinical relevance of VExUS progression in septic shock management (Table 4).

4. Discussion:

Our study analyzed 40 adult patients with septic shock in ICU, revealing that those who developed AKI had significantly higher VExUS scores (VExUS 2 and 3) on Days 2, 3, 4, and 6 of admission. The correlation between AKI and higher VExUS highlights VExUS's role in early AKI prediction. Several studies support the prognostic value of VExUS scores in predicting AKI. Rola et al. [13] demonstrated that higher VExUS scores correlate with increased AKI risk in heart failure patients. Similarly, Viana-Rojas et al [14]. Assessed the association between VExUS score and AKI in patients with acute coronary syndrome (ACS) and found that patients with a VExUS score ≥1 significantly raised the risk of developing acute AKI (Odds ratio (OR) = 6.8, P = 0.001). Additionally, Beaubien-Souligny et al [15]. studied the predictability of AKI using VExUS with 145 patients who underwent cardiac surgery and showed that a VExUS score >1 at admission offered a useful positive likelihood ratio (+LR = 6.37) in predicting AKI in these patients, aligning with our findings. These studies demonstrate that elevated VExUS scores correlate with higher AKI risk across various patient populations such as those with ACS, heart failure, and post cardiac surgery. However, one study other than ours, focused on role of VExUS in prediction of AKI in septic shock patients. Prager et al [16]. Found that ICU Septic patients with venous congestion, as assessed by VExUS, had a higher risk of requiring renal replacement therapy (Hazard ratio (HR) = 3.35), though not statistically significant.

Our findings reinforce VExUS's efficacy in evaluating venous congestion and its renal function impact. Andrei et al [17].

which studied VExUS scores in 145 general ICU patients showed no significant association between admission VExUS >1 and AKI development (OR = 0.499, P = 0.136) in ICU patients. This suggests that VExUS may not be a good indicator of volume status in general ICU patients and that general ICU patients may have low susceptibility to developing severe systemic congestion, unlike our population which included patients with septic shock that have higher incidence of venous congestion and AKI. Additionally, they followed up patients for only 72 hours after admission, restricting the interpretation to this time window. Our study also studies the relation between VExUS scores and clinical course of AKI, but it was not statistically significant. This observation aligns with the findings of Bhardwaj et al, who studied 30 ICU patients with a provisional diagnosis of cardiorenal syndrome and found that AKI resolution correlated significantly with improved VExUS scores (P = 0.003) [8].

Rihl et al [18]. Demonstrated that guiding diuretic use based on VExUS scores led to significantly more renal replacement therapy-free days over 28 days in patients with severe AKI and that patients with higher initial VExUS scores who reduced their scores within 48 hours benefited the most. Furthermore, Bitar et al [19]. Assessed ExUS in 33 patients with sepsis and cardiorenal syndromes and found a link between AKI resolution and improvement in VExUS grades (P = 0.005). The diagnostic role of VExUS ≥2 on admission for predicting AKI development showed high specificity (83.3%) but low sensitivity (25%), suggesting it is a strong AKI indicator when present, but its absence does not rule out AKI.

A study by Natraj et al [6]. Found that a VExUS score>2 was associated with AKI following congenital heart surgeries and that a VExUS score >2 had a specificity of 84%, which supports our study findings.

This study found a strong link between worsening VExUS scores and signs of volume overload, such as pedal edema, pulmonary edema, and ascites, indicating VExUS's validity as a marker for fluid overload in septic shock. This ability to identify volume overload could help optimize fluid management and reduce AKI risk.

Our research showed lower cumulative fluid balance in patients with improving VExUS scores, aligning with findings from Bhardwaj et al [8]. which showed a significant association between fluid balance and VExUS scores in patients

with cardiorenal syndrome (P = 0.03) and Bitar et al. [19] showed a significant association between changes in VExUS grades and fluid balance (P = 0.006). This association between VExUS scores and fluid balance further supports its potential role in optimizing fluid management and preventing complications related to fluid overload. Central venous pressures (CVP), a traditional measure of fluid status, was significantly higher in patients with worsening VExUS scores on days 5 and 7 after admission, same as Menéndez-Suso et al [20]. which showed a significant association between VExUS scores and CVP elevation in critically ill children (P<0.001). This suggests that VExUS might offer additional insights beyond CVP for assessing fluid status in septic shock. Additionally, serum creatinine levels, a critical marker of renal function, were significantly elevated in patients exhibiting worsening VExUS scores by day 7 post-admission.

This aligns with findings from Gravina et al [21]. which reported a strong correlation between VExUS score changes and improvements in renal function metrics. These findings highlight the potentiality of VExUS as an effective tool for predicting AKI, enabling clinicians to adjust management strategies for patients at high risk. Worsening VExUS scores in the study were significantly associated with adverse clinical outcomes, including: increased rates of dialysis, mechanical ventilation,and higher mortality rates. This was consistent with Beaubien-Souligny et al [12]. showed a significantly increased mortality in patients with VExUS 2 (HR = 4.03, P<0.001), and VExUS 3 (HR = 2.7, P = 0.03), compared to patients with VExUS scores 0 and 1. These findings highlight the clinical relevance of VExUS in predicting and potentially preventing complications in septic shock. The ability of VExUS to identify patients at risk of adverse outcomes may facilitate the implementation of targeted interventions to improve prognosis.

Limitations:

One of the limitations of this study is related to the sample size calculation. The estimated sample size was based on a population proportion formula due to the lack of sufficient prior data regarding expected differences in primary outcomes such as AKI or mortality between VExUS score groups. Ideally, the sample size should be calculated based on the anticipated effect size of the primary outcome. However, in the absence of reliable reference data, a proportion-based approach was used to

ensure feasibility. Future studies with larger cohorts and more robust preliminary data are needed to allow for outcome-specific sample size estimations. Second, conducting the study at a single center could introduce selection bias. Additionally, the study did not assess the impact of interventions such as diuretics based on VExUS scores on clinical outcomes. Another limitation of this study is that the statistical analysis of VExUS scores was conducted across all categories collectively, without performing pairwise comparisons between each group. This approach may limit the ability to definitively assess the statistical significance of differences between specific groups definitively, especially for the VExUS 3 scores observed on Day 3. Future studies should consider incorporating pairwise analysis to provide more precise insights into group-specific differences We need further research to validate the prognostic value of VExUS scores across different populations and settings. Standardized protocols for VExUS assessment and training programs for healthcare providers could also enhance the accuracy and consistency of measurements.

5. Conclusion:

Our study highlights the significant association between VExUS scores and AKI development in septic shock patients. These findings underscore the role of venous congestion in AKI pathophysiology and using VExUS as a bedside tool for risk prediction and management in critically ill patients.

Declarations

Ethics approval and Consent to Participate

This study was conducted from January 2023 to March 2024 in the intensive care unit (ICU) at Menoufia University Hospitals, after obtaining informed written consent from the patient or patient's legal surrogates and the approval of the Institutional Review Board (IRB) of Menoufia University, Menoufia, Egypt (Approval No. 12/2022 ANES28) on December 1, 2022.

Data availability statement:

Data is available upon reasonable request from the corresponding author.

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Author contributions statement:

- Conception and study design: HME, GMF, YIF. Data collection: HME, MAA, GMF, ATH. Statistical analysis: HME, HAA, YIF. Interpretation of data: HME, HAA, YIF, GMF, ATH. Writing up the first draft of the paper: HME, MAA, GME. Critical revision of the manuscript: HME, HAA, YIF. Final approval of the manuscript: all authors.

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Table 1: Characteristics of the study Groups.

Variables		All patients (N = 40)	VExUS status (N = 40)			*P-value*
			Improving (N = 12)	Worsening (N = 12)	No change (N = 16)	
Sociodemographic data						
Age	Mean ± SD Min.–Max	52.9 ± 14.3 18 – 78	54.08± 19.05 18–72	56.9 ±13.4 32–78	48.9 ±10.28 32–67	0.151
Sex	Male, n (%) Female, n (%)	23 (57.5%) 17 (42.5%)	9 (75%) 3 (25%)	7 (58.3%) 5 (41.7%)	7 (43.8%) 9 (56.3%)	0.253
Weight	Mean ± SD Min.–Max.	82 ± 19 40 – 140	80.41 ± 22.7 40 –120	88.33± 21.77 65 –140	77.5± 13.5 60– 100	0.335
Comorbidities						
HTN	Yes, n (%)	9 (22.5%)	4 (33.3%)	2 (16.7%)	3 (18.8%)	0.557
DM	Yes, n (%)	15(37.5%)	5 (41.7%)	5 (37.5%)	5 (31.3%)	0.801
IHD	Yes, n (%)	4 (10%)	2 (16.7%)	1 (8.3%)	1 (6.3%)	0.644
Malignancy	Yes, n (%)	7 (17.5%)	1 (8.3%)	2 (16.7%)	4 (25%)	0.515
Clinical scores						
APACHEII	Median (IQR)	12 (10 – 14)	14 (11 – 15)	11 (10 – 13)	10 (10 – 13)	0.213
SOFA, Median (IQR)	Admission Day 7	9 (8 – 12) 4 (1 – 8)	9 (8 – 12) 1(1 – 4)	10 (8 – 12) 9 (5 – 13)	10 (8 – 11) 2 (1 – 7)	0.763 0.01*
Vital data						
MAP (mmHg)	Median (IQR)	49 (43 – 55)	53 (45 – 55)	48 (43 – 53)	49 (44 – 55)	0.689
Heart rate (bpm)	Mean ± SD	114 ± 22	112 ± 25	112 ± 18	116 ± 23	0.867
Respiratory rate (bpm)	Median (IQR)	28 (25 – 30)	27 (25 – 32)	28 (25 – 30)	27 (25 – 29)	0.812
SPO2 (%)	Median (IQR	92 (89 – 95)	90 (85 – 95)	91 (88 – 95)	92 (90 – 99)	0.255

Laboratory finding						
Serum creatinine (mg/dL) Median (IQR)	Admission Day 7	1 (0.9 –1.3) 1.2 (1 – 2.5)	1.2 (1 – 1.3) 1.1 (1 – 2)	1.2 (1 – 1.3) 2.6 (1.2 – 3.5)	1(0.8 – 1.1) 1.1 (1 – 1.4)	0.074 0.039*
Serum lactate (mmol/L) Median (IQR)	Admission Day 7	4.8 (4 – 6) 2 (1 – 4.5)	5.3 (4.2 – 6.1) 2 (1 – 4.3)	4.2 (4 – 6) 3.3 (1.9 – 5)	4.9 (4.2 – 6) 1.9 (1 – 4.3)	0.484 0.362
BUN (mg/dL)	Median (IQR)	40 (27 – 60)	40 (26 – 52)	45 (40 – 62)	31 (26 – 53)	0.201
Hb(g/dl)	Median (IQR)	11.1 (9.4 – 12.9)	12.3 (9.2 – 13.8)	10.3 (9 – 11.8)	11.2 (9.7 – 11.5)	0.426
Na (mEq/L)	Median (IQR)	137 (135 – 140)	140 (138 – 141)	135 (134 – 139)	136 (134 – 140)	0.098
K (mEq/L	Median (IQR)	4.7 (3.9 – 5.2)	5 (3.7 – 5.2)	4.9 (4.4 – 5.2)	4.1 (3.8 – 4.9)	0.133
CL (mEq/L)	Median (IQR)	118 (101 – 132)	115 (102 – 130)	129 (98 – 134)	116 (104 – 131)	0.965

VExUS: venous excess ultrasound score. HTN: hypertension. DM: diabetes millitus. IHD: ischemic heart disease. ABACHII: Acute Physiology and Chronic Health Evaluation II. SOFA: Sequential Organ Failure Assessment MAP: Mean arterial pressure. SPO2: Peripheral capillary oxygen saturation. Hb: Hemoglobin. BUN: Blood Urea Nitrogen. Na: sodium. K: potassium. CL: chloride * Significant (p value < 0.05).

Table 2: Frequency of VExUS scores and AKI development in all Study groups.

Variable		All patients (N = 40)	All patients (N = 40)		*P-value*
			AKI (N = 16)	No AKI (N = 24)	
Day 1	VExUS 0, n (%)	15 (37.5%)	4 (25%)	11 (45.8%)	0.491
	VExUS 1, n (%)	17 (42.5%)	8 (50%)	9 (37.5%)	
	VExUS 2, n (%)	8 (20%)	4 (25%)	4 (16.7%)	
	VExUS 3, n (%)	0 (0)	0 (0)	0 (0)	
Day 2	VExUS 0, n (%)	1 (2.5%)	0 (0)	1 (4.2%)	0.012*
	VExUS 1, n (%)	17 (42.5%)	3 (18.8%)	14 (58.3%)	
	VExUS 2, n (%)	16 (40%)	8 (50%)	8 (33.3%)	
	VExUS 3, n (%)	6 (15%)	5 (31.2%)	1 (4.2%)	
Day 3	VExUS 0, n (%)	2 (5%)	1 (6.3%)	1 (4.2%)	0.013*
	VExUS 1, n (%)	18 (45%)	4 (25%)	14 (58.3%)	
	VExUS 2, n (%)	15 (37.5%)	6 (37.5%)	9 (37.5%)	
	VExUS 3, n (%)	5 (12.5%)	5 (31.2%)	0 (0)	
Day 4	VExUS 0, n (%)	9 (22.5%)	1 (6.3%)	8 (33.3%)	0.028*
	VExUS 1, n (%)	12 (30%)	5 (31.2%)	7 (29.2%)	
	VExUS 2, n (%)	15 (37.5%)	6 (37.5%)	9 (37.5%)	
	VExUS 3, n (%)	4 (10%)	4 (25%)	0 (0)	
Day 5	VExUS 0, n (%)	6 (15%)	1 (6.3%)	5 (20.8%)	0.101
	VExUS 1, n (%)	20 (50%)	7 (43.8%)	13 (54.2%)	
	VExUS 2, n (%)	11 (27.5%)	5 (31.2%)	6 (25%)	
	VExUS 3, n (%)	3 (7.5%)	3 (18.8%)	0 (0)	
Day 6	VExUS 0, n (%)	8 (20%)	3 (18.8%)	5 (20.8%)	0.046*
	VExUS 1, n (%)	23 (57.5%)	6 (37.5%)	17 (70.8%)	
	VExUS 2, n (%)	6 (15%)	5 (31.2%)	1 (4.2%)	
	VExUS 3, n (%)	3 (7.5%)	2 (12.5%)	1 (4.2%)	
Day 7	VExUS 0, n (%)	16 (40%)	4 (25%)	12 (50%)	0.113
	VExUS 1, n (%)	12 (30%)	4 (25%)	8 (33.3%)	
	VExUS 2, n (%)	7 (17.5%)	4 (25%)	3 (12.5%)	
	VExUS 3, n (%)	5 (12.5%)	4 (25%)	1 (4.2%)	

Data are presented as numbers (N) (%). VExUS: venous excess ultrasound score.

AKI: acute kidney injury. * Significant (p value < 0.05).

Table 3: Diagnostic performance of VExUS ≥ 2 on admission and AKI development.

Diagnostic performance	Value	95% CI	
		Lower Limit	Upper Limit
Sensitivity	25%	7.3%	52.4%
Specificity	83.3%	62.6%	95.3%
Positive predictive value	50%	22.6%	77.4%
Negative predictive value	62.5%	54.4%	70%
Accuracy	60%	43.3%	75.1%

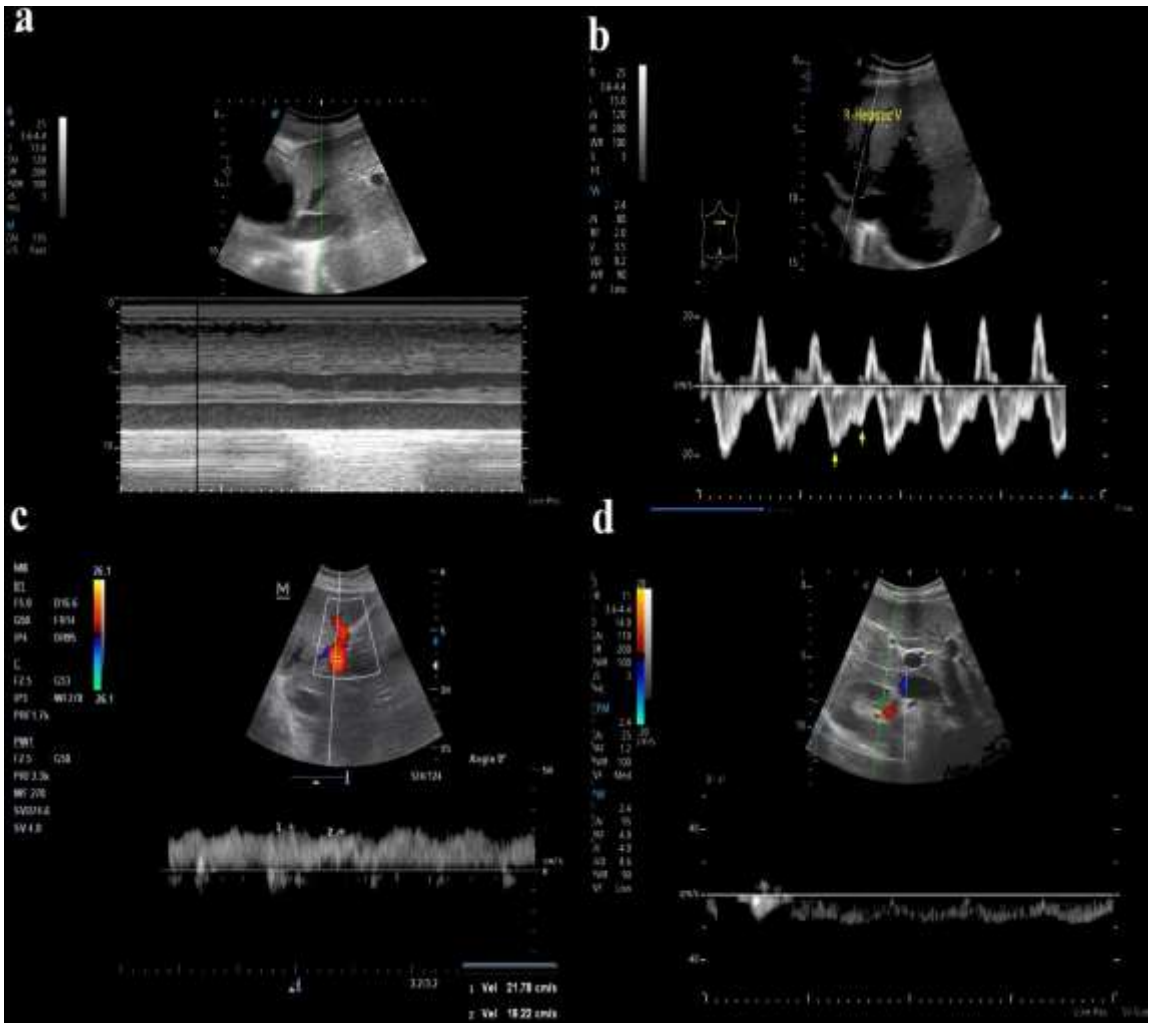
VExUS: venous excess ultrasound score. AKI: Acute kidney injury. CI: Confidence interval.

Table 4: The relation of the VExUS scores status and signs of volume overload, central venous pressure, cumulative fluid balance, morbidities, and mortality in all patients (N = 40)

Variable	All patients (N = 40)	VExUS status (N = 40)			*P value*
		Improving (N = 12)	Worsening (N = 12)	No change (N = 16)	
Signs of volume overload, N (%)	25 (62.5%)	6 (50%)	12 (100%)	7 (43.7%)	0.008*
Pulmonary edema, N (%)	14 (35%)	4 (33.3%)	8 (66.7%)	2 (12.5%)	0.016*
Pleural effusion, N (%)	13 (32.5%)	3 (25%)	7 (58.3%)	3 (18.8%)	0.077
Pedal edema, N (%)	23 (57.5%)	5 (41.7%)	11 (91.7%)	7 (43.8%)	0.018*
Ascites, N (%)	8 (20%)	0 (0)	7 (58.3%)	1 (6.3%)	0.001*
CVP (cmH2O), Mean ± SD					
1) Admission	10.6 ± 5.8	12.7 ± 5.4	12.4 ± 3.9	7.7 ± 6.4	0.031*
2) Day 3	13 ± 4.9	12.8 ± 3.2	14.8 ± 4.1	11.9 ± 6.2	0.308
3) Day 5	13.3 ± 4.5	13.2 ± 2.4	15.9 ± 3.7	11.6 ± 5.4	0.034*
4) Day 7	12.3 ± 4.9	10.3 ± 2	16.9 ± 3.1	10.4 ± 5.3	<0.001*
Fluid balance (mL), Median (IQR)	1950 (1200 – 2500)	1350 (-700 – 2000)	1800 (1450 – 2450)	2050 (1825 – 2750)	0.081
C. fluid balance (mL), Median (IQR)	4200 (1355 – 6575)	850 (-1950 – 3600)	6150 (4375 – 7980)	4550 (2350 – 6500)	0.005*
Clinical outcomes					
Needed dialysis, N (%)	7 (17.5%)	0 (0)	5 (41.7%)	2 (12.5%)	0.031¥*
Needed MV, N (%)	20 (50%)	8 (66.7%)	8 (66.7%)	4 (25%)	0.036*
Days on MV (days), Median (IQR)	1 (0 – 6)	2 (0 – 4)	7 (0 – 12)	0 (0 – 1)	0.019*
ICU stay (days), Median (IQR)	10 (8 – 14)	10 (8 – 14)	10 (8 – 14)	10 (7 – 14)	0.91
Mortality (died), N (%)	9 (22.5%)	1 (8.3%)	7 (58.3%)	1 (6.3%)	0.004¥*

VExUS: venous excess ultrasound score. CVP: central venous pressure. SD: standard deviation. IQR: interquartile range. C. fluid balance: cumulative fluid balance. MV: mechanical ventilation. P values followed by ¥ used Monte Carlo Test correction for the Chi-squared Test. *Statistically significant at P<0.05.

Figure 1: Steps for the venous excess ultrasound score. The tracing represents a normal patient with typical venous waveform patterns. This example is not from the study population.: Panel a: Measurement of the IVC diameter. Panel b: The hepatic veins with normal triphasic waveform. Panel c: Portal vein normal waveform pattern. Panel d: Interlobar veins, revealing a normal flow with a negative tracing



IVC: Inferior vena cava.

Figure 2: Vexus grading (9)

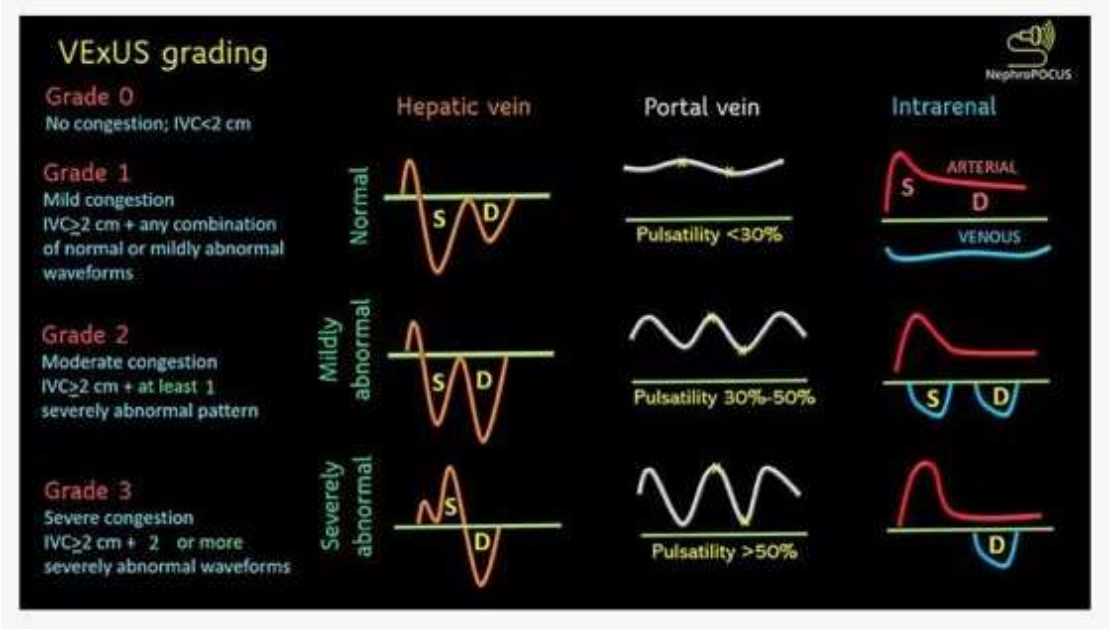
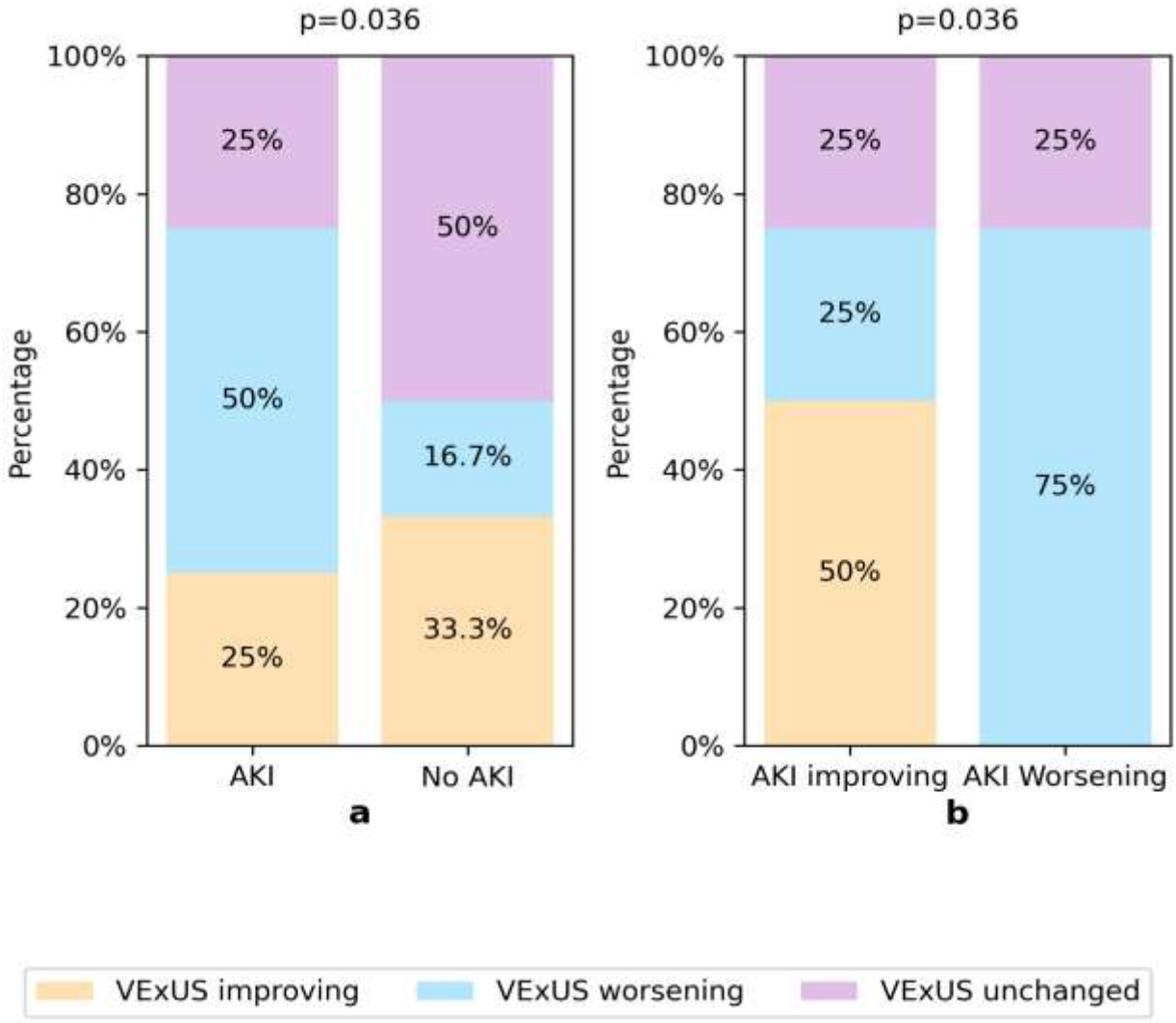


Figure 3: Frequency of VExUS scores in **a)** all study group (N= 40) and in **b)** patients who developed AKI (N = 16).



VExUS: venous excess ultrasound score. AKI: Acute kidney injury.