ORIGINAL ARTICLE

Cracking the Code of AKI: Evaluating the Predictive Power of VExUS Scoring in Critically Ill Noncardiac Patients

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Abstract

Background: Numerous signs of venous congestion exist, but each has limitations. Previous studies have shown the utility of venous excess ultrasound (VExUS) scoring in predicting acute kidney injury (AKI) in patients postcardiac surgery. This study aimed to evaluate whether serial VExUS scoring could predict AKI in intensive care unit (ICU) patients without cardiac conditions.

Materials and methods: This single-center observational study was conducted in the main ICU of PGIMER, Chandigarh, India. Thirty patients with an inferior vena cava (IVC) diameter of ≥2 cm and a normal biventricular function were included. Serial VExUS scoring was performed on admission and daily for up to six days or until AKI developed, whichever occurred first.

Results: Among 30 participants, 22 (73.3%) developed AKI. In the AKI group, mean VExUS scores were 1.95 on day 2, 1.92 on day 3, and 3.0 on day 5 ($p = 0.001$, 0.003, and 0.002, respectively). A significant positive correlation was observed between VExUS scores and fluid balance on day 2 ($\rho = 0.375$, $p = 0.041$) and day 3 ($\rho = 0.579$, $p = 0.006$). Multivariate analysis showed no correlation between the VExUS score on day 2 and fluid balance, duration of mechanical ventilation, or ICU length of stay. No association was found between VExUS scores and 30-day mortality.

Conclusion: In critically ill noncardiac patients, VExUS scores do not predict AKI onset. However, higher daily fluid balance may moderately correlate with VExUS scores.

Keywords: 2D Echocardiography, Acute kidney injury, Critical care, Intensive care unit, Mortality, Learning ultrasound in critical care.

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Highlights

- Fluid overload is a critical risk factor for acute kidney injury (AKI) and mortality in critically ill patients, often resulting from excessive fluid administration and third-space loss.
- Venous excess ultrasound (VExUS) has shown potential in predicting AKI in critically ill cardiac patients, and this study aims to explore its applicability in noncardiac patients.

Introduction

Fluid overload in critically ill patients is often caused by overzealous fluid administration and increased third-space loss. It is a significant risk factor for the development of AKI and has a considerable impact on mortality in those with AKI.[1–3]

Traditional clinical and radiological techniques for assessing fluid status have limitations, prompting the increased use of bedside lung ultrasound (USG) in critical care settings.[4,5] A systematic review of 20 studies on the caval index [inferior vena cava (IVC) collapsibility or distensibility] and six studies on IVC diameter found sensitivities of 71% and specificities of 75% for predicting fluid responsiveness.[6,7]

Doppler flow measurements in intra-abdominal vessels provide a novel method for assessing volume status and have been associated with venous congestion and subsequent end-organ damage.[8]

The VexUS score evaluates venous congestion by integrating USG assessments of the IVC, hepatic vein, portal vein, and renal vein. Previous studies have demonstrated its utility in predicting AKI in patients undergoing cardiac surgery and those with cardio renal syndrome.[8,9] However, its role in identifying AKI risk in critically ill noncardiac patients remains unexplored.

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Conflict of interest: None

This study hypothesized that the VExUS score could identify critically ill noncardiac patients at risk for AKI. The study was designed to evaluate the role of VExUS scoring in predicting AKI in this patient population.

Materials and Methods

It was a prospective observational study conducted from February 2022 to January 2023 in Main intensive care unit (ICU), Nehru Hospital, PGIMER Chandigarh, India. Institutional ethics committee approval (IEC-INT/2022/DM-244) and written informed consent were taken for the same. CTRI registration (CTRI/2022/10/046820) was done.

The study focused on critically ill noncardiac patients aged 18 years or older. Patients with known cardiac illness, chronic

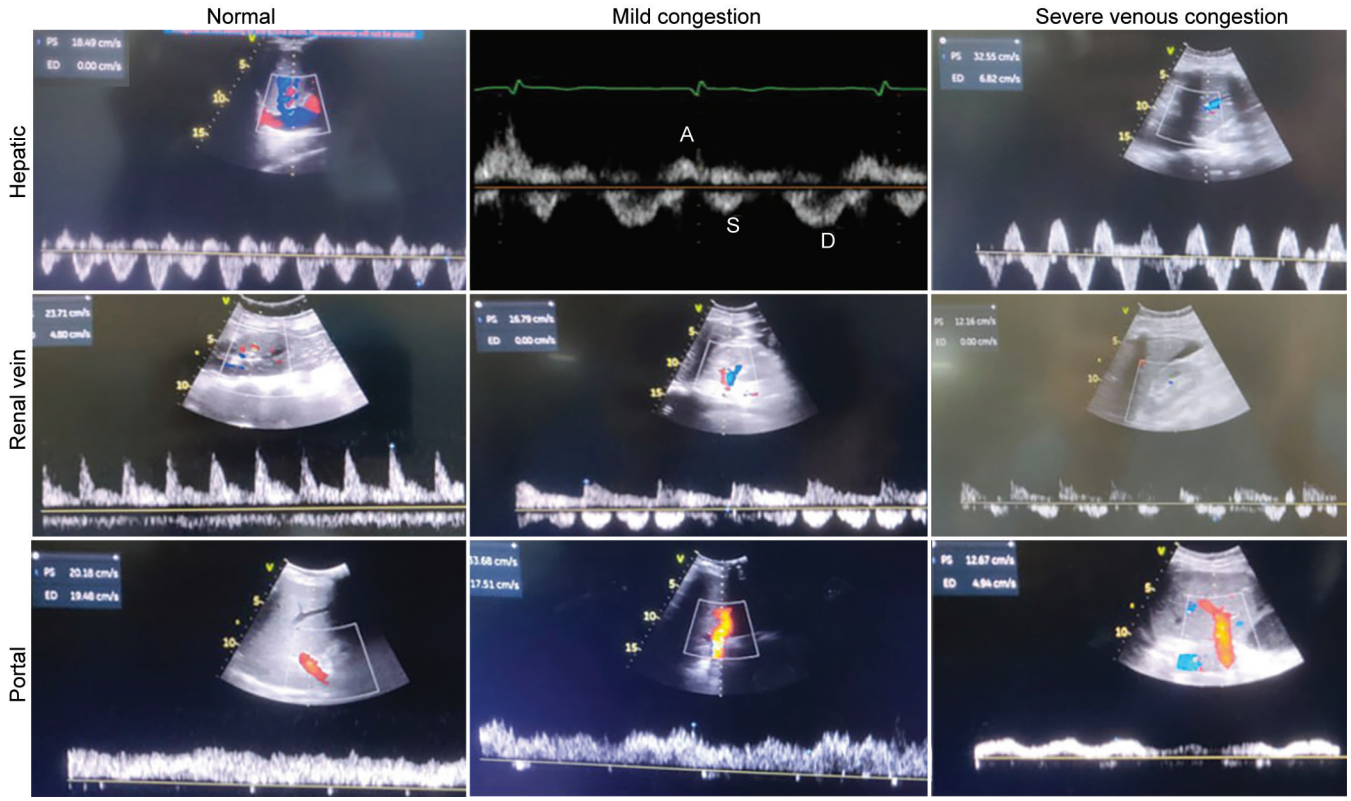

Fig. 1: Doppler ultrasound images demonstrating venous congestion patterns in hepatic, portal, and renal veins used for VExUS scoring in critically ill patients

kidney disease in failure (eGFR <15 mL/min/1.73 m^2), post-renal transplantation, pre-existing AKI, nephrotic syndrome, chronic liver disease with cirrhosis or portal hypertension, pancreatitis, IVC thrombus, inadequate USG windows, or those unwilling to undergo USG examination were excluded.

On admission, detailed data collection included patient demographics, body mass index (BMI), diagnosis, Acute Physiology and Chronic Health Examination (APACHE II) score, Glasgow coma score (GCS), mean arterial pressure (MAP), heart rate (HR), respiratory rate (RR), vasopressor use, PaO_2/FiO_2 (P/F) ratio, visual left ventricular ejection fraction (LVEF), tricuspid annular plane systolic plane excursion (TAPSE), IVC diameter, VExUS score, serum urea, and creatinine levels.

Serial VExUS scores were measured on the day of admission and subsequently on a daily basis for up to six days or until the patient developed AKI, whichever occurred earlier (Fig. 1). The scoring was performed in a manner similar to that described by Bharadwaj et al.[9] Daily assessments also included GCS, MAP, HR, RR, vasopressor use, P/F ratio, daily fluid balance, serum urea, creatinine, and acute kidney injury network (AKIN) stage.

The primary objective was to assess the association between serial VExUS scores and the development of AKI, as defined by the AKIN criteria. Additionally, the study evaluated correlations between VExUS scores and fluid balance, P/F ratio, duration of mechanical ventilation, ICU length of stay, Glasgow Outcome Score, and 30-day mortality.

Screening echocardiography was performed to exclude cardiac causes of venous congestion. Patients with a visually estimated LVEF ≥50% (normal LV function) and TAPSE ≥1.7 cm (normal RV function) were considered to have normal cardiac function. Patients with an IVC diameter of 2 cm or more underwent serial VExUS scoring, which included Doppler assessments of the hepatic, portal, and renal veins following established protocols.

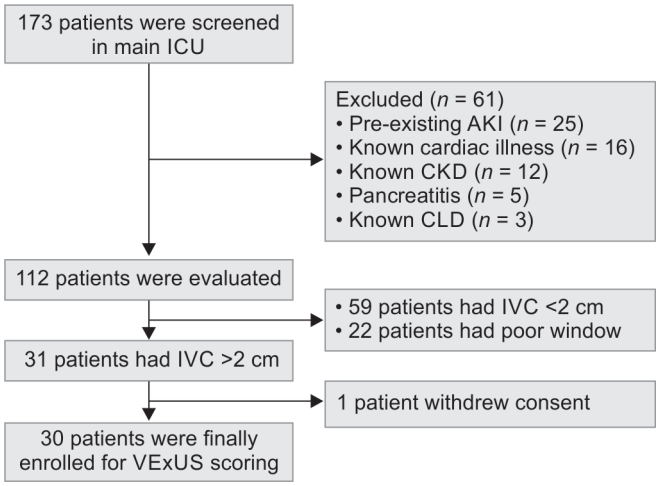

Fig. 2: CONSORT diagram

The study aimed to provide a comprehensive understanding of the role of VExUS scoring in predicting AKI and other critical outcomes in this patient population.

Results

Out of 173 patients screened, 30 met the inclusion criteria and were included in the final analysis (Fig. 2). Sociodemographic and

Table 1: Sociodemographic and clinical profile of patients in AKI and non-AKI groups

Parameters	Non-AKI (Group N) (n = 8) Mean ± SD or median (IQR)/ f (%)	AKI (Group A) (n = 22) Mean ± SD or median (IQR)/ f (%)	p-value
Age (years)	43.50 ± 18.59	41.95 ± 19.39	0.847
Sex			
M	4 (50)	10 (45.5)	1.000
F	4 (50)	12 (54.5)	
BMI	23.76 ± 3.16	24.04 ± 3.91	0.860
APACHE II score	16.38 ± 2.83	17.86 ± 4.97	0.433
Visual ejection fraction			
50–55	6 (75)	14 (63.6)	0.682
55–60	2 (25)	8 (36.4)	

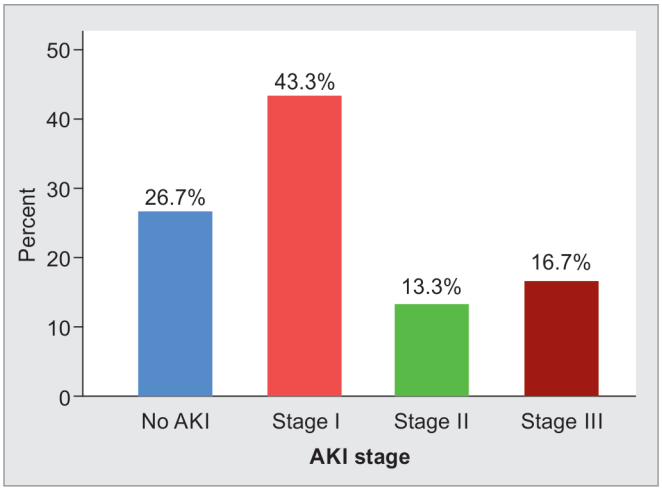

Fig. 3: Distribution of AKI stages among patients, based on AKIN criteria

clinical profile were comparable in both these groups (Table 1). Using the AKIN criteria, 73.3% (22/30) of patients were diagnosed with AKI, while 26.7% (8/30) did not develop the condition. Within the AKI group, 43.3% were classified as stage I, 13.3% as stage II, and 16.7% as stage III AKI (Fig. 3). Renal replacement therapy (RRT) was needed in 27.3% of AKI patients (6/22), while none in the non-AKI group required it. This difference, however, was not statistically significant.

Evaluation of the Association between Serial VExUS Scores and AKI Development in the AKI and Non-AKI Groups

The mean VExUS scores were significantly higher in the AKI group compared to the non-AKI group on days 2 (1.95 vs 1.0, $p = 0.001$), day 3 (1.92 vs 1.0, $p = 0.003$), and day 5 (3.0 vs 1.13, $p = 0.002$) (Table 2). The ROC analysis demonstrated that VExUS scores had a strong ability to distinguish between patients with and without AKI on days 2 and 3 (Table 3, Fig. 4). There was no significant correlation between day-wise VExUS scores and development of AKI (Supplement Table 1). The regression analysis showed that VExUS scores on both days had no statistically significant predictive value (Table 4).

Table 2: Comparison of mean VExUS scores among both the groups

Day-wise VExUS score	No AKI (n = 8)	AKI (n = 22)	p-value
VExUS day 1	1.13 ± 0.35	1.32 ± 0.57	0.378
VExUS day 2	1 ± 0	1.95 ± 0.49	0.001
VExUS day 3	1 ± 0	1.92 ± 0.76 (n = 13)	0.003
VExUS day 4	1 ± 0	1.33 ± 0.57 (n = 3)	0.104
VExUS day 5	1.13 ± 0.35	3 (n = 1)	0.002
VExUS day 6	1.13 ± 0.35	–	NC
VExUS day 7	1 ± 0	–	NC

NC, not calculated

Evaluation of the Association between Serial VExUS Scores and Key Clinical Metrics in the AKI and Non-AKI Groups

- *Fluid Balance:*
  On day 3, the fluid balance was significantly higher in the AKI group compared to the non-AKI group (1233.92 ± 280.33 mL vs 255.75 ± 436.93 mL, $p = 0.001$) (Supplement Table 2). Correlation analysis revealed a moderate positive association on day 2 ($\rho = 0.375$, $p = 0.041$) and a stronger association on day 3 ($\rho = 0.579$, $p = 0.006$) (Figure 5; Supplement Table 3). Linear regression analysis showed that a 1000 mL increase in fluid balance on day 3 (independent variable) led to a 0.001 increase in VExUS score (dependent variable) ($p = 0.009$) (Supplement Table 4).
- *P/F Ratio:*
  There was no significant correlation between VExUS scores and P/F ratios across all days, indicating no relationship with oxygenation status.
- *30-day Mortality:*
  Mortality rates were similar between AKI (50%) and non-AKI groups (37.5%, $p = 0.689$). ROC curve analysis on day 2 showed poor discriminative ability for mortality (AUC = 0.531, $p = 0.771$), and mean VExUS scores did not differ significantly between survivors and non-survivors (Supplement Table 5).
- *Duration of Mechanical Ventilation, ICU Stay, or Glasgow Outcome Score:*
  The duration of mechanical ventilation (35 ± 29.44 vs 25.50 ± 31.70 days), length of ICU stays (34 ± 29.31 vs 24.64 ± 31.21 days), and Glasgow Outcome Score (2.88 ± 1.89 vs 2.36 ± 1.62) were comparable in both the groups. Weak correlations observed between VExUS on day 2 and both ventilation duration ($\rho = -0.398$, $p = 0.03$) and ICU stay ($\rho = -0.369$, $p = 0.045$) were not predictive in regression models.

Discussion

Organ congestion, particularly in encapsulated organs like the kidney and liver, can result from fluid treatment that is not titrated according to the patient's volume status or from excessive third-space fluid loss. Acute kidney infection has been linked to venous congestion in previous investigations on VExUS in patients who had recently undergone cardiac surgery and those with cardiorenal syndrome.[8,9]

Table 3: Diagnostic accuracy of VExUS scores for predicting AKI: Area under the curve (AUC), optimal cut-off points, and corresponding sensitivity and specificity

Day-wise VExUS score	*AUC*	*SE*	*p-value*	*95% CI of AUC*		*Cut-off point of VExUS score*	*Sensitivity*	*Specificity*
				Lower bound	*Upper bound*			
VExUS day 1	0.577	0.114	0.527	0.354	0.800	>1	27.3%	87.5%
VExUS day 2	0.932	0.047	0.0001	0.841	1.000	>1	86.4%	100%
VExUS day 3	0.846	0.086	0.009	0.677	1.000	>1	69.2%	100%
VExUS day 4	0.667	0.212	0.414	0.252	1.000	>1	33.3%	100%
VExUS day 5	NC	NC	NC	NC	NC	NC	NC	NC
VExUS day 6	NC	NC	NC	NC	NC	NC	NC	NC
VExUS day 7	NC	NC	NC	NC	NC	NC	NC	NC

NC, not calculated

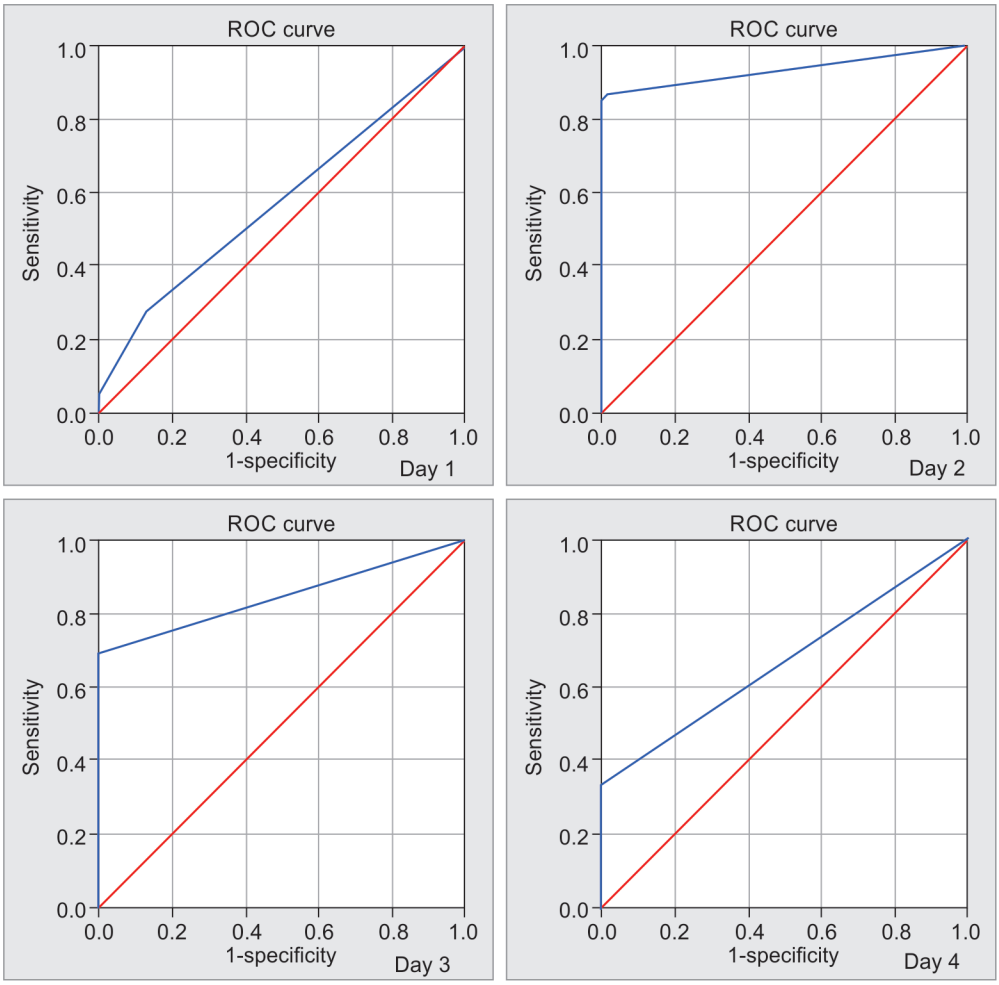

Fig. 4: Receiver operating characteristic (ROC) curves for VExUS scores from day 1 to day 4, illustrating the predictive ability of the VExUS score for AKI. The red diagonal line in each ROC curve represents the line of no discrimination (AUC = 0.5), indicating a model performing no better than random chance. The closer the ROC curve is to the upper left corner, the better the VExUS score's predictive performance for AKI on each respective day

Evaluation of the Association between Serial VExUS Scores and AKI Development in the AKI and Non-AKI Groups

Acute kidney infection was discovered in 22 (73.3%) of the study's 30 subjects. Contrasting prevalence was found in research by Beaubien et al. There are numerous factors contributing to this considerably higher incidence in our contexts.[8] First, despite increasing doses of vasopressors, we did not exclude patients with uncontrolled shock. Additionally, compared to individuals undergoing elective surgery, critically ill patients typically have a higher incidence of AKI.

Nearly half (43.3%) of the patients in the AKI group were classified as stage I (Fig. 3). Andrei et al. identified a similar distribution of patients, indicating that stage I AKI often affects the majority of patients.[10]

Mean VExUS score was significantly higher in the AKI group on days 2, 3, and 5 (Table 2). The ROC analysis demonstrated a

strong discriminative ability of VExUS scores for predicting AKI on days 2 and 3 (Figure 4). Subsequently, regression analysis was conducted to explore the relationship between VExUS scores and AKI development. Despite a good model fit, logistic regression revealed no significant predictive value for VExUS scores (Table 4). Andrei et al. in a similar study also demonstrated that there was no association between admission VExUS and AKI after logistic regression.[10]

It is notable that VExUS was initially investigated to predict AKI in a particular sample of cardiac surgery patients. Due to the underlying myocardial dysfunction, activation of the renin-angiotensin system, and susceptibility to both decreased forward cardiac output and backward congestion causing a decrease in the net renal perfusion pressure, these patients are more likely to develop AKI.

Beaubien et al. identified abnormal intrarenal Doppler findings and portal vein pulsatility as significant, independent predictors of AKI (8). In heart surgery patients, adding hepatic vein Doppler to these parameters led to the development of the VExUS score, which was also linked to an increased risk of AKI.[11] Bhardwaj et al. later analyzed the same cohort and found that 46.7% of patients developed AKI, with improvement in VExUS scores associated with AKI resolution.[9]

In our study, the VEXUS score was higher in the AKI group, though it was not statistically significant. Our findings can be understood by keeping in mind that the level of congestion is important. Moderate and severe congestion might not have the same effects on the kidneys.

Table 4: Logistic regression analysis of VExUS on day 2 and day 3 to predict AKI

Fitness of model	*Day 2*	*Day 3*
Cox and Snell R square	0.518	0.452
Nagelkerke R square	0.755	0.615
	p-value	*Odds ratio*
VExUS score	0.998	20.36
	0.998	12.19
Constant	0.998	0.000
	0.998	0.000

In the AKI group, mild congestion (VExUS score 1) was observed in 25 readings (41.0%), while moderate congestion (VExUS score 2) was the most frequent, accounting for 29 readings (47.5%) (Table 5). Severe congestion (VExUS score 3) was less common, recorded in only 7 readings (11.5%). Previous studies have suggested that mild congestion may not be predictive of AKI, which is consistent with the poor correlation observed in our findings.[10]

Acute kidney infection and admission VExUS scores did not significantly correlate, according to Andrei et al.[10] Acute kidney infection was not linked to moderate congestion or admission VExUS. They proposed a number of noncardiac causes of AKI, including iatrogenic, inflammatory, sepsis, anemia, and trauma. These patients are less susceptible to developing severe systemic congestion. Intensive care unit patients are frequently mechanically ventilated, and that may also have a bearing on the VExUS scoring. Its effects on patterns of portal vein pulsatility were studied by Huette et al. using different levels of positive pressure ventilation.[12]

In our study, hepatic and renal venous Doppler were mostly normal or showed only mild congestion. Portal vein Doppler, on

Table 5: Distribution of patients based on VExUS scores

No. of patients assessed each day	*Non-AKI*			*AKI*		
	Frequency (%)			*Frequency (%)*		
	VExUS score 1	*VExUS score 2*	*VExUS score 3*	*VExUS score 1*	*VExUS score 2*	*VExUS score 3*
Day 1 (*n* = 30)	7 (87.5)	1 (12.5)	–	16 (72.7)	5 (22.7)	1 (4.5)
Day 2 (*n* = 30)	8 (100)	–	–	3 (13.6)	17 (77.3)	2 (9.1)
Day 3 (*n* = 21)	8 (100)	–	–	4 (30.8)	6 (46.2)	3 (23.1)
Day 4 (*n* = 11)	8 (100)	–	–	2 (66.7)	1 (33.3)	–
Day 5 (*n* = 9)	7 (87.5)	1 (12.5)	–	–	–	1 (100)
Day 6 (*n* = 8)	7 (87.5)	1 (12.5)	–	–	–	–
Day 7 (*n* = 8)	8 (100)	–	–	–	–	–

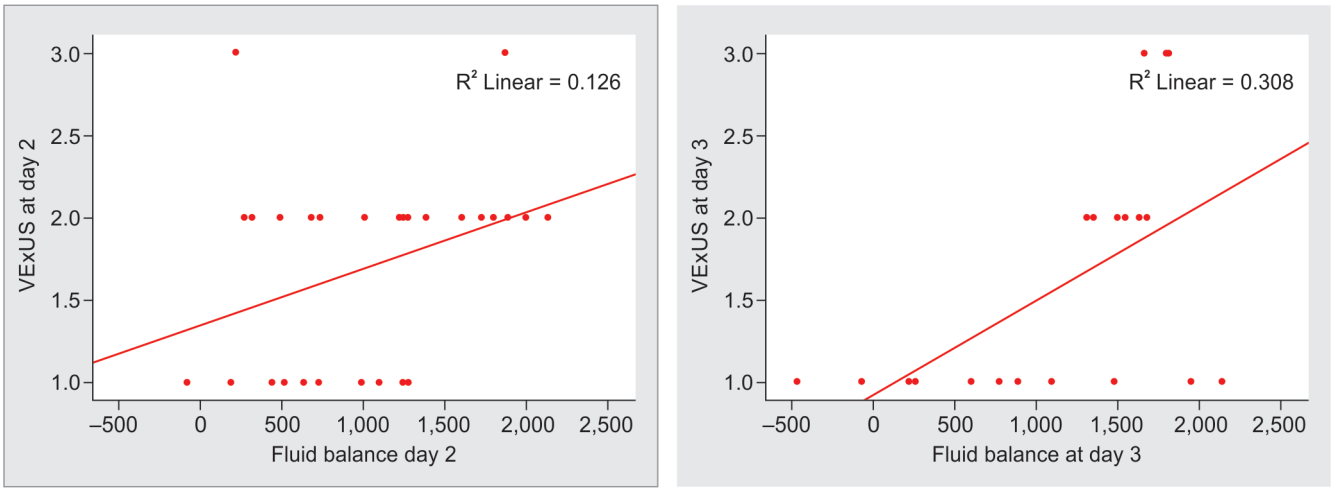

Fig. 5: A scatter plot illustrating the relationship between VExUS scores and fluid balance reveals a low positive correlation on day 2 ($R^2 = 0.126$) and a moderate correlation on day 3 ($R^2 = 0.308$). The data suggest that higher fluid balances are generally associated with elevated VExUS scores

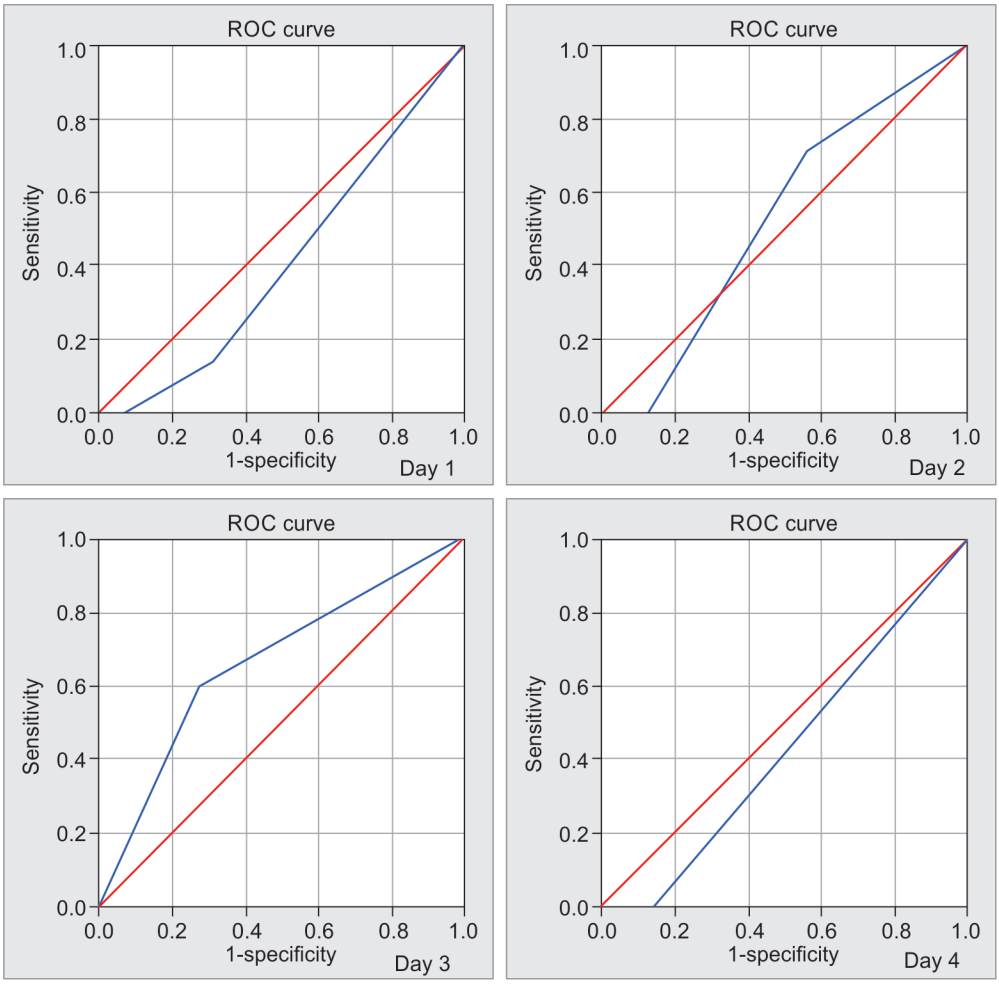

Fig. 6: ROC curves for VExUS scores from day 1 to day 4, illustrating the predictive ability of the VExUS score for mortality. The red diagonal line in each ROC curve represents the line of no discrimination (AUC = 0.5), indicating a model performing no better than random chance. The closer the ROC curve is to the upper left corner, the better the VExUS score's predictive performance for mortality on each respective day

the other hand, had a greater proportion of patients with visible severe congestion and thus was the main determinant (among all 3) of increased VExUS score. Spiegel et al. discovered, in contrast to this result, that anomalies of the hepatic and portal veins were both linked to a higher risk of MAKE 30.[13,14] Additionally, Beaubien et al. discovered that portal flow pulsatility was linked to severe changes in intrarenal venous flow and an elevated risk of AKI.[8]

This study highlights a high prevalence of AKI in critically ill patients, driven by their elevated baseline risk. VExUS scores on days 2 and 3 effectively identified AKI but had limited predictive value. Portal vein Doppler was the primary contributor to elevated VExUS scores, while noncardiac factors like sepsis and ventilation likely influenced AKI development, reducing the correlation with admission VExUS scores.

Evaluation of the Association between Serial VExUS Scores and Key Clinical Metrics in the AKI and Non-AKI Groups

Association between VExUS Scoring and Fluid Balance

By day 3, a significant difference in fluid balance emerged between the AKI and non-AKI groups, with the AKI group showing much higher levels (Supplement Table 2). The link between fluid overload and venous congestion became increasingly apparent by day 3 (Figs 5 and 6; Supplement Table 3), where each additional liter of fluid corresponded to a measurable rise in VExUS scores, indicating heightened congestion (Supplement Table 4). These findings are consistent with Bhardwaj et al.'s report of a strong association between fluid balance and VExUS grade changes and similar evidence linking cumulative fluid balance to severe portal flow congestion (odds ratio 1.27).[8,9]

This underscores the critical need for vigilant fluid management in critically ill patients to mitigate venous congestion and its adverse effects on kidney function.

Association between VExUS Scoring and 30-day Mortality

Among 30 patients, 14 (46.6%) died within the 30-day follow-up period, with similar mortality rates observed between AKI and non-AKI groups. Day 2 ROC curve analysis showed poor discriminatory ability for predicting mortality, and mean VExUS scores did not differ significantly between survivors and non-survivors.

Messmer et al. found a 1.19-fold increase in mortality per liter of fluid overload after 3 days in ICU, particularly in patients with AKI, sepsis, and post-surgery.[3] While earlier meta-analyses supported restrictive fluid management for reduced mortality in critically ill

patients, recent studies found no mortality benefit of restrictive over liberal fluid strategies in sepsis.[15,16] Andrei et al. reported no association between admission VExUS or VExUS >2 and 28-day mortality.[10]

Overall, mortality in the ICU is influenced by multiple factors, and mild congestion as indicated by VExUS scores may not be a significant determinant. Fluid balance and individualized management strategies remain critical for improving outcomes.

Association between VExUS Scoring and PaO_2/Fio_2 Ratio

In the study we conducted, there was no discernible correlation between the VExUS score and P/F ratio. Theoretically, a high VExUS score suggests severe congestion, which, given that the lung should also be congested, would lead to a decrease in PFR. However, we were unable to find any relevant literature to confirm or refute this hypothesis.

Association between VExUS Scoring and Other Outcome Parameters

A weak negative correlation was observed between the day two VExUS score and ICU stay duration and mechanical ventilation. Linear regression revealed no significant relationship between day two VExUS scores and fluid balance, mechanical ventilation, or ICU stay length. The negative correlation may stem from higher VExUS scores being associated with non-survivors, leading to shorter ICU stays and ventilation time. Further research is needed to clarify the relationship between VExUS and these outcomes, due to limited existing literature.

The fact that many patients with a higher VExUS score did not survive may be the cause of this negative link. As a result, less time was spent on mechanical breathing and in the ICU. Future research should concentrate on the association between VExUS and these outcome characteristics because there is insufficient literature on the subject.

Limitations

This study has several limitations. Out of 173 patients initially screened, only 30 were eligible for analysis, representing less than one-fifth of the total, which is a small sample size. Many patients were excluded due to pre-existing renal dysfunction (AKI/CKD) or known cardiac illnesses. Additionally, patients admitted to the ICU were often under-resuscitated, leading to non-distended IVCs, which further restricted the study population.

The study was conducted in a single center and focused on one ICU in the institution, limiting its generalizability to other critically ill noncardiac patient populations. Furthermore, while VExUS scoring is an emerging concept, limited existing literature restricts its validation, and more extensive studies are required to strengthen its clinical applicability.

The methodology for excluding cardiac patients relied solely on clinical history and biventricular function, which may lack precision. No inter-rater agreement was conducted to ensure the validity and reproducibility of echocardiography findings performed by the primary investigator. Additionally, the potential influence of diuretic use on VExUS scores was not accounted for, which could confound the results.

Another limitation was the lack of incorporation of critical clinical and therapeutic variables such as detailed fluid management strategies, vasoactive medication usage, and comorbid conditions. These factors could significantly impact venous congestion and clinical outcomes, and their exclusion limits the depth of interpretation and broader applicability of the findings.

Finally, as the study focused on short-term outcomes like AKI and 30-day mortality, it did not address longer-term impacts or complications, such as chronic kidney disease progression or overall recovery trajectories. Larger, multicenter trials with comprehensive data collection are required to further elucidate the role of VExUS in predicting clinical outcomes in this population.

Conclusion

In critically unwell noncardiac patients, the VExUS score cannot predict the onset of AKI. Higher daily fluid balance may have a low to moderate correlation with VExUS score. Poorer Glasgow outcome scores, longer durations of mechanical breathing, longer stays in the ICU, and higher 30-day mortality do not result from higher scores.

Clinical Significance

This study investigates the relationship between VExUS scoring and outcomes like AKI, fluid balance, and mortality in critically ill noncardiac patients. While higher VExUS scores on days 2 and 3 were linked to an increased risk of AKI, the score was not consistently predictive when adjusted for other factors. There was a moderate correlation between fluid overload and higher VExUS scores, suggesting potential use in guiding fluid management. However, due to a small sample size and several limitations, further research is needed to validate these findings.

Supplementary Material

The supplementary tables 1 to 5 are available online on the website www.ijccm.org.

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