JACC: ADVANCES VOL. 5, NO. 3, 2026

ORIGINAL RESEARCH

VExUS Point-of-Care Ultrasound Tool to Detect Changes in Volume Status

A Prospective Observational Study

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ABSTRACT

BACKGROUND Venous excess ultrasound score (VExUS) is an emerging point-of-care ultrasound tool to evaluate venous congestion using inferior vena cava (IVC) diameter and hepatic vein pulse-wave Doppler. The utility of VExUS to detect changes in intravascular volume is not well established.

OBJECTIVES The objective of the study was to investigate the ability of a standardized point-of-care ultrasound exam to capture dynamic changes in volume status.

METHODS This was a prospective observational study of inpatients with end-stage renal disease. Patients underwent VExUS exams before and after hemodialysis (HD). Patient with an IVC diameter <2 cm had a VExUS score of 0. For patients with an IVC diameter >2 cm, the scores of the component were totaled for a composite score. The primary outcome was change in composite VExUS score. A univariate linear regression analysis was used to evaluate for a linear relationship between the volume of fluid removed and change in composite VExUS score.

RESULTS Forty-six patients (92 paired ultrasound exams) were included. The median volume of fluid removed with HD was 2,000 mL (IQR: 985-2,500 mL). Wilcoxon signed-rank test of pre-HD and post-HD VExUS scores revealed a median score decrease of 1.5 (95% CI: 1-2; $P < 0.001$) on a VExUS scale ranging from 0 to 4. There was not a significant linear relationship between volume removed and change in VExUS score.

CONCLUSIONS Fluid removal with HD was associated with changes in the VExUS score, highlighting the utility of VExUS to capture dynamic shifts in intravascular volume in patients with end-stage renal disease. (JACC Adv. 2026;5:102538)

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The authors attest they are in compliance with human studies committees and animal welfare regulations of the authors' institutions and Food and Drug Administration guidelines, including patient consent where appropriate. For more information, visit the Author Center.

Manuscript received July 11, 2024; revised manuscript received December 15, 2025, accepted December 17, 2025.

ISSN 2772-963X https://doi.org/10.1016/j.jacadv.2025.102538

ABBREVIATIONS AND ACRONYMS

AKI = acute kidney injury

ASE = American society of echocardiography

AUC = area under the curve

ESRD = end-stage renal disease

HD = hemodialysis

IVC = inferior vena cava

ICI = IVC collapsibility index

RAP = right atrial pressure

RHC = right heart catheterization

VExUS = venous excess ultrasounds score

The evaluation of volume status is essential to clinical decision-making in the cardiac intensive care unit, yet multiple studies have shown that physical exam does not reliably estimate a patient's volume. Bedside assessments of intravascular volume remain subjective and often vary significantly between providers.[1-5] Invasive methods (ie, the direct measurement of central venous pressure via right heart catheterization [RHC]) remain the gold standard for the evaluation of intravascular congestion, but these approaches carry risk and additional expense and are not universally available. More importantly, such procedures cannot be performed serially at the bedside to inform clinical decisions such as the initiation or discontinuation of diuresis or renal replacement therapy.[6,7] Even indwelling pulmonary artery catheters, which can be used for serial monitoring over time, are associated with added cost and risk of complications.[8,9] As we move toward the personalization of care for critically ill patients with conditions such as decompensated heart failure, it is increasingly pressing to develop a standardized point-of-care method for evaluating volume status that can inform clinical decision-making in real time.[10-17]

Venous excess ultrasound score (VExUS) is an emerging volume assessment tool that uses inferior vena cava (IVC) diameter and pulse-wave Doppler waveforms of the portal, hepatic, and renal veins to evaluate venous congestion (**Figure 1**). A point-of-care ultrasound exam initially developed by Beaubien-Souligny et al,[19] VExUS represents a reproducible, noninvasive, and accurate means of assessing venous congestion. This four-point examination has been shown to surpass the limits of other bedside ultrasound exams (eg, measurement of IVC diameter alone) and to correlate with clinically relevant outcomes, such as the development of acute kidney injury (AKI) in postcardiac surgery patients and patients with acute coronary syndrome.[19-21]

More recently, VExUS has been validated against RHC.[21,22] Although VExUS scores were shown to correlate with elevated cardiac filling pressures (ie, right atrial pressure [RAP] and pulmonary capillary wedge pressure) at a static point in time, the ability of VExUS to capture dynamic changes in volume status is less established, particularly in patients with end-stage kidney disease.

The objective of this analysis was to evaluate the ability of the VExUS exam to appraise rapid changes in a patient's hemodynamic state, particularly venous congestion. We hypothesized that paired VExUS examinations performed before and after hemodialysis (HD) would reflect changes in venous congestion in an inpatient population.

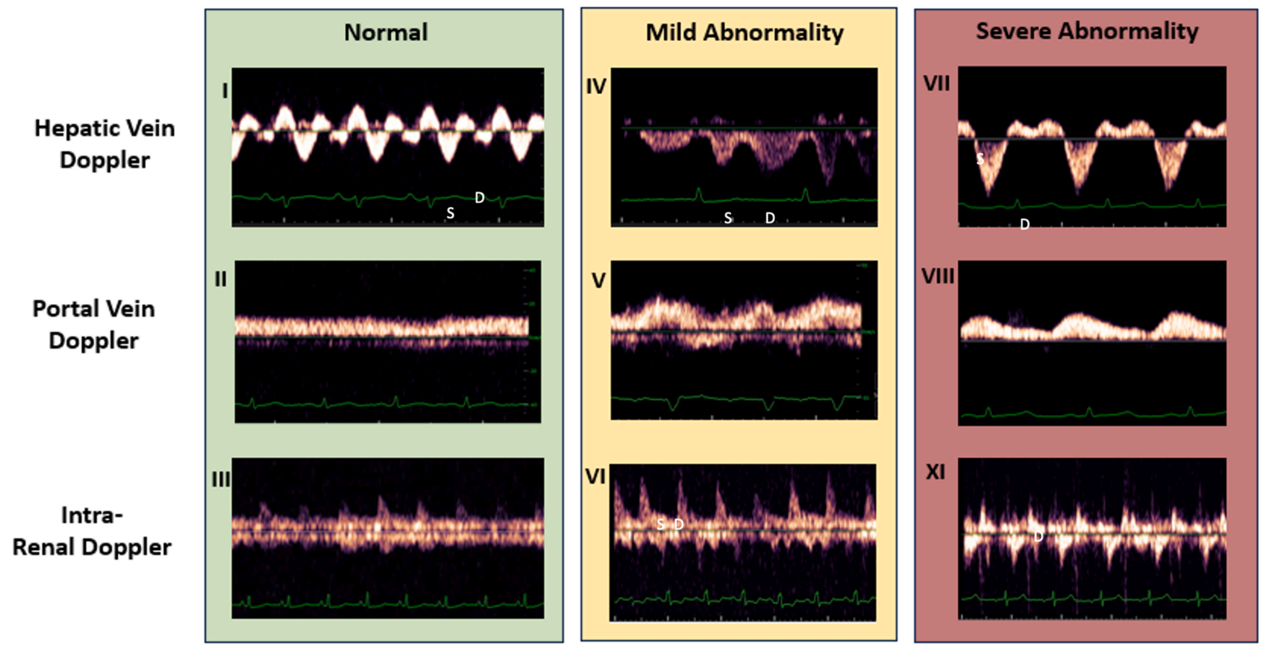
METHODS

ENROLLMENT AND IMAGE ACQUISITION. This study received ethical approval from the local Colorado Multiple Institutional Review Board (#22-2024). Inpatients with end-stage renal disease (ESRD) scheduled to undergo intermittent HD at 2 tertiary medical centers near Denver, Colorado, were screened for enrollment in this study from May to December 2023. Inclusion criteria were inpatient admission, age >18 years, scheduled HD, and ability to provide informed consent. Exclusion criteria included pregnancy, continuous renal replacement therapy, presence of an open abdominal wound, incarceration, and inability to provide informed consent. Patients undergoing invasive mechanical ventilation were also excluded for this analysis so as to eliminate the confounding effect of positive pressure ventilation.

Clinical characteristics of enrolled patients were obtained via chart review and stored in a secure database. ESRD etiology was determined by reviewing clinical documentation from nephrology advanced practice providers, fellow physicians, or attending physicians. Etiologies were not considered mutually exclusive, and more than one etiology was recorded for patients with multiple contributors to their renal disease. Left ventricular ejection fraction was determined from transthoracic echocardiogram reports, considering only echocardiograms obtained within the past 5 years. If more than 1 transthoracic echocardiogram report was available, the left ventricular ejection fraction value from the most recent report was used. Given that this was historical clinical data, the method of left ventricular ejection fraction estimation was at the discretion of the interpreting cardiologist. Left ventricular ejection fraction was estimated by Simpson's biplane, Simpson's single plane, or visual estimation. Echocardiograms and ejection fraction data were available for 93% of patients included in the final analysis. Image graders were blinded to recorded clinical characteristics, as images were assigned a unique identifier.

Enrolled patients were evaluated with 2 transabdominal VExUS and lung ultrasonography exams—1 before and 1 after same-day HD. Exams were performed in the patient's hospital room, either in the intensive care unit or on the inpatient ward. VExUS exams were performed using the standardized protocol previously described.[19,21] In patients who had

FIGURE 1 Representative Pulse-Wave Doppler Waveforms for Each Venous Excess Ultrasound Component



Any patient whose IVC diameter is <2 cm is assigned a VExUS score of 0, indicating no venous congestion. For any patient who has an IVC diameter >2 cm, the scores of the component parts are totaled to compute a composite score. Any combination of normal and mildly abnormal scores is assigned a VExUS score of 1, indicating mild venous congestion. Any patient with 1 severely abnormal waveform is assigned a VExUS score of 2, indicating moderate congestion. Two or more severely abnormal waveforms results in a VExUS grade of 3, indicating severe congestion.[18]

received a prior renal transplant, either of the native kidneys was scanned, but the transplanted kidney was not given that the anastomosis of the renal vein of a transplanted kidney to the iliac vein (rather than the IVC) is likely to confound the interpretation of renal Doppler waveforms. Lung ultrasonography was performed using a standardized protocol that involved ultrasonographic examination of 8 lung zones—4 anterior zones and 2 lateral zones on each side—to evaluate for the presence of B-lines (ie, vertical sonographic lines that can indicate the presence of interstitial edema).[23] A lung zone that contained >3 B-lines was considered positive for B-lines.[24] Sonographers recorded the number and distribution of lung zones with positive B-lines while performing both pre-HD and post-HD ultrasound exams. Each patient was asked to report the severity of their dyspnea on a numeric rating scale ranging from 1 (“no shortness of breath”) to 5 (“difficult to breath at all”). Patient-reported dyspnea scores were recorded by sonographers as they were conducting the ultrasound exam.

The sonographers were internal medicine resident physicians who had undergone a 4-h online training course in VExUS, followed by at least 2 in-person training sessions with physicians with experience performing the VExUS exam. There were 7 sonographers in total, and the same sonographer did not necessarily perform both the pre-HD and the post-HD VExUS exam for each patient, given that our group recently demonstrated that the VExUS exam has a high degree of interuser reproducibility (high level of consistency between exams performed by different sonographers) when sonographers are trained in this manner (intraclass correlation coefficient 0.8 and Light’s Kappa Statistic 0.63 for overall VExUS grade, indicating substantial agreement between sonographers).[25] Members of the research team were not part of the patients’ clinical team, and study data were not made available to enrolled patients or to clinical team members. Acquired images were anonymized and uploaded to a secure database.

IMAGE INTERPRETATION. VExUS exams were graded by readers blinded to the patient’s clinical status. Images were each assigned a unique identifier. Image readers were able to identify patients only by this identifier and did not have a way to associate the images with the patient's clinical record. The interpretation team was comprised of internal medicine resident physicians who were proficient in the VExUS exam and had completed a 4-video imaging course on VExUS interpretation. In a recent study of the inter-rater reliability, (degree of consistency in grade assigned between exam readers) of VExUS, our group found a high level of agreement when image interpreters were trained in this manner (intraclass correlation coefficient 0.83 and Light's Kappa Statistic 0.71 for overall VExUS grade).[25] The interpretation team did not participate in image acquisition. Images were interpreted and scored according to the standardized protocol previously described by Beaubien-Souligny et al[19] and used in the RHC validation study by Longino et al[21] Graders assigned a score to each component of the VExUS exam in addition to determining a composite score and an image quality score.

OUTCOMES. The primary outcome was change in composite VExUS score before and after HD, termed delta VExUS. Delta VExUS grade was calculated as pre-HD VExUS score minus post-HD VExUS score, so that a positive delta VExUS grade represents a decrease in composite VExUS score after HD. The secondary outcomes were change in any of the components of the VExUS score. Components of the VExUS score include IVC diameter, hepatic vein pulse-wave Doppler waveform, portal vein pulse-wave Doppler waveform, and renal vein pulse-wave Doppler waveform. Pulse-wave Doppler waveforms were determined to be normal, mildly abnormal, or severely abnormal based on the directionality and relative height of the systolic and diastolic waves (Figure 1) as detailed in the seminal publication of Beaubien-Souligny et al, originally describing the VExUS method. For the hepatic vein, a normal waveform (indicating no vascular congestion) is negative (away from the probe) in both systole and diastole, with the velocity of the systolic waveform exceeding that of the diastolic waveform. Systolic flow reversal in the hepatic vein indicates a severely abnormal waveform. A normal portal vein waveform (indicating lack of vascular congestion) is continuous and nonpulsatile, whereas increasing degrees of pulsatility indicate increasingly abnormal waveforms. A normal renal vein waveform is characterized by continuous flow throughout the cardiac cycle with only a brief interruption of venous flow during atrial contraction. Discontinuous flow in the renal vein is abnormal, with discontinuous biphasic flow (with distinct systolic and diastolic components) representing a mildly abnormal pattern and predominantly diastolic flow representing a severely abnormal pattern (severe venous congestion).

Any patient whose IVC diameter is $<$2 cm was assigned a VExUS score of 0, indicating no venous congestion. For any patient who has an IVC diameter $>$2 cm, the scores of the component parts are totaled to compute a composite score. Any combination of normal and mildly abnormal scores is assigned a VExUS score of 1, indicating mild venous congestion. Any patient with 1 severely abnormal waveform is assigned a VExUS score of 2, indicating moderate congestion. Two or more severely abnormal waveforms results in a VExUS grade of 3, indicating severe congestion. Image quality was assessed using an ordinal scale from 1 ("uninterpretable") to 5 ("unambiguously high quality"). Images with a quality score $<$3 were excluded from the analysis. A sample of images was reviewed and interpreted by 2 graders to ensure consistency in image scoring.

STATISTICAL ANALYSES. Descriptive characteristics of the study cohort were summarized as median and IQR for continuous variables. For categorical variables, descriptive statistics were summarized as frequency and percentage. The minimum IVC diameter (IVC_{min}) (ie, IVC diameter measured on inspiration) and maximum IVC diameter (IVC_{max}) were measured as part of each VExUS exam and used to calculate IVC collapsibility indices (ICIs) using the formula $ICI = (IVC_{max} - IVC_{min})/IVC_{max}$.[26] The Shapiro-Wilk test was used to assess normality of VExUS grade results. The Wilcoxon signed-rank test was then used to detect differences between pre-HD and post-HD VExUS scores (including both composite and component scores), B-line scores, patient-reported dyspnea scores, and pre-HD and post-HD IVC diameters and ICIs. A univariate linear regression analysis was used to evaluate for a linear relationship between the volume of fluid removed and change in composite VExUS score. All calculations were performed in R (version 4.3.2, R Foundation for Statistical Computing) and RStudio (version 2023.12.1 + 402, RStudio, Inc). A predetermined P value of $<$0.05 was considered statistically significant for all calculations.

RESULTS

STUDY POPULATION. Fifty-six patients were screened for inclusion in the study, and 10 were excluded due to insufficient image quality or incomplete exams. Ninety-two paired VExUS exams were included in the final analysis. The mean age of all subjects was 60 ± 14.87 years. Twenty-six (57%)

TABLE 1 Clinical and Demographic Characteristics of the Study Population (N = 46)

Sex	
Male	26 (57%)
Female	20 (43%)
Age	60 (49-65)
Body mass index	25.9 (23.5-28.6)
ESRD etiology	
Hypertension	2 (4.3%)
Diabetes	15 (33%)
Autoimmune	6 (13%)
Other	13 (28%)
Unknown	13 (28%)
Comorbidities	
History heart failure with reduced ejection fraction	10 (22%)
History of myocardial infarction	6 (13%)
History of chronic obstructive pulmonary disease	6 (13%)
History of pulmonary hypertension	12 (26%)
History of cirrhosis	4 (8.7%)
Charlson Comorbidity Index	5 (3-7)

Values are n (%) or median (IQR). ESRD etiologies were determined based on documentation by the nephrology fellow or attending physician. Etiologies were not mutually exclusive, and more than one etiology was recorded for patients with multiple contributors to their renal disease.

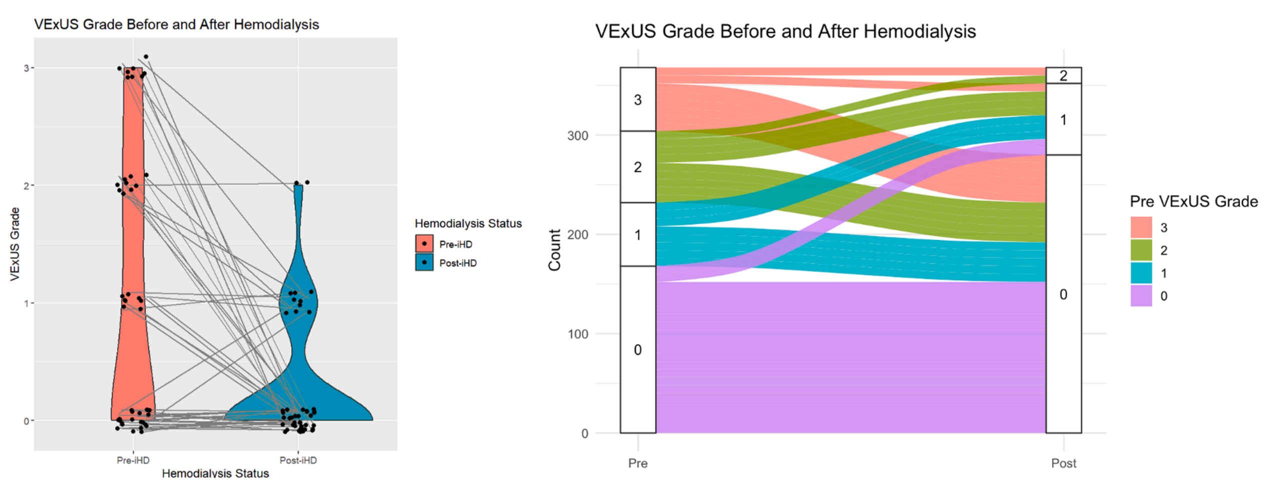
ESRD = end-stage renal disease.

were males, and 20 (43%) were females. The most common comorbidity was pulmonary hypertension (26%), followed by heart failure with reduced ejection fraction (22%). Patients with both AKI with unknown renal recovery and diagnosed ESRD were screened for inclusion in this study. All 46 patients included in the final analysis carried a diagnosis of ESRD, and the most common ESRD etiology was diabetes mellitus (32.6%). The mean Charlson Comorbidity Index for all included patients was 5 (range 3-7) (Table 1). None of the patients enrolled in this study were undergoing positive pressure ventilation.

PAIRED PRE-HD AND POST-HD VExUS SCORES. The volume of fluid removed with HD ranged from zero to 4,000 mL, with a median fluid removal of 2,000 mL (IQR: 985-2500 mL). The median VExUS score before HD was 1 (IQR: 0-2), and the mean VExUS score after HD was 0 (IQR: 0-0) (Figure 2). Nearly half of patients (46% or n = 21) had a VExUS grade of 0 before HD, indicating an absence of venous congestion. A smaller portion of patients demonstrated mild or moderate congestion, with 17% having a pre-HD VExUS grade of 1 and 20% having a pre-HD VExUS grade of 2. Only 17% of patients had severe venous congestion (as indicated by a VExUS grade of 3) before HD. After HD, 76% of patients had a VExUS grade of 0, 20% had a VExUS grade of 1, and 4.3% had a VExUS grade of 2. There were no patients with a VExUS grade of 3 (ie, severe venous congestion) following HD (Table 2).

The distribution of delta VExUS scores (change in VExUS score before and after HD) is presented in Table 3 and was assessed for normality using a Shapiro-Wilk test. The Shapiro-Wilk test was significant with a p value of <0.05, suggesting a

FIGURE 2 Venous Excess Ultrasound Grades Before and After Hemodialysis



Matched pre-HD and post-HD VExUS grades. Wilcoxon signed-rank analysis of pre-HD and post-HD VExUS scores revealed a significant change in VExUS scores (estimated shift of 1.5 (95% CI: 1-2; $P < 0.001$). HD = hemodialysis; VExUS = venous excess ultrasound.

TABLE 2 Distribution of Pre-HD and Post-HD VExUS Scores (N = 46)

	Pre-HD	Post-HD
Maximum IVC diameter	2.01 (1.57-2.27)	1.88 (1.43-1.99)
Minimum IVC diameter	1.55 (0.94-1.87)	1.22 (0.74-1.75)
Hepatic vein status		
Normal	16 (35%)	30 (65%)
Mildly abnormal	10 (22%)	9 (20%)
Severely abnormal	15 (33%)	4 (8.7%)
Unable to assess	5 (11%)	3 (6.5%)
Portal vein status		
Normal	18 (39%)	30 (65%)
Mildly abnormal	8 (17%)	10 (22%)
Severely abnormal	16 (35%)	2 (4.3%)
Unable to assess	4 (8.7%)	4 (8.7%)
Renal vein status		
Normal	18 (39%)	26 (57%)
Mildly abnormal	7 (15%)	2 (4.3%)
Severely abnormal	4 (8.7%)	18 (39%)
Unable to assess	17 (37%)	0 (0%)
VExUS grade		
0	21 (46%)	35 (76%)
1	8 (17%)	9 (20%)
2	9 (20%)	2 (4.3%)
3	8 (17%)	0 (0%)

Values are median (IQR) or n (%). Including both component scores and composite VExUS scores. None of the subjects were severely congested (VExUS grade 3) after HD.

HD = hemodialysis; IVC = inferior vena cava; VExUS = venous excess ultrasound.

non-normal distribution. The Wilcoxon signed-rank testing of pre-HD and post-HD VExUS scores revealed a statistically significant difference in VExUS grade before and after HD, with an estimated shift of 1.5 (95% CI: 1-2; $P < 0.001$) (**Central Illustration**). Although there were significant differences in IVC diameter before and after HD, there was no significant change in ICI. The median pre-HD IVC_{min} was 1.55 cm (IQR: 0.94-1.87 cm) compared to a median post-HD IVC_{min} of 1.22 cm (IQR: 0.74-1.75 cm), and the median pre-HD IVC_{max} was 2.00 cm (IQR: 1.57-2.27 cm) compared to a median post-HD IVC_{max} of 1.88 cm (IQR: 1.43-1.99 cm) ($P = 0.048$). The estimated shift in IVC_{min} and IVC_{max} were 0.23 cm ($P = 0.016$; 95% CI: 0.06-0.41 cm) and 0.21 cm ($P = 0.04$; 95% CI: 0.01-0.38 cm), respectively. The median ICI was similar pre-HD (0.28, IQR: 0.15-0.41) and post-HD (0.35, IQR: 0.17-0.49). The estimated ICI shift was −0.05 ($P = 0.26$; 95% CI: -0.130 to 0.03).

TABLE 3 Delta VExUS Grade (N = 46)

−1	2 (4.3%)
0	23 (50%)
1	9 (20%)
2	6 (13%)
3	6 (13%)

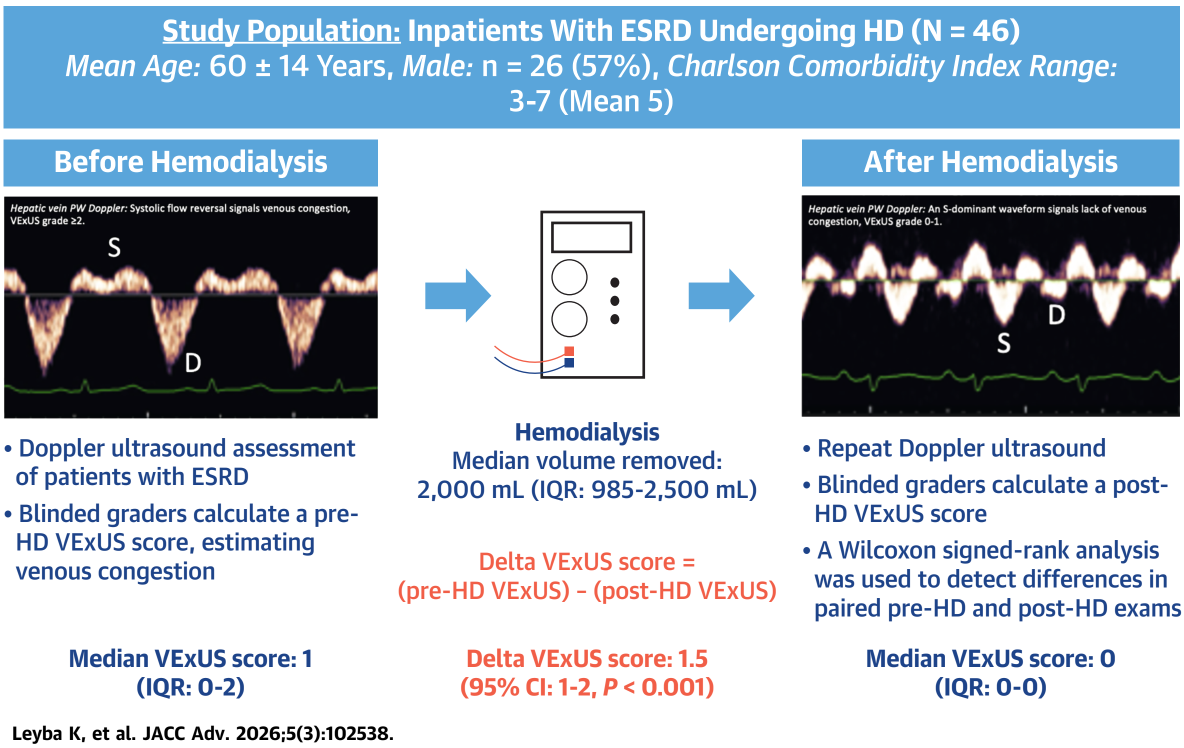
Values are n (%). Delta VExUS grade was calculated as pre-HD VExUS score minus post-HD VExUS score, so that a positive delta VExUS grade represents a decrease in composite VExUS score after HD.

Abbreviations as in Table 2.

The individual components of hepatic vein VExUS score and portal vein VExUS score significantly decreased after HD, with median pre-HD scores of 1 (IQR: 0-2) and 1 (IQR: 0-1) for both components. The median post-HD scores were 0 (IQR: 0-1) ($P = 0.002$ by Wilcoxon signed-rank test with estimated shift 1.0, 95% CI: 0.99-1.5) and 0 (IQR: 0-0.75) ($P < 0.001$ by Wilcoxon signed-rank test with estimated shift 0.5, 95% CI 2-0.5), for hepatic vein and portal vein VExUS scores, respectively. There was a statistically significant increase in renal venous VExUS score before and after HD. The median renal venous score before HD was 0 (IQR: 0-0), and the median score after HD was 0 (IQR: 0-2), with an estimated shift of −0.5 (95% CI: -2 to −0.5) by Wilcoxon signed-rank test ($P = 0.005$). Pre-HD and post-HD component and composite VExUS scores are further outlined in **Table 2**. There was no significant linear relationship between the volume of fluid removed and change in composite VExUS score assessed via a univariate linear regression analysis ($P = 0.25$; slope −194.7; 95% CI: -529.4 to 140.0). The mean difference in B-line score following HD was 0.8 ($P = 0.001$). There was no statistically significant difference in subjective dyspnea score before and after HD ($P = 0.410$).

Given the incongruency of the renal component of the VExUS score with composite VExUS score—as well as the precedent of excluding renal venous Doppler assessments in prior studies of patients with ESRD given the strong potential for dampened and unreliable waveforms in atrophic kidneys—we conducted a post hoc sensitivity analysis by calculating a modified VExUS score, which was a combination of the hepatic vein and portal vein scores only to assess for pre-HD and post-HD change.[27-29] Renal images were excluded from this modified VExUS score. We compared pre-HD and post-HD modified VExUS scores using the nonparametric Wilcoxon signed-rank test. The mean modified VExUS score before

CENTRAL ILLUSTRATION Venous Excess Ultrasound Score Changes With Volume Removal During Hemodialysis



The VExUS exam is a point-of-care ultrasound exam that objectively measures venous congestion using pulse-wave (PW) Doppler. In this investigation, we performed VExUS exams before and after patients with end-stage renal disease (ESRD) received hemodialysis (HD), demonstrating that VExUS score dynamically changes with volume removal. Delta VExUS score was statistically significant as determined by Wilcoxon signed-rank testing. ESRD = end-stage renal disease; HD = intermittent hemodialysis; PW = pulse-wave Doppler; VExUS = venous excess ultrasound.

HD was 1.07 ± 1.14, and the mean modified VExUS score after HD was 0.28 ± 0.54. This difference was found to be statistically significant ($P < 0.001$).

DISCUSSION

Large-volume fluid removal with HD was represented by changes in VExUS score, highlighting the utility of the VExUS exam to capture dynamic shifts in volume status in patients with ESRD. This study builds on a growing body of evidence suggesting that the VExUS exam can augment traditional measures of volume status and venous congestion in patients undergoing HD.[27,28]

The VExUS exam has previously been shown to outperform both ICI and the measurement of IVC diameter—two metrics routinely incorporated into standard echocardiogram protocols—in the estimation of RAP.[21,30,31] Our group recently published a study validating VExUS against RHC, an analysis that found that the area under the curve (AUC) for VExUS grade as a predictor of RAP >10 mm Hg was 0.9, whereas the AUC for ICI and IVC diameter as predictors of RAP >10 mm Hg were 0.65 and 0.77, respectively. Similarly, the AUC for VExUS grade as predictor of RAP <7 mm Hg was 0.79, whereas the AUC for ICI and IVC diameter as predictors of RAP <7 mm Hg were 0.62 and 0.74, respectively, highlighting the fact that VExUS was superior to ICI or IVC diameter for the detection of euvolemia or hypovolemia in addition to venous congestion. These findings hold true in the current study as well. Although the VExUS exam was able to detect significant changes in volume status, ICI was not. There was no statistically significant change in paired ICI scores before and after HD, underscoring the limitations of this unidimensional metric.[30,31] The American Society of Echocardiography's (ASE) guidelines for the estimation of RAP include both ICI and IVC diameter. A combination of IVC diameter >2.1 cm and ICI <50% is indicative of an RAP 10 to 20 mm Hg, whereas a combination of IVC diameter <2.1 cm and ICI >50% suggests RAP <3 mmHg. In the current analysis, the mean pre-HD IVC_{max} was 2.01 cm, and the mean post-HD IVC_{max} was 1.88 cm. According to ASE criteria, an IVC diameter of <2.1 cm is suggestive of a RAP <5 mm Hg.[32] Using this schema, both the pre-HD and post-HD cohorts would have been considered to be uncongested, but there would have been no indication that a significant volume loss occurred between paired pre-HD and post-HD exams, as an IVC diameter of 2.01 cm and an IVC diameter of 1.88 cm both signal a low RAP. Similarly, an appraisal of ICI would suggest that both the pre-HD and post-HD cohort trended toward hypervolemia given their ICIs of 0.30 and 0.33, respectively.[32] This interpretation does not reflect the fact that a mean volume change of nearly negative 2 L occurred between paired pre-HD and post-HD ultrasound exams. Although there was a statistically significant difference in pre-HD and post-HD IVC diameter, an interpretation of IVC diameter using ASE guidelines would yield a misleadingly static conclusion.

Overall, these findings underscore the previously described constraints of binary metrics (eg, IVC size >2.1 cm vs <2.1 cm or ICI >50% vs <50%) for the estimation of a patient's degree of venous congestion and highlight an opportunity to expand on the IVC evaluation that is integrated into current echocardiographic protocols.[33-36] VExUS represents an objective, validated, multidimensional, and more nuanced appraisal of hemodynamic status that moves beyond the assessment of IVC alone to incorporate data from multiple encapsulated abdominal organs in addition to the IVC. The tiered scoring system used by VExUS (ie, scores 0-3, representing no venous congestion, mild congestion, moderate congestion and severe congestion, respectively) expands on current schema for the estimation of venous hypertension and allows for more gradation in the valuation of a patient's volume status. The supplement of 3 additional views (ie, the hepatic vein, portal vein, and intralobar renal vasculature) with pulse-wave Doppler wave forms has the potential to augment the already marked clinical utility of volume assessment via ultrasound exam, either as part of full echocardiographic exam or a stand-alone limited protocol.

Beyond the integration of VExUS into formal sonographic procedures, there also lies an opportunity to incorporate VExUS into routine clinical care as an easily accessible, point-of-care exam. Although there are certain challenges to pulse-wave Doppler assessments (eg, difficulty obtaining images and accurate velocity measurements, especially in patients who are unable to participate in the exam), VExUS offers the unique advantage of being a noninvasive, inexpensive, and reproducible ultrasound protocol, making it highly accessible to bedside clinicians. As such, the VExUS exam can be used to serially assess changes in a patient's volume status over time, marking it as an ideal tool for evaluating rapid changes in a patient's hemodynamic status in real time, such as diuresis in hypervolemic states (eg, decompensated heart failure). Together with the utilization of lung ultrasonography, which detected a significant decrease in pulmonary edema before and after HD, VExUS can provide a comprehensive representation of a patient's volume status that can inform clinical decision-making. Future studies should evaluate change in VExUS grade with intravenous diuretic administration in various patient populations, with the ultimate goal of evaluating the capacity of a standardized bedside ultrasound protocol to guide inpatient volume optimization.

The VExUS exam was validated in diverse patient populations with multiple compounding comorbidities and is intended as a tool to interrogate venous congestion across a spectrum of critical illness.[21,22] The seminal study by Beaubien-Souligny et al, for instance, investigated the ability of VExUS to predict AKI in patients who had recently undergone cardiac surgery with the use of cardiopulmonary bypass, and the recent analyses by Longino et al investigated the utility of VExUS to estimate RAP occurred in patients undergoing RHC, overall suggesting that the multivariate nature of the exam confers robustness and validity even in the setting of chronic disease.[19,21,22] In the current analysis, the renal vasculature score did not decrease between paired pre-HD and post-HD exams, but the composite VExUS score decreased concordantly with the remaining component scores, suggesting that the redundancy of the overall VExUS exam is effective at mitigating variation between patients and disease states. The inclusion of renal Doppler waveforms in this analysis of patients with

ESRD is novel. This portion of the VExUS exam has long been excluded in investigations of patients with ESRD, with the thought renal vein assessment is too unreliable to even be worthy of assessment in this patient population. Here, we demonstrate objectively that the renal vasculature score deviated from the other component scores and the composite VExUS score before and after HD. Furthermore, the change in renal VExUS scores did not correlate at all with fluid removal, reinforcing the supposition that renal vein Doppler assessment does not add value in patients with ESRD. Future studies are warranted to expressly validate VExUS in specific subpopulations, including patients with ESRD, cirrhosis or undergoing positive pressure ventilation. Although the utility of components of the VExUS exam in these populations has been previously evaluated, and our group's recent analysis comparing venous congestion as assessed by VExUS to RAP as assessed by RHC included a diverse patient population; the analysis included relatively few patients with ESRD or cirrhosis and did not include any patients undergoing positive pressure ventilation.[22,37-42] As the VExUS exam continues to gain traction, further investigations explicitly: 1) evaluating the accuracy of the composite VExUS score in approximating RAP; and 2) assessing the utility of VExUS to guide clinical decision-making in these patient populations will help to further define the role of VExUS in clinical practice.

STUDY LIMITATIONS. Although this analysis demonstrates the ability of the VExUS exam to capture changes in venous congestion that occur in the setting of large-volume fluid removal in patients undergoing HD, it does not assess the ability of the VExUS exam to detect volume loss in other clinical settings (eg, diuresis, gastrointestinal losses or hemorrhage), nor does it assess the ability of the VExUS exam to detect rapid volume expansion. Moreover, this investigation was conducted entirely by novice sonographers who had undergone dedicated training. Although the acquisition of images by novice sonographers may replicate clinical practice, it also has the potential add variability. Of the 56 patients screened for inclusion in this study, 10 (17.9%) were excluded due to image quality. Although this degree of exclusion for image quality is not necessarily unexpected for an ultrasound study, it does underscore a potential limitation of this study and highlight challenges to the practical application of the VExUS technique serially for the assessment of volume status. VExUS has been broadly studied in a vast array of clinical settings in recent years, but not all studies have been positive, and several studies have failed to find significant added clinical utility in the incorporation of the VExUS exam, further highlighting this limitation.[43,44] Image graders were not blinded to the sequence of image acquisition. CIs were not adjusted for multiple comparisons and thus should be interpreted with caution. Finally, this study included only patients with ESRD, and the effect of chronic renal disease on the renal component of the VExUS exam has not been directly investigated, leaving open the possibility that ESRD necessitating HD may impair the interpretation of renal vein pulse-wave Doppler waveforms. In fact, chronic diabetic nephropathy has been shown to impede the interpretation of interlobar renal venous waveforms even before to progression to ESRD, and prior studies have deferred Doppler assessment of the intrarenal vein when assessing populations with ESRD.[27-29,45]

CONCLUSIONS

Large-volume fluid removal with HD was represented by changes in VExUS score, highlighting the utility of the VExUS exam to capture dynamic shifts in volume status. VExUS holds potential as an addition to formal sonographic protocols and as a point-of-care bedside tool that can be used to detect changes in venous congestion in real-time. Future studies should evaluate change in VExUS grade with intravenous diuretic administration in various patient populations, with the ultimate goal of evaluating the capacity of a standardized bedside ultrasound protocol to guide inpatient volume optimization.

FUNDING SUPPORT AND AUTHOR DISCLOSURES

Dr Leyba has received funding from NHLBI: 5 R38 HL 143511-4. All other authors have reported that they have no relationships relevant to the contents of this paper to disclose.

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PERSPECTIVES

COMPETENCY IN MEDICAL KNOWLEDGE: VExUS is a point-of-care ultrasound exam that has previously been shown to correlate with RAP as assessed by RHC and thus represents a valuable tool for assessing venous congestion at the bedside. This analysis determined that VExUS is also effective at detecting dynamic changes in volume status, outperforming widely used metrics such as ICI and IVC diameter.

TRANSLATIONAL OUTLOOK: Future basic science studies should interrogate the impact of chronic venous congestion on pulse-wave Doppler waveforms in encapsulated organs, while further clinical studies are warranted to expressly validate VExUS in specific subpopulations, such as patients with ESRD or advanced heart failure. Future studies should also evaluate change in VExUS grade with intravenous diuretic administration in various patient populations, with the ultimate goal of evaluating the capacity of a standardized bedside ultrasound protocol to guide inpatient volume optimization.

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KEY WORDS **Doppler ultrasound, end-stage renal disease (ESRD), hemodialysis (HD), point-of-care ultrasonography (POCUS), venous congestion**