

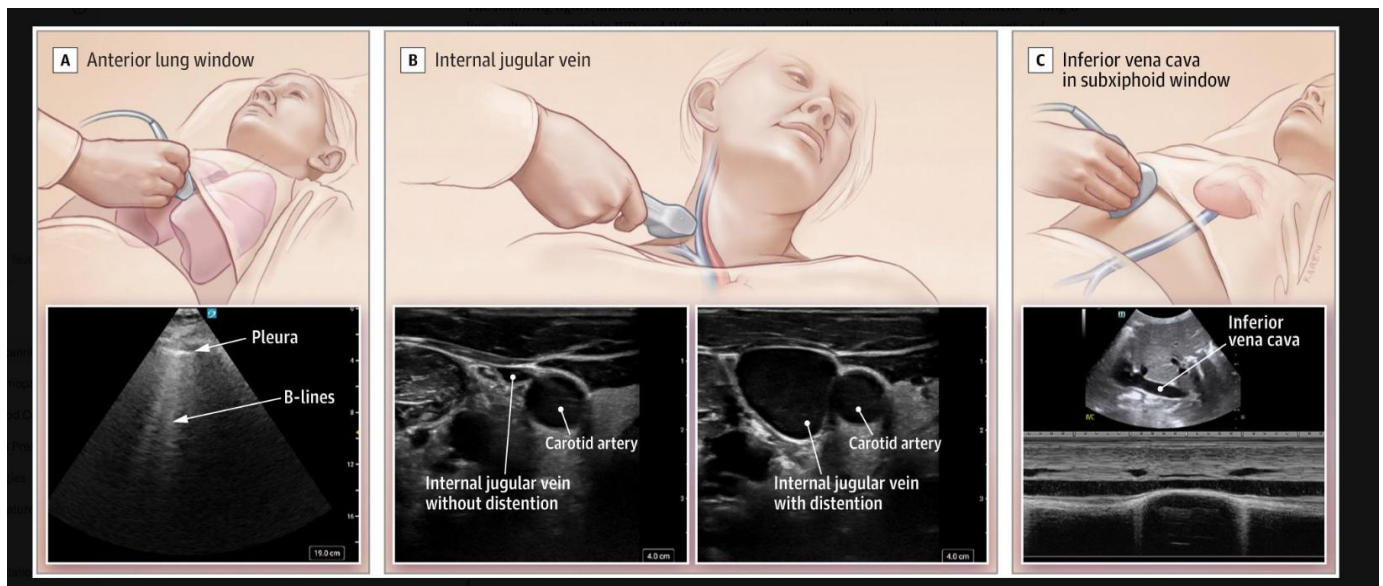
Volume Status Assessment Interfaced With Cardiac Output

The assessment of volume status in critically ill patients needs to be an integration of:

1. Venous congestion
2. Stroke volume/cardiac output
3. Fluid responsiveness and tolerance
4. Tissue perfusion

1. Assessment of venous congestion

- Peripheral edema, elevated proBNP and vascular congestion/pulmonary edema on CXR, in association with fluid balance, are useful to identify patients with volume status but have limitations.
- Presence of pulmonary B-lines and assessment of IVC/IJ collapsibility/distensibility index by ultrasonography perform better than the above for determining volume status but also have limitations.
- VExUS (Venous Excess Ultrasound Score) assess the interaction between venous return and cardiac function, **not pure volume status**.



https://jamanetwork.com/journals/jama/fullarticle/10.1001/jama.2026.0446?utm_source=openevidence&utm_medium=referral

Lung ultrasound

B-lines are hyperechoic lines perpendicular to the pleural lines extending to the bottom of the screen without fading and moving synchronously with lung sliding.

- One or two B-lines can be seen in normally aerated lungs, more than two are abnormal.

IVC Ultrasound

The IVC is imaged with a probe placed subxiphoid in the longitudinal plane, measuring diameter ~2 cm distal to the right atrium at end-expiration.

- *Collapsibility index* = (max – min diameter) / max diameter × 100. Used for IVC assessment in spontaneously breathing patients
- *Distensibility index* = (max – min diameter / min diameter × 100. Used for IVC assessment in mechanically ventilated patients
 - IVC >2 cm with <50% inspiratory collapse suggests elevated CVP
 - IVC ≤2 cm with >50% collapse suggests normal CVP (0–5 mmHg).
 - Limitations: Affected by positive-pressure ventilation, elevated intra-abdominal pressure, obesity, bowel gas, and RV dysfunction. The 2026 Surviving Sepsis Campaign guidelines note that IVC measurements "principally reflect CVP and are subject to the same limitations as CVP measurement".

VExUS (Venous Excess Ultrasound Score)

- It was developed by Beaubien-Souligny et al in 2020 to quantify systemic venous congestion by combining IVC diameter with pulsed-wave Doppler of three venous beds. <https://pubmed.ncbi.nlm.nih.gov/32270297>
- It reflects the interaction between venous return and cardiac function, not pure volume status.

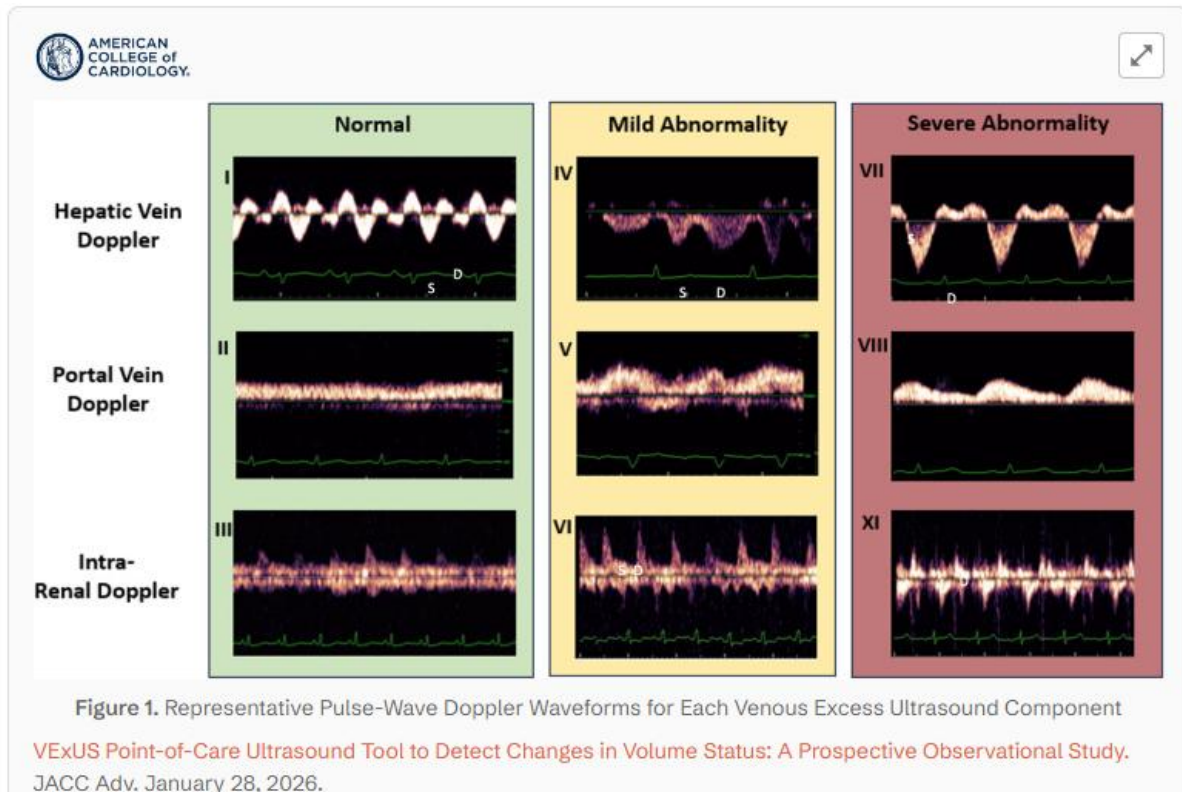
Components and grading involves four assessments: (1) IVC diameter (gatekeeper), (2) hepatic vein Doppler, (3) portal vein Doppler, and (4) intrarenal vein Doppler. Each Doppler component is classified as normal, mildly abnormal, or severely abnormal:

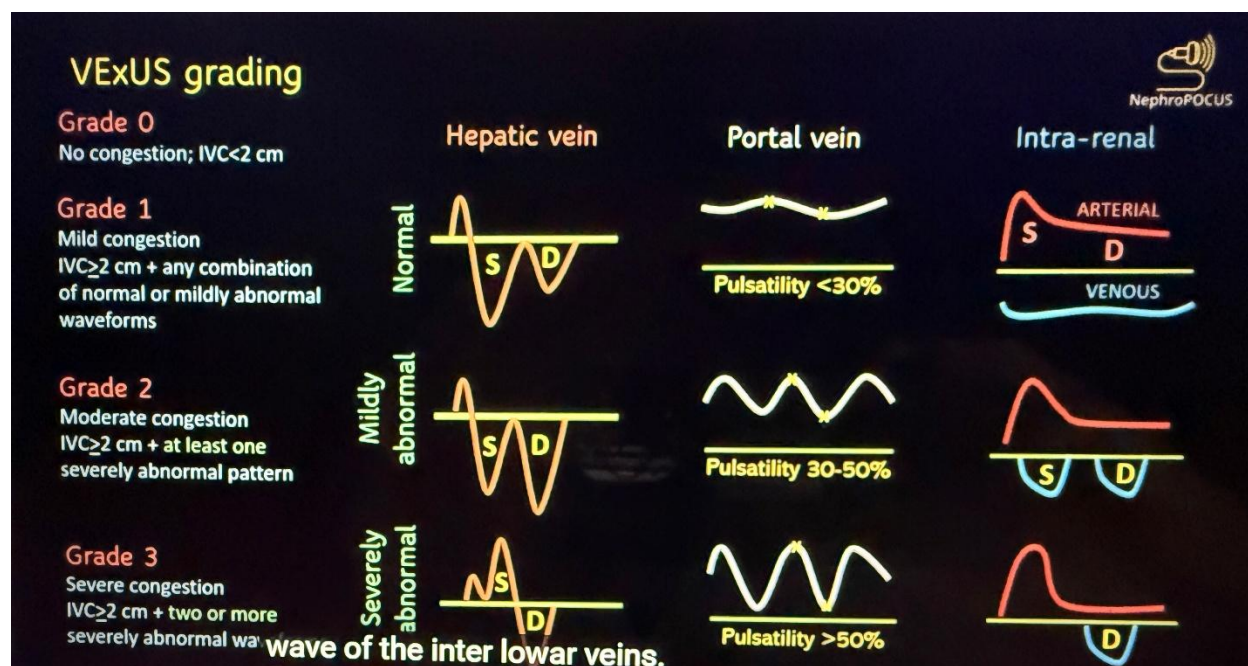
VExUS Grade	Criteria	Interpretation
0	IVC < 2 cm (regardless of Doppler)	No congestion
1	IVC $\geq$ 2 cm + no severely abnormal Doppler	Mild congestion
2	IVC $\geq$ 2 cm + 1 severely abnormal Doppler	Moderate congestion
3	IVC $\geq$ 2 cm + $\geq$ 2 severely abnormal Doppler	Severe congestion

Severely abnormal patterns include:

- Hepatic vein systolic flow reversal
- Portal vein pulsatility $\geq$ 50%
- Monophasic diastolic intrarenal venous flow.

The following figure shows representative Doppler waveforms for each component across the normal-to-severe spectrum:





The prognostic value of VExUS is **strongly population-dependent**:

In cardiac patients, VExUS ≥ 2 is significantly associated with AKI and mortality, whereas in general ICU populations, **no significant association with either outcome has been demonstrated** at the same threshold.

The mechanistic explanation is straightforward: cardiac patients have a high prevalence of venous congestion (39% had VExUS 3 in the acute HF cohort), and the pathophysiology of congestive AKI — elevated renal venous pressure reducing the transrenal perfusion gradient — is directly captured by VExUS Doppler patterns.

Three key factors explain the divergent performance:

1. **Low prevalence of congestion in general ICU.** Only 12–22% of general ICU patients have VExUS ≥ 2, compared with ~50–60% in acute HF cohorts. Low event rates limit statistical power and clinical utility of the score as a screening tool.
2. **VExUS reflects cardiac function–venous return interaction, not pure volume.** Patients with cardiogenic shock may have high VExUS despite low fluid balance, while volume-overloaded patients with preserved cardiac function may score low. In heterogeneous ICU populations with diverse shock etiologies (distributive, hypovolemic), the venous Doppler patterns are driven by different pathophysiology than in cardiac failure.

3. **AKI in general ICU is multifactorial.** Septic AKI involves microvascular dysfunction, inflammation, and tubular injury — mechanisms not captured by venous congestion assessment. Congestive AKI (the mechanism VExUS detects) is a more dominant pathway in cardiac populations.

Practical Implications

- **In cardiac patients** (post-cardiac surgery, acute HF, cardiorenal syndrome): VExUS ≥ 2 is a validated prognostic marker and can meaningfully guide decongestion strategies. Serial measurements to track trajectory add further value.
- **In general ICU patients:** A single VExUS measurement has limited prognostic utility and should not be used in isolation to guide fluid management. However, VExUS trajectory and its use as a dynamic test during fluid challenges may still provide clinically actionable information. No RCT has tested whether VExUS-guided management improves hard outcomes in any population.
- **Across all settings:** VExUS should be interpreted as a measure of the cardiac function–venous return interaction, not as a pure volume status indicator. Integration with other ultrasound/Doppler modalities (lung ultrasound, LVOT VTI) and clinical context remains essential

2. Assessment of stroke volume/cardiac output

Continuous measurement of SV and consequently CO/CI by thermodilution along with pulmonary and cardiac filling pressures through PA catheter and systemic pressure through arterial line are of paramount importance when evaluating volume status interfaced with CO.

When PA catheter is not in place, the estimation of the **left ventricular outflow tract velocity time integral (LVOT VTI)** by echocardiogram is a very useful noninvasive variable to estimate SV.

- SV is estimated via LVOT cross-sectional area $\times$ velocity-time integral (VTI), measured from the apical 5-chamber view using pulsed-wave Doppler ~5 mm proximal to the aortic valve.

$$SV = LVOT\ CSA \times VTI = \pi \times (LVOT\ diameter/2)^2 \times VTI$$

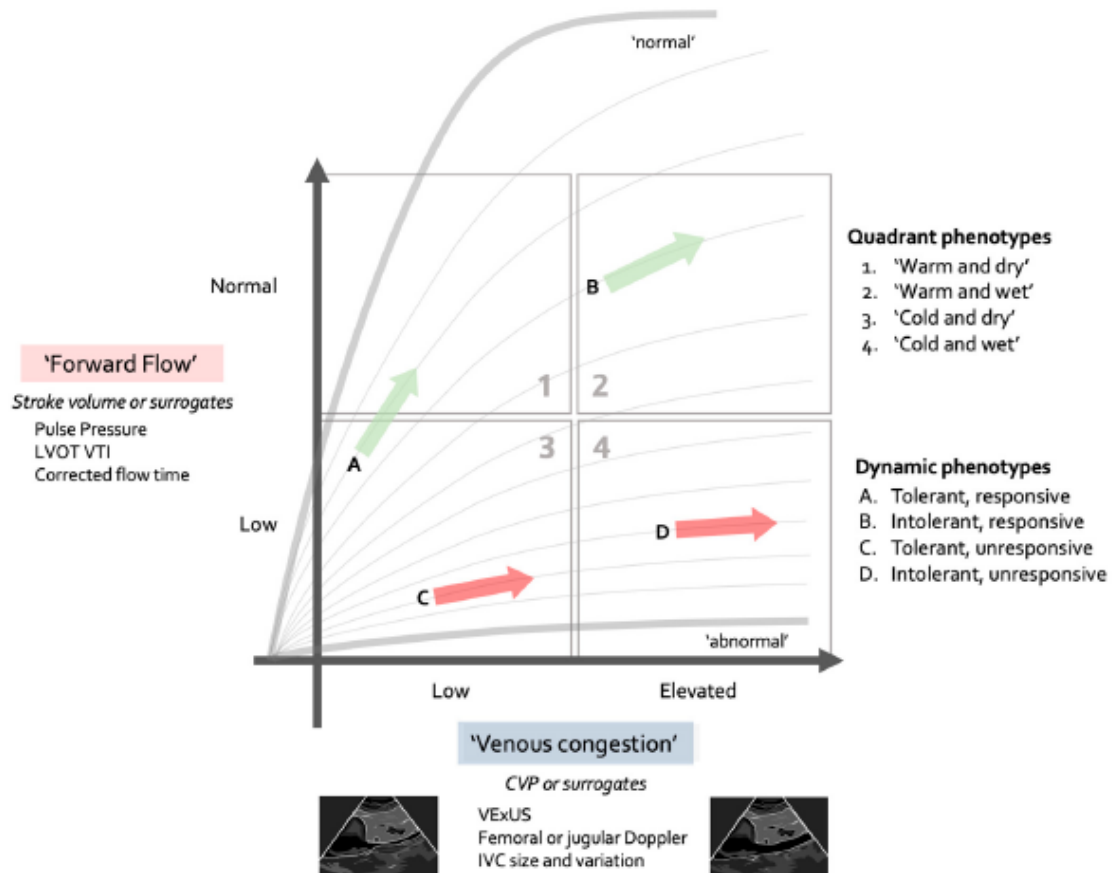
- It is the most validated ultrasound-Doppler-derived hemodynamic parameter in critical care.
 - It provides accurate SV/CO estimation ($r = 0.94\text{--}0.95$ vs. thermodilution)
 - It is the strongest single echocardiographic predictor of mortality in cardiogenic shock outperforming LVEF.

- It has the highest diagnostic accuracy of any bedside test (LR+ 11) for the assessment of fluid responsiveness.
- The key practical principle is to use VTI alone (not full SV calculation) for serial assessments, average ≥ 3 beats in sinus rhythm, and ensure the same operator performs sequential measurements to stay within the $\sim 11\%$ least significant change threshold. <https://pubmed.ncbi.nlm.nih.gov/34710882>
 - The ASE recommends tracking VTI alone for serial measurements, as LVOT diameter remains constant and its measurement introduces additional errors.
- *Normal LVOT VTI* is **22 ± 4 cm** across age groups.
- **VTI < 18 cm**: generally considered low, associated with reduced forward flow.

3. Assessment of fluid responsiveness and tolerance

The most accurate dynamic test for fluid responsiveness is the pre and post passive leg raise (PLR) or IVF bolus assessment of SV.

- A $\geq 10\%$ increase in SV is considered a positive response.
- If the patient has a positive response, the next step is to assess if the patient tolerates the volume by assessing venous congestion (VExUS and cardiac filling pressures).
 - The Forrester–Kenny diagram showing the four phenotypic quadrants as well as potential dynamic changes after therapeutic interventions. From J. Pers. Med. 2025, 15, 207. <https://doi.org/10.3390/jpm15050207>



4. Assessment of tissue perfusion

- If the patient has a positive response and tolerates the volume, the next step is to determine if it is beneficial by assessing markers of tissue perfusion including capillary refill time (CRT), lactate, mixed venous oxygen saturation (SvO₂), UO, and Cr.