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Diagnostic, therapeutic and prognostic value of the inferior vena cava collapsibility index in hemodynamically unstable septic children and adults in resource limited intensve care settings

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Keypoints

The Inferior Vena Cava Collapsibility Index is a pragmatic, low-cost bedside tool with demonstrable diagnostic, therapeutic, and emerging prognostic utility in septic, hemodynamically unstable patients.

Abstract

Fluid resuscitation remains a cornerstone in the management of septic shock, yet achieving the right balance between under- and over-resuscitation is especially challenging in resource-limited intensive care settings. The inferior vena cava collapsibility index (IVCCI), derived from respiratory variations in the inferior vena cava diameter, has emerged as a simple, noninvasive, and reproducible bedside tool for assessing intravascular volume status. Evidence from both adult and pediatric studies highlights its diagnostic and prognostic relevance, showing correlations with central venous pressure, cardiac output variations, and sepsis-related mortality. However, factors such as mechanical ventilation, intra-abdominal pressure, and operator skill can influence its accuracy. Recent research, particularly in pediatric and neonatal populations, supports its use in predicting fluid responsiveness and guiding resuscitation even under constrained technical conditions. In resource-limited ICUs, IVCCI provides a helpful strategy for individualized fluid management in sepsis, potentially improving outcomes while minimizing complications associated with fluid overload. Sandardization of measurement protocols and focused training in point-of-care ultrasound are essential to fully integrate IVCCI monitoring into routine critical care practice.

Keywords

Inferior Vena Cava; Collapsibility Index; Sepsis; Hemodynamic Monitoring; Ultrasonography; Critical Care.

Introduction

Sepsis and septic shock remain leading causes of morbidity and mortality in both adults and children worldwide, particularly in low- and middle-income countries (LMICs) where limited intensive care resources constrain advanced hemodynamic monitoring. Contemporary sepsis guidelines emphasize early recognition and individualized resuscitation, advocating the use of **dynamic** rather than **static** indices to guide fluid therapy and vasopressor use [1]. In these environments, **point-of-care ultrasound (POCUS)** has emerged as an indispensable bedside tool, enabling real-time, non-invasive assessment of cardiac function and intravascular volume status at low cost [2]. Among available sonographic parameters, the **Inferior Vena Cava Collapsibility Index (IVCCI)—** the percentage change in IVC diameter during respiration—has gained prominence as a pragmatic marker of preload responsiveness.However, the diagnostic accuracy, therapeutic applicability, and prognostic relevance of IVCCI vary across age groups (children vs adults), ventilation modes (mechanically ventilated vs spontaneous), and comorbid conditions (cardiac dysfunction, intra-abdominal hypertension). In LMIC ICUs, additional challenges—limited equipment, training gaps, and infrastructural constraints—coexist with opportunities for innovation.This commentary synthesizes current evidence, emerging innovations, and context-specific adaptations of IVCCI monitoring to support safe and effective implementation in resource-limited intensive care units.

Principles and physiology of IVCCI

The IVCCI is calculated as

$$\mathbf{IVCCI} = \frac{\mathbf{IVCmax - IVCmin}}{\mathbf{IVCmax}} X100$$

In spontaneously breathing patients, negative intrathoracic pressure during inspiration increases venous return and decreases IVC diameter, so a **high collapsibility** suggests preload dependence. In mechanically ventilated patients, positive-pressure inspiration reverses these dynamics, expanding the IVC during insufflation. Thus, threshold interpretation must be adapted to ventilation mode [2,3].

Dynamic indices such as IVCCI are superior to static measures like central venous pressure (CVP), which poorly predict fluid responsiveness in sepsis [1,2]. The IVCCI's simplicity, reproducibility, and compatibility with portable ultrasound make it particularly relevant in settings lacking invasive monitors or advanced cardiac output tools [2,3].

Diagnostic performance: what the evidence shows

Adults

In adults, meta-analyses and guideline reviews show that respiratory variation of the IVC can predict fluid responsiveness with moderate accuracy in selected populations — principally mechanically ventilated patients without spontaneous breathing efforts, significant arrhythmias, or major right heart dysfunction [2]. However, heterogeneity across studies (technique, thresholds, patient selection, mode of ventilation) yields variable sensitivity and specificity. Performance diminishes in spontaneously breathing adults because respiratory efforts are variable and unpredictable.

Children and neonates

Pediatric data are less abundant but growing. Xiong and colleagues demonstrated that respiratory variation of IVC diameter predicted fluid responsiveness in ventilated children with septic shock, reporting reasonable diagnostic accuracy when age- and size-appropriate thresholds were used [4]. Yildizdaş and Aslan similarly indicated that collapsibility/distensibility indices might assess volume status in critically ill pediatric patients, but they stressed that normative values and thresholds differ from those in adults and necessitate pediatric calibration [5]. Neonatal data, including the work by Mi et al., suggest that IVC and aortic metrics may be abnormal in early-onset septic shock, but thresholds and predictive capability are not yet standardized [6]. Smaller IVC size, higher respiratory variability, and the technical challenge of imaging in infants further complicate pediatric application.

Special populations and confounders

Conditions such as increased intra-abdominal pressure, right ventricular dysfunction, pericardial disease, mechanical ventilation with spontaneous efforts, and obesity can alter IVC dynamics independently of preload status and invalidate simple IVCCI interpretation. In hemodialysis and nephrotic syndrome populations, relationships between IVC indices and true intravascular volume are complex and sometimes counterintuitive [7]. Thus, IVCCI should never be interpreted in isolation but integrated within a broader clinical and echocardiographic assessment [8].

Therapeutic utility: guiding resuscitation and avoiding harm

The central therapeutic promise of IVCCI is to help clinicians decide whether a fluid bolus is likely to increase stroke volume (i.e., whether the patient is fluid responsive), thereby avoiding unnecessary fluid loading that can precipitate organ edema and worse outcomes [9]. Repeated IVCCI measurements can monitor response to therapy and support a de-resuscitation strategy when indices and clinical status suggest lack of benefit or harm from continued fluids [9].

In resource-limited ICUs, IVCCI provides an actionable tool: a rapid scan before a fluid bolus may alter management, prompting vasopressors first in non-responders or cautious fluid boluses in probable responders. Comparative studies indicate that IVCCI-guided approaches can align with other dynamic tests (e.g., passive leg raise) in non-ventilated patients, though head-to-head evidence is mixed [10]. In pediatric care, where invasive cardiac output monitoring is rare, IVCCI may be the most accessible dynamic marker — Xiong et al. and others demonstrate that ventilated children with certain IVCCI thresholds are more likely to respond to fluids [4,11].

Nevertheless, the therapeutic application requires protocolization: which thresholds to use, how to measure (subxiphoid long axis vs short axis, 2–3 cm from right atrium), how many respiratory cycles, and how to interpret in the presence of confounders. Without standardized technique and training, measurement variability undermines clinical utility [2,3].

Prognostic implications

Beyond short-term prediction of fluid responsiveness, IVCCI has potential prognostic value. Studies indicate that abnormal IVC dynamics correlate with higher vasopressor requirements, longer ICU stays, and increased mortality in some cohorts [5,6]. Mi et al. showed that neonates with early-onset septic shock exhibited IVC/aorta abnormalities associated with severity [5]. Persistent IVC collapsibility despite resuscitation could reflect ongoing hypovolemia, myocardial depression, or unresolved distributive shock — each portending worse outcomes. Conversely, very low variability (fixed dilated IVC) may signal fluid overload or right heart failure, also associated with adverse prognosis. However, robust prognostic models integrating IVCCI with other clinical and laboratory markers are lacking and represent an important area for research.

Technical standardization: how to measure reliably

Variability in technique explains much interstudy heterogeneity. The following pragmatic standard operating steps are recommended:

1. **Imaging window:** subxiphoid long-axis view with IVC measured ~2 cm caudal to the hepatic vein junction to the right atrium. If a subxiphoid window is impossible, a lateral view may be used.
2. **Respiratory cycle sampling:** average over 3–5 respiratory cycles to reduce beat-to-beat noise.
3. **Measurement mode:** use M-mode to capture maximal and minimal diameters precisely.

4. **Position du patient:** supine ou semi-recumbent, avec élévation de la tête notée ; la position affecte le diamètre de la VCI.
5. **Ventilation context:** document whether the patient is mechanically ventilated and whether spontaneous breathing efforts exist — thresholds differ.
6. **Index choice and threshold:** for spontaneously breathing adults, collapsibility (IVCmax–min)/IVCmax; a commonly cited adult threshold of ~40% suggests fluid responsiveness, but local validation is essential. In pediatrics and neonates, age-adjusted thresholds are necessary [4,5].

Standardized training programs and job aids (video tutorials, pocket cards) markedly improve measurement reliability in resource-limited settings and should accompany implementation [2,3,11].

Innovations and practical solutions for resource-limited settings

Several technological and operational innovations increase IVCCI feasibility in LMIC ICUs:

1. Handheld ultrasound devices and low-cost POCUS — Portable, battery-operated probes have become affordable and robust, enabling bedside IVC scans in wards and ICUs without infrastructure for cart-based machines [2]. Their image quality is often sufficient for diameter measurements.

2. Automated image analysis and AI assistance — Emerging algorithms can detect IVC borders and compute diameters and collapsibility automatically, reducing operator dependence and enabling less-experienced clinicians to obtain reliable indices. Early prototypes and research platforms show promise but require validation in diverse pediatric and adult populations [3].

3. Tele-ultrasound and remote mentorship — Remote real-time guidance via smartphone or tablet allows experts in tertiary centers to coach novice sonographers during scans, elevating image quality and interpretation reliability across networked hospitals [11].

4. Algorithmic integration with simple clinical triggers — Embedding IVCCI within a stepwise algorithm (e.g., clinical assessment → IVCCI → passive leg raise if uncertain → targeted bolus/vasopressor strategy) improves decision consistency and reduces inappropriate fluid use [10].

5. Focused training modules — Short, competency-based POCUS curricula adapted to LMIC contexts (simulation, supervised scans, competency checklists) increase retention and translation into practice [2,11].

These innovations lower the barriers to widespread, safe use of IVCCI in settings where every liter of fluid and every monitoring decision carry outsized consequences.

Limitations, pitfalls, and safety considerations

Despite promise, IVCCI has notable limitations :

- **High false positives/negatives in unselected cohorts :** heterogeneity of sepsis presentations, mechanical ventilation modes, and arrhythmias reduce predictive accuracy [2,4].
- **Pediatric challenges:** Small IVC size, rapid breathing rates, and compliance differences demand bespoke pediatric thresholds and more refined technique; neonatal evidence remains limited [5,6].
- **Confounders:** Elevated intra-abdominal pressure, obesity, pericardial disease, RV dysfunction, positive end-expiratory pressure (PEEP), and spontaneous breathing activity undermine interpretation [2].
- **Operator dependency:** Without training and quality assurance, measurement variability is substantial.
- **Overreliance risk:** IVCCI must not replace comprehensive clinical assessment; it is an adjunct, not a stand-alone determinant.

These pitfalls call for cautious, protocolized use, continuous training, and integration with other markers (passive leg raise, focused echocardiography for cardiac function, and lactate trends).

Practical pathway for implementation in resource-limited ICUs

A pragmatic implementation roadmap :

1. **Assess needs and resources:** inventory ultrasound devices, staff, and internet/telemedicine capacity.
2. **Adopt a simple protocol:** define who performs scans, when (e.g., before fluid bolus decisions), measurement technique, and thresholds (initially using published adult thresholds and pediatric adaptations from the literature, but flagging local validation).
3. **Train and certify:** short modular courses with supervised scanning sessions and competency checklists. Use tele-mentoring where local experts are scarce [11].
4. **Quality assurance :** weekly or monthly review of saved scans, blinded interobserver audits, and retraining as needed.
5. **Data collection and local validation :** prospectively record IVCCI, interventions, cardiac output changes when possible, and outcomes to derive local thresholds and build the evidence base.
6. **Integration into workflows :** standardize documentation in charts and link IVCCI results to clear treatment actions (fluid bolus vs vasopressor preference vs further imaging).

This approach harmonizes immediate clinical utility with capacity building and data generation for local adaptation.

Research priorities

To strengthen evidence and implementation, priority research questions include:

Population-specific limits: studies from multiple centers to create and confirm IVCCI limits for children and newborns in low- and middle-income [4–6].

Comparative effectiveness: randomized or pragmatic trials comparing IVCCI-guided resuscitation vs standard care or passive leg raise strategies in both children and adults, focusing on fluid volume administered, organ dysfunction, and mortality [11].

1. **Automation and AI validation :** prospective evaluation of automated IVCCI tools against expert sonographers in diverse settings.
2. **Hybrid monitoring strategies:** evaluation of combined protocols (IVCCI + focused cardiac ultrasound + lactate kinetics) to improve predictive accuracy and outcomes.
3. **Implementation science :** studies on training models, tele-mentoring efficacy, and sustainability of POCUS programs in LMIC health systems [2].

Addressing these gaps will permit evidence-based scale-up of IVCCI use where it may have the greatest impact.

Conclusion

The Inferior Vena Cava Collapsibility Index is a pragmatic, low-cost bedside tool with demonstrable diagnostic, therapeutic, and emerging prognostic utility in septic, hemodynamically unstable patients. Its greatest potential lies in resource-limited settings where POCUS may supplant unavailable invasive monitoring modalities. To realize that potential, clinicians and health systems must adopt standardized measurement techniques, invest in focused training and quality assurance, and participate in collaborative research to refine thresholds and protocols—especially for pediatric and neonatal populations. Innovations in portable ultrasound, automated image analysis, and telementoring can accelerate safe implementation. Ultimately, IVCCI is most powerful when integrated into a multimodal, patient-centered hemodynamic strategy rather than used in isolation.

Conflict of Interest

The authors declare that there are no conflicts of interest related to the publication of this article.

Ethical approval

Not applicable, as this commentary did not involve direct research on human subjects.

Consent for publication

Not applicable.

Author Contributions

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- All authors have read and approved the final manuscript and agree to be accountable for all aspects of the work.

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