Workflow and Framework for Collecting and Implementing Point-of-Care Ultrasound Data in the Management of Heart Failure Patients

Ilan Kedan[1], **Kade Birkeland**[2], **Alan C. Kwan**[1], **Raymond Zimmer**[1], **Susan Cheng**[1]

[1] Cedars-Sinai Hospital, Department of Cardiology, Smidt Heart Institute [2] Cedars-Sinai Enterprise Information System

Corresponding Author

Ilan Kedan
kedani@cshs.org

Citation

Kedan, I., Birkeland, K., Kwan, A.C., Zimmer, R., Cheng, S. Workflow and Framework for Collecting and Implementing Point-of-Care Ultrasound Data in the Management of Heart Failure Patients. *J. Vis. Exp.* (209), e67040, doi:10.3791/67040 (2024).

Date Published

July 12, 2024

DOI

10.3791/67040

URL

jove.com/video/67040

Abstract

Management and prevention of acute decompensated heart failure remain highly prevalent and challenging medical conditions. Incorporation of Point-of-Care Ultrasound (POCUS) as an adjunctive tool for assessing volume status and treatment response has shown significant promise. POCUS can be used for imaging internal anatomic structures serially and capturing these images for comparison and measurement over time. This protocol describes a scalable and standardized methodology for the serial assessment of the inferior vena cava (IVC). The methodology includes serial image collection, measurement, and presentation in the electronic medical record. A workflow for POCUS-acquired images of the IVC was created to capture the images and measure the diameter in a discrete data field for direct comparison over time and in response to clinical management. The protocol also includes the assessment of the presence or absence of pleural effusion as discrete data in the standardized workflow. By integrating POCUS into heart failure management, clinicians can improve patient outcomes through more precise and timely adjustments in treatment.

Introduction

Point-of-care ultrasound (POCUS) is an emerging technology that can be used in day-to-day clinical settings. Although commercially available hand-carried ultrasound devices have been marketed for over 13 years, regular use outside of bedside procedures has been limited[1]. POCUS offers an intuitive application in the acute care setting for the diagnosis of specific disease states like cardiac arrest, congestive heart failure, identification of pneumothorax, assessment of pericardial effusion, and detection of free intra-abdominal fluid in trauma or surgery patients[2]. POCUS is well established as an evidence-based tool in assessing patients for the diagnosis of heart failure[3]. However, the implementation of POCUS using serial assessment in response to therapy is less well-established[4].

POCUS-guided heart failure management includes the visual assessment of central venous pressure (CVP) and right atrial pressure by observing the diameter and collapsibility of the inferior vena cava (IVC). Additionally, POCUS can be used to observe the presence of pleural effusions and anatomical changes that correlate with physiological changes during treatment, including biventricular cardiac function, heart rate, contractility, mitral valve regurgitation, and acute changes in clinical status not self-evident with physical examination[5].

In 2011, the clinical practice group began incorporating POCUS into the routine physical examination for all face-to-face inpatient and outpatient encounters (approximately 40,000). Anecdotal observations of anatomical changes visualized by POCUS often seemed to correspond with clinical events and biomarker measurements[6] (**Figure 1**).

In the study institution, beginning in 2015, a discrete data field was built within the electronic health record to track the diameter and compressibility of the inferior vena cava (IVC). A binary data field was also created to document the presence or absence of pleural effusions identified with POCUS. In over seven years of patient care with the incorporation of POCUS in the clinical management of hospitalized heart failure patients, the acquisition and incorporation of POCUS data and IVC measurements have been recorded for more than 6,000 encounters. From an experiential perspective, the clinical practice group found the use of POCUS valuable in assisting with optimizing medical management and refining guideline-directed medical therapy, thereby personalizing the care of heart failure patients.

In this study, a POCUS exam was conducted using a phased-array hand-carried ultrasound device with a digital display screen. Images of the inferior vena cava (IVC) were obtained by scanning the patient through the subcostal acoustic window[7] (**Figure 2**). The IVC images were acquired and measured on the digital display, specifically at a level caudal to the middle hepatic vein. Live images were paused, and a frame-by-frame image scroll on the device was utilized to identify and measure the maximal IVC diameter during the cardiac and respiratory cycle. The measurement was recorded in a data flowsheet within the patient's electronic medical record, and a screenshot of the measured image was uploaded into the patient chart to document the location and angle of measurement acquisition. Subsequently, the measurement flowsheet and uploaded image were added to the patient's progress note.

Protocol

The Institutional Review Board approval from Cedars-Sinai Medical Center in Los Angeles, California, USA was obtained prior to the collection of patient data and evaluation. Written informed consent was waived because the use of POCUS in patient care is a standard and routine clinical examination practice for patients seen within the included cohort. It was offered in addition to standard clinical practice and did not alter the minimal standard of care. Each patient care encounter included a POCUS exam alongside conventional medical history, physical exam, and review of clinical data. POCUS was not used as a substitute for standard clinical practice or in place of indicated testing or imaging. Data were collected from a cohort of hospitalized heart failure patients at Cedars-Sinai Hospital from January 1, 2016, through December 31, 2021. Patients were included in the cohort if they had a primary admitting diagnosis of heart failure or if heart failure was among the top five diagnosis codes on admission (ICD-10 I50*). The analysis included discrete data fields within a commercially purchased electronic health record, such as IVC measurements, presence of pleural effusion, length of stay, survival, and 30-day readmission. The details of the equipment used for this study are listed in the **Table of Materials**.

Inclusion/exclusion criteria:
Patients included in the care cohort were those identified as being cared for by the cardiology consultative service at Cedars-Sinai Hospital, where POCUS devices were utilized. The inclusion criteria specified the use of a protocol for IVC measurement with POCUS and the inclusion of data within the discrete IVC data field in the electronic health record. The care was provided by a team consisting of 6 cardiologists and 2 nurse practitioners. Patients who were unable to undergo imaging with POCUS or who were not imaged with POCUS were excluded from the clinical experience.

1. Patient and equipment preparation

1. Position the patient appropriately to expose the area of interest.
2. Ensure the ultrasound machine (see **Table of Materials**) is set up and calibrated correctly for the type of scan needed.
3. Select the probe and adjust the settings. Choose the appropriate ultrasound probe (linear, curved, phased array) based on the depth and type of tissue being imaged.
4. Adjust the frequency and depth settings on the ultrasound machine to optimize image resolution.

2. Image acquisition (for inferior vena cava)

1. Position the patient in the supine position for optimal POCUS image acquisition.
2. Apply a sufficient amount of ultrasound gel to the skin surface to ensure good acoustic coupling and reduce air between the probe and the skin.
3. Use a phased array ultrasound probe (2-5 MHz) (see **Table of Materials**) to obtain inferior vena cava (IVC) measurements at the level caudal to the insertion of the hepatic vein.
   NOTE: Ultrasound wave frequency varies depending on the depth setting on the ultrasound device.
4. Capture the IVC image with measurements displayed, including the anatomy and beam depth gauge, on the image display screen.
5. Record the IVC measurement into a prebuilt discrete data field within the electronic health record flowsheet (**Supplementary File 1**).
6. Include the prebuilt IVC measurement data field flowsheet, designed for and embedded within the electronic health record, and screen-captured images in the patient progress note.
   NOTE: This ensures visualization of each patient's anatomy and IVC measurement for more reproducible and consistent measurement location over time (**Figure 2**). Patient images uploaded directly into the electronic health record flow into the patient's medical record and are not stored on personal mobile devices.

3. Image acquisition (for pleural spaces)

1. Position the patient upright or in the lateral decubitus posture, alternating between right and left sides serially.
2. Utilize a 2-5 MHz phased array probe to scan for echo-free space inferior to the lung pleural border and superior to the ipsilateral diaphragm during scanning.

3. Document **yes** for the presence of pleural effusion, identified by increased echo-free space in the ipsilateral pleural space, or **no** for the absence of pleural effusion.
4. Enter the response into the corresponding cell in the electronic health record flowsheet (**Figure 3**).

4. Cleaning of the equipment and disposing of the gel

1. After completing the scan, clean the ultrasound probe and accompanying display screen or associated device/ machine.
2. Dispose of used ultrasound gel appropriately and ensure the patient is comfortable post-procedure.

5. Follow-up procedures

1. Identify actionable findings that influence clinical care decision-making on a patient-by-patient basis.
2. Identify IVC images consistent with physiology associated with elevated or reduced central venous pressure (CVP).
3. Modify medical therapy (diuretics, vasodilators, volume expanders) as indicated, aiming to optimize clinical physiology by adjusting CVP levels (either lowering or raising).

Representative Results

Through an iterative process over the course of months, a workflow for incorporating POCUS data, specifically IVC measurements, was formulated and standardized. It involves capturing a photographed image of the IVC and entering corresponding measurements into a chronological, discrete data field flowsheet (**Supplementary File 1**). The collection of patient data and its incorporation into a live clinical patient electronic health record demonstrates the development of a novel POCUS discrete data collection strategy. These data can augment clinical care and serve as a trackable clinical data field for both clinical and scientific purposes (**Figure 3**, **Figure 4**, and **Figure 5**).

The results illustrate a workflow for the clinical care team to measure POCUS-acquired IVC diameter dynamically and serially over time. These images can be longitudinally compared to prior and future measurements, potentially influencing clinical care decision-support.

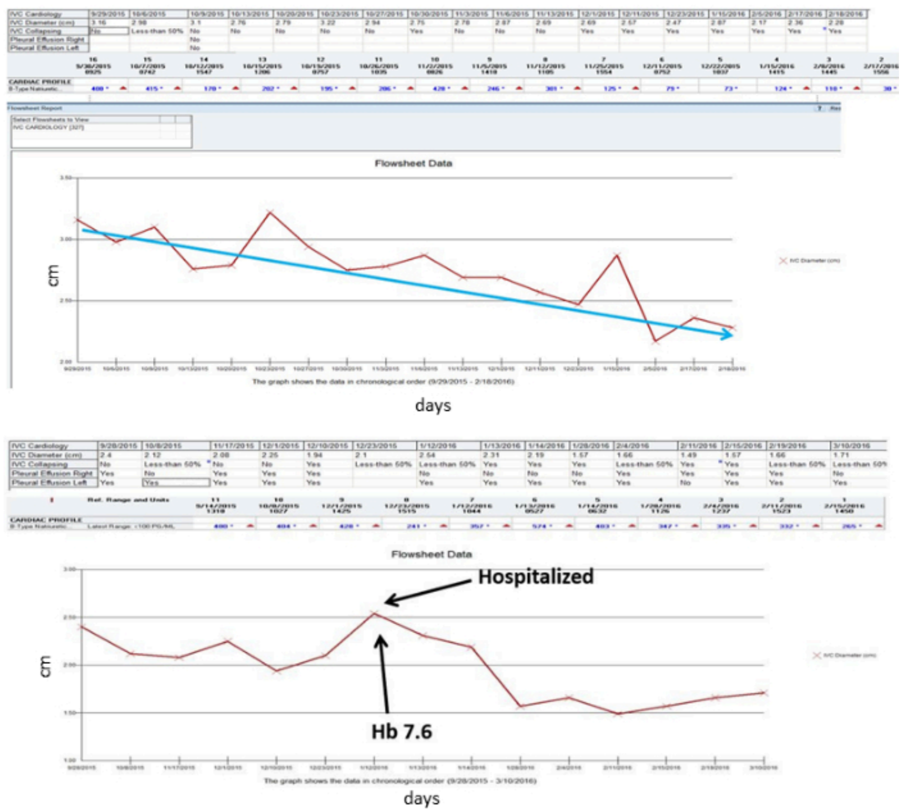

Figure 1: Patient examples. Plotted Inferior Vena Cava (IVC) diameters in two different heart failure patients before and after treatment. The top panel illustrates the IVC flowsheet with decreasing numerical values, corresponding to decreasing B-type natriuretic peptide levels. Graphs depict IVC diameter (y-axis, in centimeters) over time (x-axis, in days). Please click here to view a larger version of this figure.

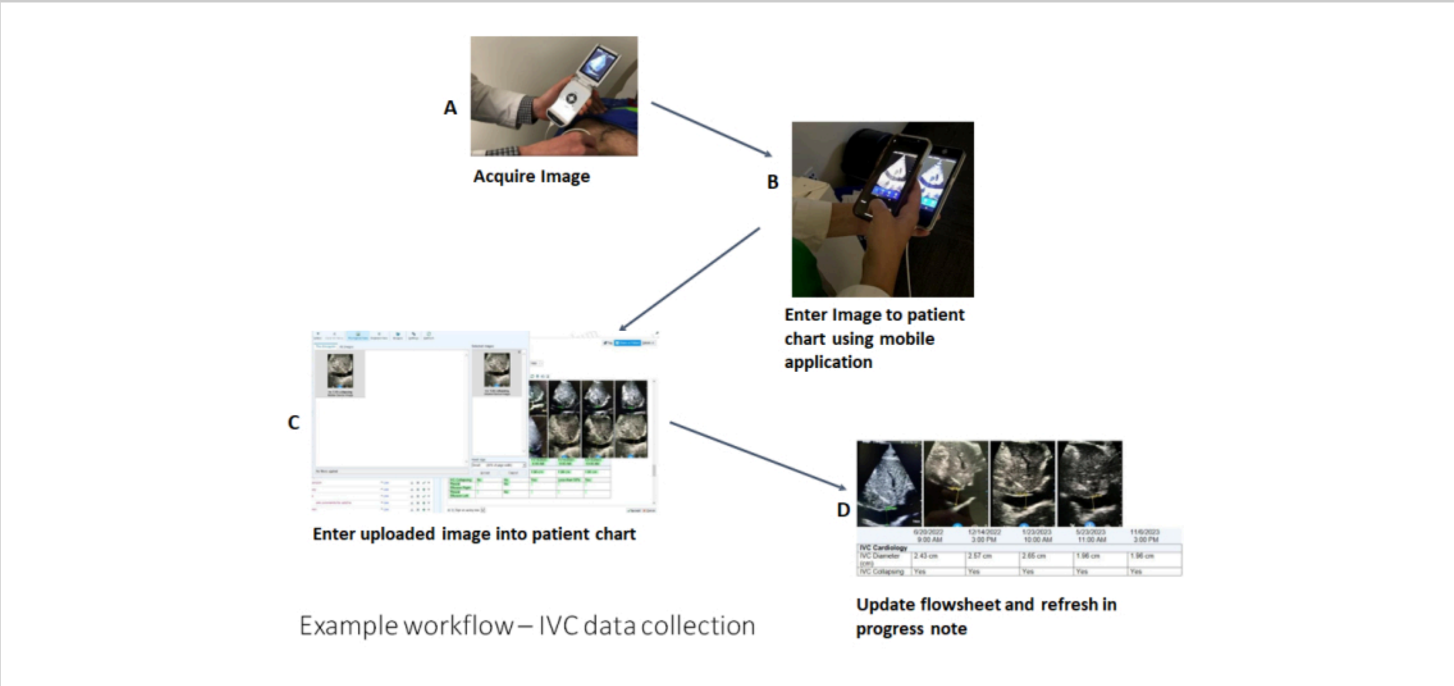

Figure 2: Representative example of inferior vena cava (IVC) workflow. (**A**) An image of the IVC is acquired using POCUS. (**B**) The maximal IVC diameter is measured (typically end-expiratory max measurement). (**C**) The image is uploaded to the patient chart using the electronic health record mobile application. (**D**) The measured IVC max diameter is entered into the IVC flowsheet. The image from the image selector tool and the corresponding flowsheet link are included in the electronic health record (refreshable data field) in the patient progress note. Please click here to view a larger version of this figure.

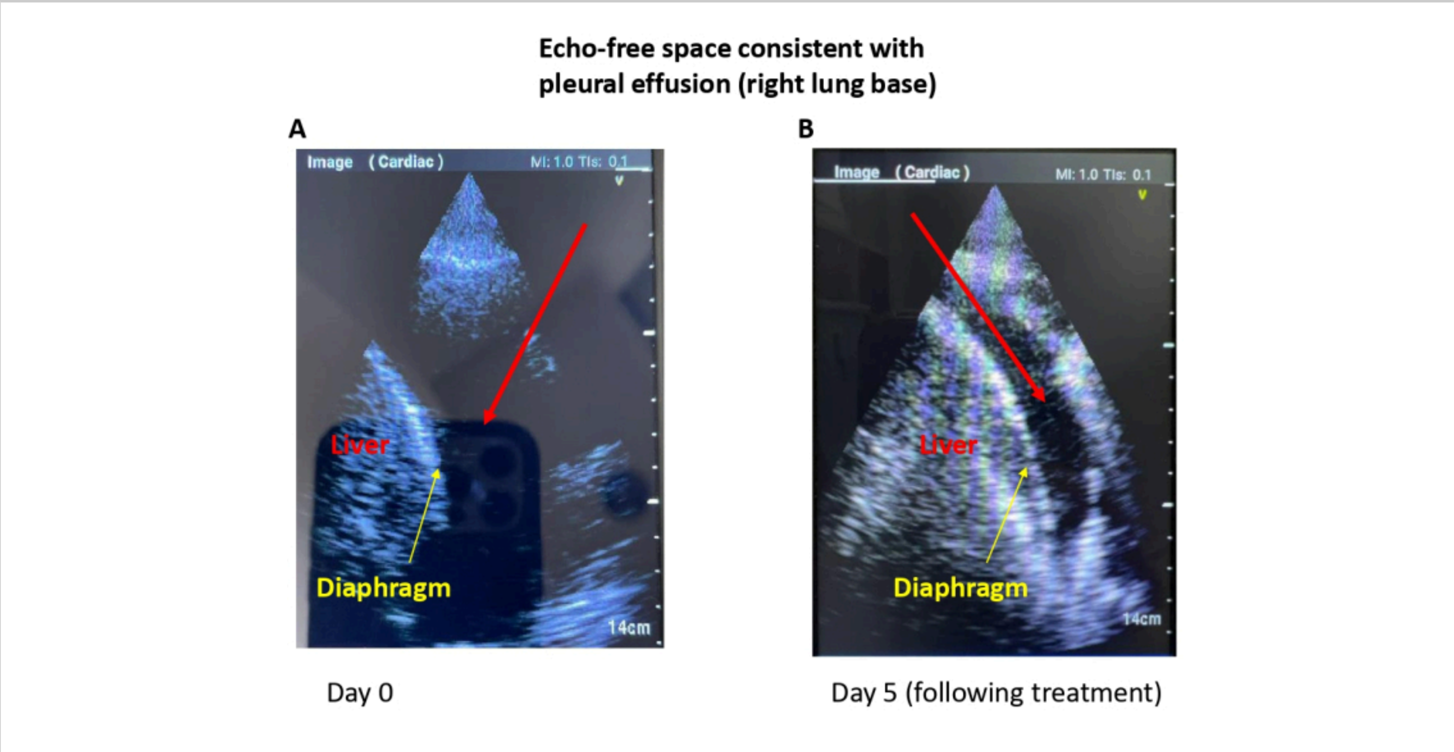

Figure 3: Representative example of pleural effusion and resolution with treatment in heart failure. Using POCUS to identify and assess treatment effects on pleural effusion in a hospitalized heart failure patient. (**A**) depicts Day 0 with a large pleural effusion. (**B**) depicts Day 5 with a small pleural effusion. Please click here to view a larger version of this figure.

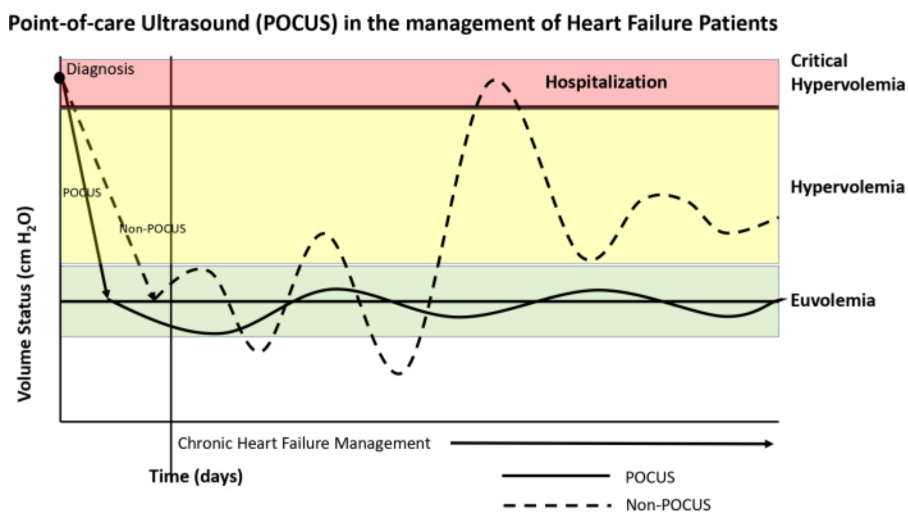

Figure 4: Goal of maintaining euvolemia with ultrasound-guided management of heart failure. Utilizing point-of-care ultrasound (POCUS) to guide patient management and achieve precise euvolemia maintenance over time in heart failure patients. The x-axis represents time in days, and the y-axis represents volume status in cm H_2O. Please click here to view a larger version of this figure.

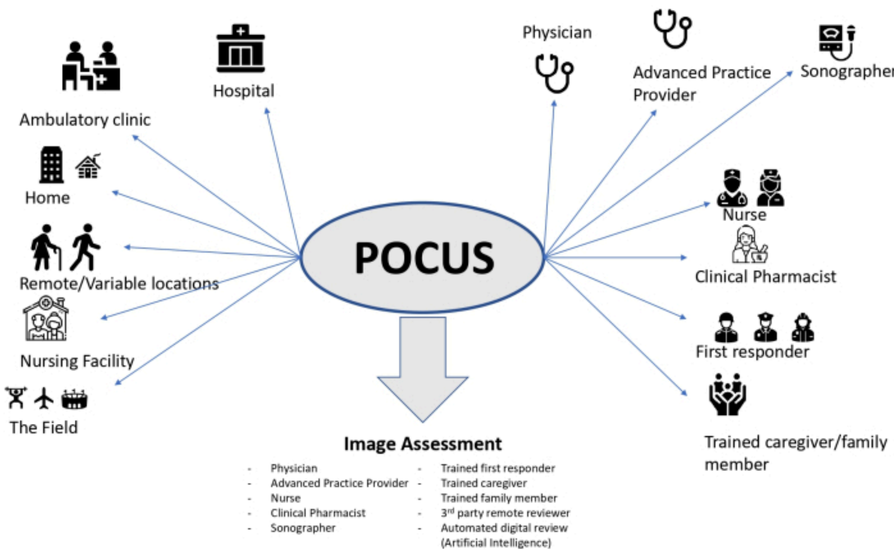

Figure 5: Point-of-Care Ultrasound (POCUS) acquired in various settings. POCUS (Point-of-care ultrasound) can be acquired in diverse settings such as hospitals, outpatient clinics, homes, various remote locations, nursing facilities, and field environments. Acquisition of POCUS is performed by physicians, advanced practice providers, sonographers, nurses, clinical pharmacists, first responders, trained caregivers, and family members. Image interpretation can be conducted by those acquiring the images, remote third-party reviewers, and through automated digital assessment and artificial intelligence. Please click here to view a larger version of this figure.

Supplementary File 1: Example of image capture of inferior vena cava (IVC) flowsheet embedded into the electronic health record. This data demonstrates the integration of an IVC flowsheet into the electronic health record, illustrating how it can be mapped to the patient chart and progress notes. Please click here to download this File.

Discussion

A valuable contribution of this publication lies in presenting a scalable clinical workflow that incorporates bedside-acquired dynamic anatomical measurements (the IVC), which correlate with and respond to physiological changes. Changes in CVP are correlated with alterations in IVC measurements. These anatomical changes occur in response to treatment and often correlate with symptoms in patients diagnosed with heart failure[5,7,8]. Guidelines describing IVC diameter measurements and the corresponding right atrial pressure values in mmHg are outlined in a standards publication from the American Society of Echocardiography[9].

Optimizing care for hospitalized heart failure patients is guided by treatment aimed at achieving euvolemia[10]. POCUS serves as a clinical tool providing a validated assessment of CVP, which dynamically changes with alterations in volume status[5]. The use of POCUS in clinical management of heart failure patients aims to assist in guiding optimal medical therapy, with the goal of directing patient care toward achieving and maintaining clinical euvolemia.

Furthermore, longitudinal care of heart failure patients guided by POCUS can help keep patients closer to or within a narrower therapeutic window, aiming for long-term sustained euvolemia (**Figure 4**).

Creating workflows to standardize, personalize, and optimize the acquisition and use of POCUS as a clinical tool in managing CHF has broad and impactful implications for how patients receive care. The clinical team has developed a scalable workflow that can be implemented by various members of the clinical care team, including nurses, sonographers, clinical pharmacists, advanced practice providers, and physicians (**Figure 5**). This POCUS-guided protocol for managing heart failure offers practitioners using the standardized workflow opportunities for iterative improvement in POCUS acquisition skills, which can translate to an enhanced ability to acquire images of other anatomical regions. This streamlined and scalable workflow may serve as a pathway to broader utilization of POCUS in other clinical areas and foster the development of innovative applications in both acute and chronic disease management.

Lung POCUS is an emerging and, in some settings, a common method for assessing lung water and, by association, lung congestion. B-lines, also known as comet tails, are reverberation artifacts originating from the lung pleural interface[11]. In acute decompensated heart failure patients, B-lines may be observed in the emergency department[12]. Challenges associated with lung ultrasound include the necessity for multiple anatomical assessments on each patient (4-8 lung imaging windows per lung POCUS exam), the time required to acquire these multiple lung POCUS images, the subjectivity and variability of imaging influenced by clinician operators and patient positioning, and the difficulty in longitudinally comparing and assessing treatment responses. Furthermore, there is a lack of empirical physiological measurements correlating with the presence, absence, or density of lung B-lines. Additionally, while POCUS-identified B-lines are indicative of pulmonary congestion, they are not specific to this condition and can also be observed in COVID-19 pneumonia and various acute and chronic pulmonary infectious and inflammatory conditions[13].

There are still limitations to the proposed workflow. Participants need to develop proficiency in POCUS imaging of the IVC and adhere to a standardized protocol for the location and timing of IVC measurements during the respiratory cycle. The clinical practice proposed aims to identify the maximal IVC diameter during end expiration, specifically caudal to the middle hepatic vein. However, a challenge lies in the variability of this anatomy among patients[14]. To address this variability, the workflow includes an image capture and measurement protocol that enables serial comparison of IVC measurements within each patient over time. This approach facilitates monitoring and may mitigate the impact of anatomical differences between individuals.

The expansion of a POCUS protocol in the management of heart failure patients beyond traditional healthcare settings holds promise for delivering more precise and personalized care. Implementing standardized POCUS workflows for heart failure management not only allows for more thorough patient evaluation but also benefits individuals who face barriers to accessing conventional healthcare settings. This includes patients residing in remote areas, those with limited mobility or transportation options, and individuals with constrained resources for healthcare services[15]. Moreover, integrating clinical tools like POCUS presents opportunities for closely monitoring symptomatic CHF patients in ambulatory settings, potentially reducing reliance on inpatient hospital resources.

This model not only enhances patient care but also optimizes resource allocation in healthcare delivery.

Potential future research could involve a prospective observational cohort study to accurately assess the value of POCUS in managing heart failure patients. Such a study could involve matching a POCUS-directed heart failure management group with a standard care heart failure treatment group to evaluate outcomes comprehensively. Given the expanding use of POCUS in clinical settings, a prospective evaluation of its efficacy and impact is crucial.

Furthermore, addressing inter-user variability in the acquisition and interpretation of IVC diameter and collapsibility with POCUS is essential. Variability in both congenital and acquired anatomical features of the IVC can pose challenges in accurately assessing its borders and dimensions, as well as its collapsibility[14]. These challenges may complicate the standardized assessment and longitudinal measurement of the IVC in clinical practice. Research aimed at understanding and mitigating these challenges could enhance the reliability and utility of POCUS measurements as a standardized clinical tool in heart failure management.

As POCUS becomes increasingly integrated into the clinical care of heart failure patients, workflows and protocols for personalized application will evolve and expand. The study group's demonstration of collecting and utilizing large volumes of POCUS data in daily clinical practice shows promise for further expansion and refinement. Future research will be crucial for refining methods of acquiring POCUS data and optimizing its use in managing heart failure patients, particularly in achieving tighter control of volume status. Longitudinal management and assessing transitions of care-from hospitalization to ambulatory settings-carry significant implications at a population level. Understanding how POCUS data can support these processes will be essential for enhancing patient outcomes and optimizing healthcare resource utilization.

Disclosures

The authors have nothing to disclose.

Acknowledgments

Cedars-Sinai Hospital Honest Enterprise Research Broker (HERB) Committee, Los Angeles, California, USA.

References

1. Diaz-Gomez, J., Mayo, P. H., Koenig, S. J. Point-of-care ultrasonography. *N Engl J Med.* **385**, 1593-1602 (2021).
2. Zieleskiewicz, L. et al. Bedside POCUS during ward emergencies is associated with improved diagnosis and outcome: An observational, prospective, controlled study. *Crit Care.* **25** (1), 34 (2021).
3. Al Deeb, M., Barbic, S., Featherstone, R., Dankoff, J., Barbic, D. Point-of-care ultrasonography of the diagnosis of acute cardiogenic pulmonary edema in patients presenting with acute dyspnea: A systematic review and meta-analysis. *Acad Emerg Med.* **21** (8), 843-852 (2014).
4. Spevack, R. et al. Serial lung and IVC ultrasound in the assessment of congestive heart failure. *Crit Ultrasound J.* **9** (1), 7 (2017).
5. Ciozda, W. et al. The efficacy of sonographic measurement of inferior vena cava diameter as an estimate of central venous pressure. *Cardiovascular Ultrasound.* **14** (1), 33 (2015).
6. Kedan, I. et al. Decreasing hospital utilization of a high risk heart failure population in a large urban Accountable

Care Organization: The use of a clinical pharmacist, serial biomarkers, and Point of Care Ultrasound. *J Am Coll Cardiol.* **67** (13 Supplement), 1298 (2016).

7. Kehl, D., Zimmer, R., Sudan, M., Kedan, I. Handheld ultrasound as a novel predictive tool in atrial fibrillation: Prediction of outcomes following electrical cardioversion. *JMIR Cardio.* **2** (1), e7 (2018).
8. Miller, W. L. Fluid volume homeostasis in heart failure: A tale of 2 circulations. *J Am Heart Assoc.* **11** (18), e026668 (2022).
9. Porter, T. R. et al. Guidelines for the use of echocardiography as a monitor for therapeutic intervention in adults: A report from the American Society of Echocardiography. *J Am Soc Echocardiogr.* **28** (1), 40-56 (2015).
10. Katz, S. D. In search of euvolemia in heart failure. *J Am Cardiol HF.* **2** (3), 306-307 (2014).
11. Bhoil, R., Ahluwalia, A., Chopra, R., Surya, M., Bhoil, S. Signs and lines in lung ultrasound. *J Ultrason.* **21** (86), e225-e233 (2021).
12. Hacialiogullari, F. et al. Role of point-of-care lung and inferior vena cava ultrasound in clinical decisions for patients presenting to the emergency department with symptoms of acute decompensated heart failure. *J Ultrasound Med.* **40** (4), 751-761 (2021).
13. Gil-Rodriguez, J. Et al. Ultrasound findings of lung ultrasonography in COVID-19: A systematic review. *Eur J Radiol.* **148**, 110156 (2022).
14. Li, S. J., Lee, J., Hall, J., Sutherland, T. R. The inferior vena cava: Anatomical variants and acquired pathologies. *Insights into Imaging.* **12** (1), 123 (2021).
15. Lam, J. et al. Accelerated remote consultation tele-POCUS in cardiopulmonary assessment (ARCTICA). *POCUS J.* **5** (2), 55-58 (2020).