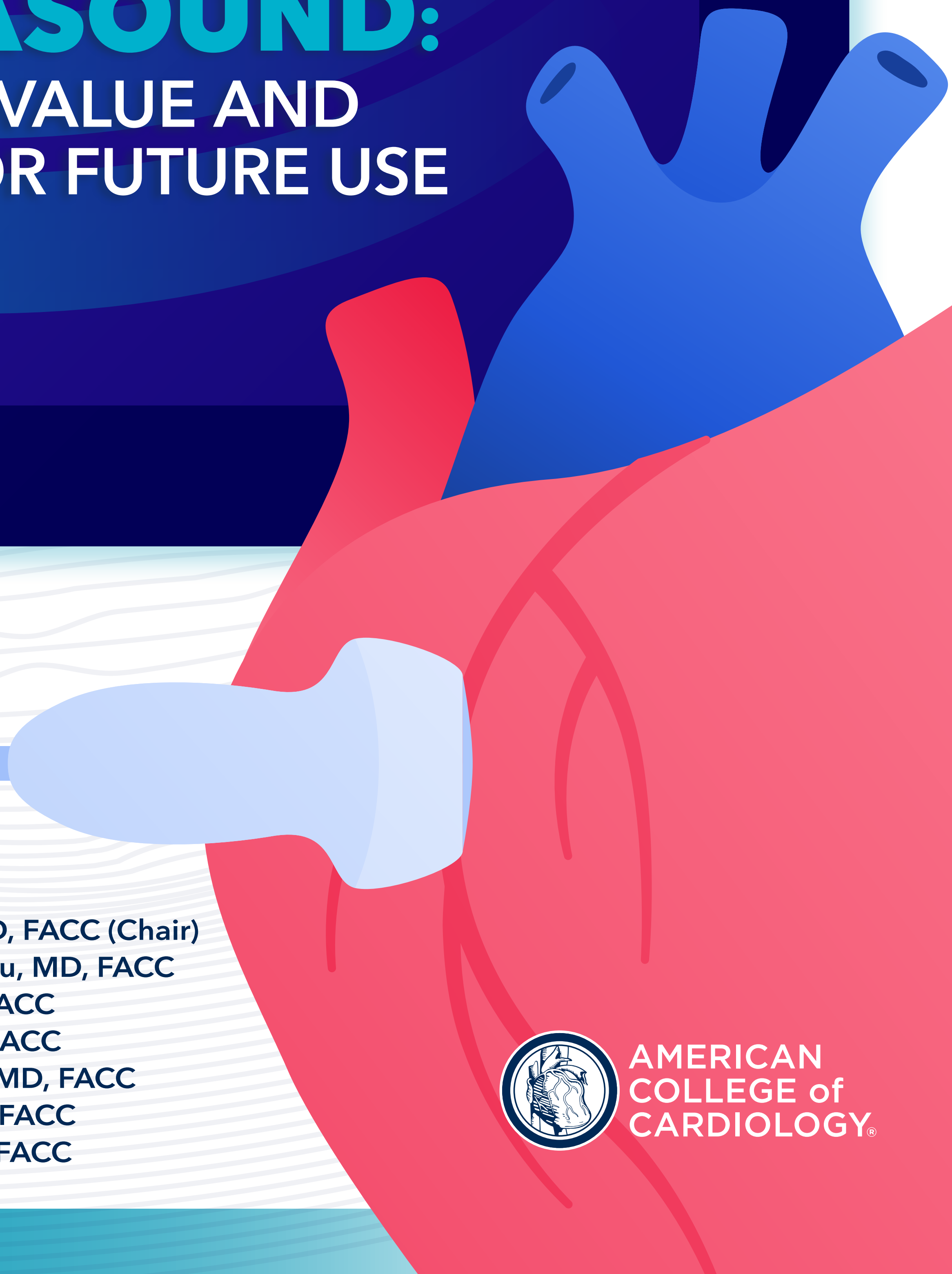
CARDIOVASCULAR POINT OF CARE ULTRASOUND: CURRENT VALUE AND VISION FOR FUTURE USE



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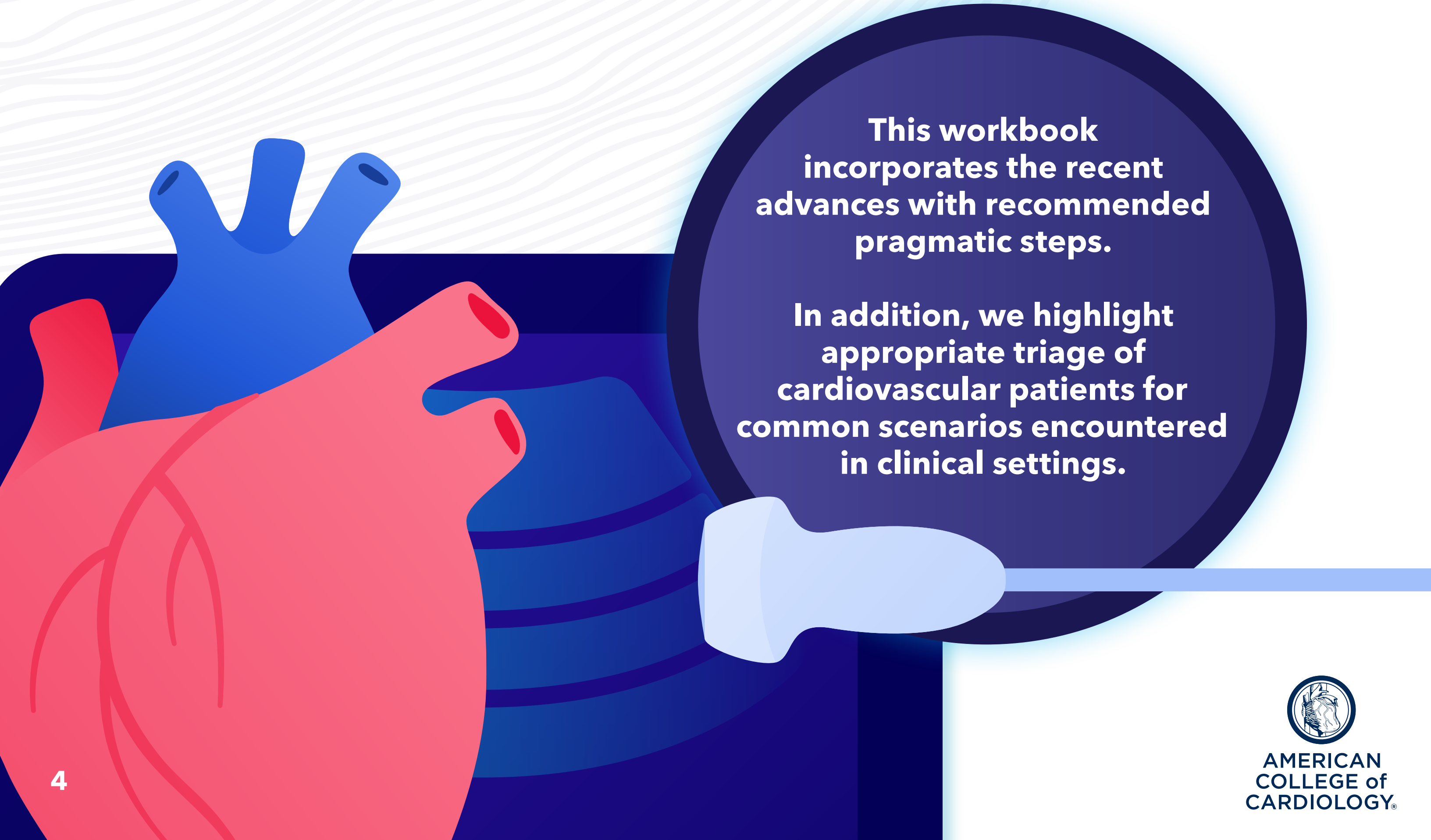
The content in this workbook is not intended to serve as official policy or clinical guidelines of the American College of Cardiology Foundation. Rather, the content is intended to provide suggestions as to best practices and mechanisms for the adoption of innovative solutions which can augment, but do not replace, usual clinical care.

INTRODUCTION

- The widespread commercial availability of "pocket, or handheld, probes" has heightened the interest of using point of care ultrasound (POCUS) assessments in clinical practice. This includes almost all specialties in a multitude of clinical care settings. POCUS is now part of medical student education in many medical schools across the U.S.
- Cardiovascular POCUS is an ultrasound examination of the heart and the vascular system. While sonographers usually perform an echocardiogram, a cardiovascular POCUS is more often performed by the clinician at the bedside (such as in the emergency room).
- "Point of care" refers to any ultrasonic examination performed at the patient's bedside. However, a routine scan employed as an extension of physical examination is usually referred to as an ultrasound augmented physical examination. The primary purpose is to screen for an abnormality during a physical examination *(Table 1)*.
- In comparison, "cardiovascular POCUS" refers to a limited imaging protocol employed to detect or characterize a subscribed list of readily apparent pathological findings or to facilitate serial assessments of specific anatomic or physiological parameters. The scope and applications of cardiovascular POCUS have been previously defined *(Table 1)*.
- Numerous studies have shown that direct visual assessment using cardiovascular POCUS is superior to cardiovascular auscultation for detecting cardiovascular diseases during routine bedside cardiovascular examination. This is true regardless of the level of experience of the operator.
- Specifically, the use of cardiovascular POCUS has grown recently as the first-line ultrasound examination performed in COVID-19 patients, which can then guide the need for further imaging. Cardiovascular POCUS has been used to detect primary cardiovascular complications in COVID-19 (e.g., cardiomyopathy) or secondary cardiopulmonary effects of COVID-19 (e.g., pulmonary hypertension).

- Because POCUS is now widely available (inexpensive and small enough to carry in a lab coat) and used by a wide variety of clinicians (who often have less training in ultrasound as compared to a specialist), there is an opportunity to further enhance the quality of image acquisition and interpretation by using artificial intelligence (AI), remote learning and guidance, web-based operations, and other technology.
  - Advances in AI enable assistance in image acquisition and interpretation by novice users. During the COVID-19 pandemic, new paradigms were introduced to use POCUS remotely through direct supervision (Tele-POCUS) or AI-driven guidance.
  - Previous studies have shown that a rigorous and consistent curriculum using evidence-based protocols can reinforce the proficiency goals for a sustainable cardiovascular POCUS program.
  - Furthermore, web-based operations and internet connectivity have introduced new opportunities for remote learning and training programs that can incorporate on-the-job competency assessment.
- However, cardiovascular POCUS is still in its early stages of adoption despite the new capabilities and is not universally utilized.



DEFINITIONS, TRAINING AND COMPETENCIES

	Diagnostic Competency	Interpretation of Findings	Quantification	Documentation	Teaching Required
Ultrasound-assisted Physical Exam (UAPE)	Imaging protocol to augment bedside examination.	Binary decision: Presence or absence of ultrasound "signs" indicative of a cardiovascular abnormality.	Usually not performed.	The recording is not obligatory; information recorded as part of physical examination.	Introductory and modest (weeks).
Cardiac POCUS	Specific imaging protocols based upon suspicion of a particular disease (e.g., rule out tamponade).	Findings related to the diagnosis sought in protocol.	Optional	Image archiving can be performed, and findings can be reported as a clinical note.	Modest (weeks to months).[1]
Lung POCUS	Assessment for B-lines.	Qualitative evaluation for the presence or absence and the amount of B-lines.	Usually not needed.	Non-obligatory storage of images. Interpretation can be added to the clinic/progress note.	Introductory and modest (weeks). No clear guidelines on formal training available.[2,3,4]
Vascular POCUS	Assessment for vascular pathology. Guidance for vascular access.	Qualitative evaluation for the presence of aneurysm, DVT, atherosclerosis.	Usually not needed beyond aneurysm measurement.	Non-obligatory storage of images. Interpretation can be added to the clinic/progress note.	Modest (weeks to months) to add training and case numbers involving vascular pathology, DVT, and vascular access.[1,5]

DVT = deep vein thrombosis

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CARDIOVASCULAR GOAL-DIRECTED POCUS

- A goal-directed, rapid (<10 minutes) approach to evaluating cardiovascular structures via POCUS is recommended to allow for initial screening and assess for changes in cardiovascular structure.
- Evaluation may focus on a specific differential diagnosis within cardiovascular POCUS.
- Cardiovascular assessment may cross-over among specific aspects of cardiac, lung and vascular POCUS.
- POCUS may also serve as a quick initial evaluation for significant post-procedural complications.
- Goal-directed POCUS may serve as a first-line evaluation to further comprehensive echocardiography.

ACQUISITION SETTINGS AND GOALS

Acute Care Settings:

- **In a symptomatic patient in an Inpatient Unit, Emergency Department, Urgent Care, or Outpatient environment**
    - The POCUS cardiovascular evaluation may uncover new cardiovascular pathologies not previously known. These include structural abnormalities like valvular heart disease or functional abnormalities like the presence of new regional wall motion abnormalities. Functional abnormalities can suggest significant coronary artery disease (CAD) or global left ventricular dysfunction as seen in cardiomyopathies.
    - POCUS cardiovascular evaluation may be helpful for rapid assessments in conditions like pericardial effusion, and pathologies affecting the right side of the heart, such as pulmonary embolism or pulmonary hypertension.
    - POCUS evaluation could be helpful in arriving at the underlying etiological diagnosis of patients, like those seen post-cardiac arrest.
    - In patients with shortness of breath or dyspnea, POCUS may enable differentiation from cardiac pathologies (e.g., congestive heart failure [CHF]) vs. primary lung pathology (e.g., chronic obstructive pulmonary disease).
    - POCUS evaluation may enable limited assessment of valvular pathology, including the presence of aortic or mitral stenosis or valvular regurgitation. However, a detailed quantitative assessment of the severity of valvular pathology, including spectral Doppler echocardiography, will typically require a full echocardiographic assessment based on current technology.
    - A vascular-focused POCUS could exclude lower extremity deep vein thrombosis (DVT). A vascular POCUS examination can also aid in line placement or confirm line placement after the procedure (refer to vascular section on page 24).

- **Intensive Care Unit/Cardiovascular Care Unit**
  - In addition to the goals listed above, the POCUS cardiovascular evaluation *(Figure 1)* may help differentiate different types of shock and evaluate volume status.
  - For hospitalized patients that underwent structural or interventional procedures *(Figure 2)*, POCUS allows for a brief, targeted approach to the most significant complications. In transcatheter aortic valve replacement (TAVR), POCUS may enable the identification of procedural complications that include coronary occlusion (via wall motion abnormality), valve malposition, or new significant paravalvular regurgitation.
  - For patients undergoing mitral transcatheter edge-to-edge repair (TEER), left atrial appendage closure, pacemaker implantation, or coronary intervention, POCUS may enable screening for new pericardial effusion or tamponade in patients with new post-procedural symptoms (e.g., chest pain) or hemodynamic instability *(Figure 2)*.
  - For patients post coronary intervention, POCUS may enable evaluation of new wall motion abnormality that may signify acute coronary stent thrombosis or a new area of myocardial infarction *(Figure 2)*.

- **Acute Care patients admitted for non-cardiovascular indications**
  - POCUS evaluation may be helpful in the pre-operative risk stratification evaluation by assessing ventricular size and function and providing a limited valvular assessment.

Non-Acute Care Settings:

- **Outpatient Visit/Long Term Care Facilities/Dialysis Centers**
  - In patients with shortness of breath or dyspnea, POCUS *(Figure 1)* may enable differentiation from cardiac pathologies (e.g., CHF) vs. primary lung pathology (e.g., chronic obstructive pulmonary disease).
  - It may also enable limited assessment of valvular pathology *(Figure 1)* in a patient with a new murmur, including the presence of aortic or mitral stenosis or valvular regurgitation. However, a detailed quantitative assessment of the severity of valvular pathology, including spectral Doppler echocardiography, will typically require a full echocardiographic assessment based on current technology.
  - In a patient with hypertension, a POCUS evaluation may aid a clinician in tailoring initial medications when medical management is indicated.
  - In a long-term care facility or dialysis center, POCUS may help assess a patient's volume status or assess for causes of hypotension.
  - POCUS evaluation in chronic heart failure management may help assess volume status. It may also evaluate if a change in medication or device therapy is indicated or if a full echocardiographic assessment is needed.

- **Virtual Care/Telemedicine Visits**
  - For patients undergoing telemedicine visits *(Figure 1)*, POCUS represents an opportunity for clinicians to evaluate real-time cardiovascular structure and function while allowing patients to stay in their home environment.
  - This POCUS approach may allow for an augmented physical examination, prevent hospital admission, and direct the management of new symptoms. To implement this model *(Figure 4)*, innovative approaches to personnel trained in POCUS would need to be available for image acquisition.

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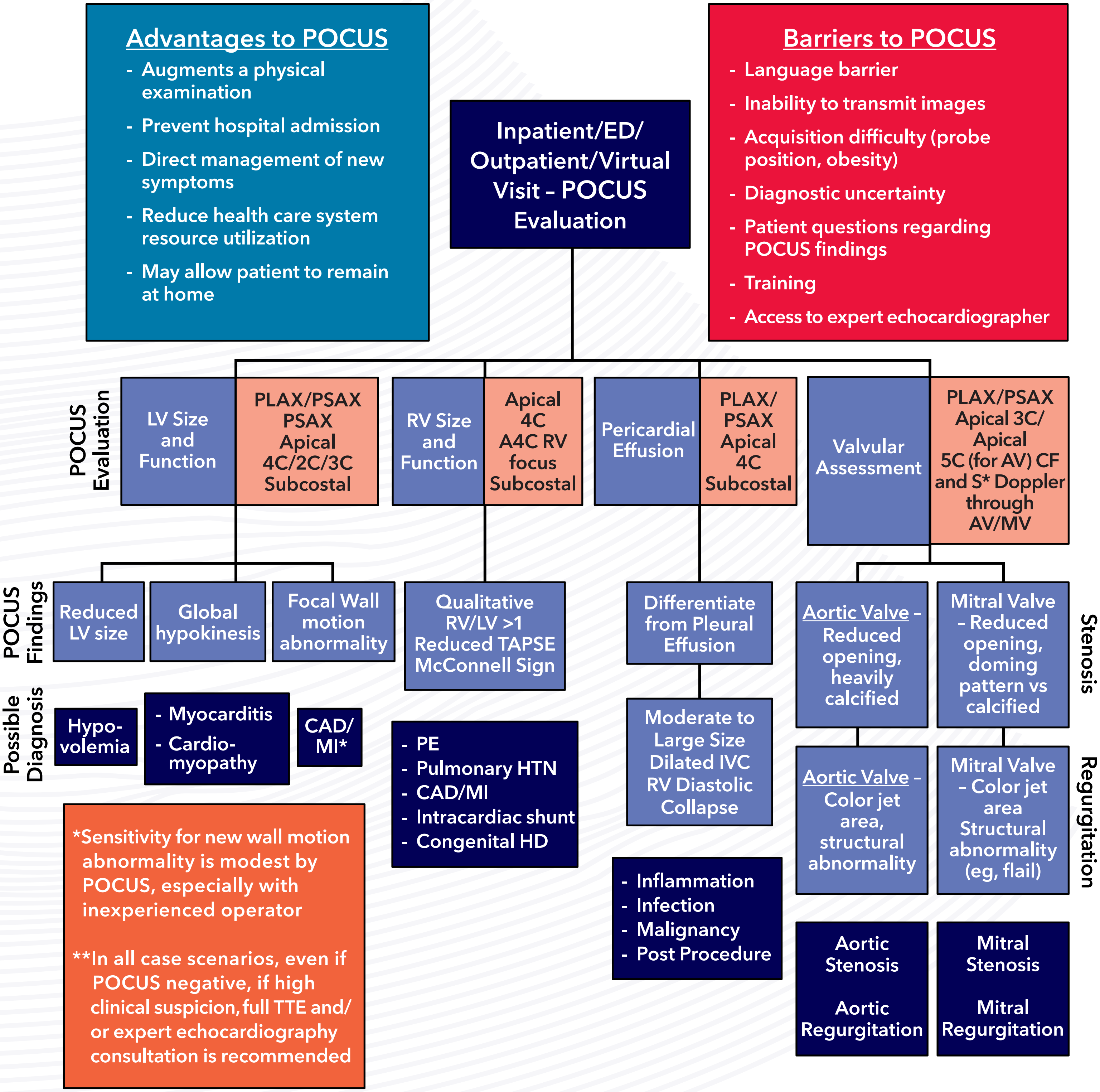
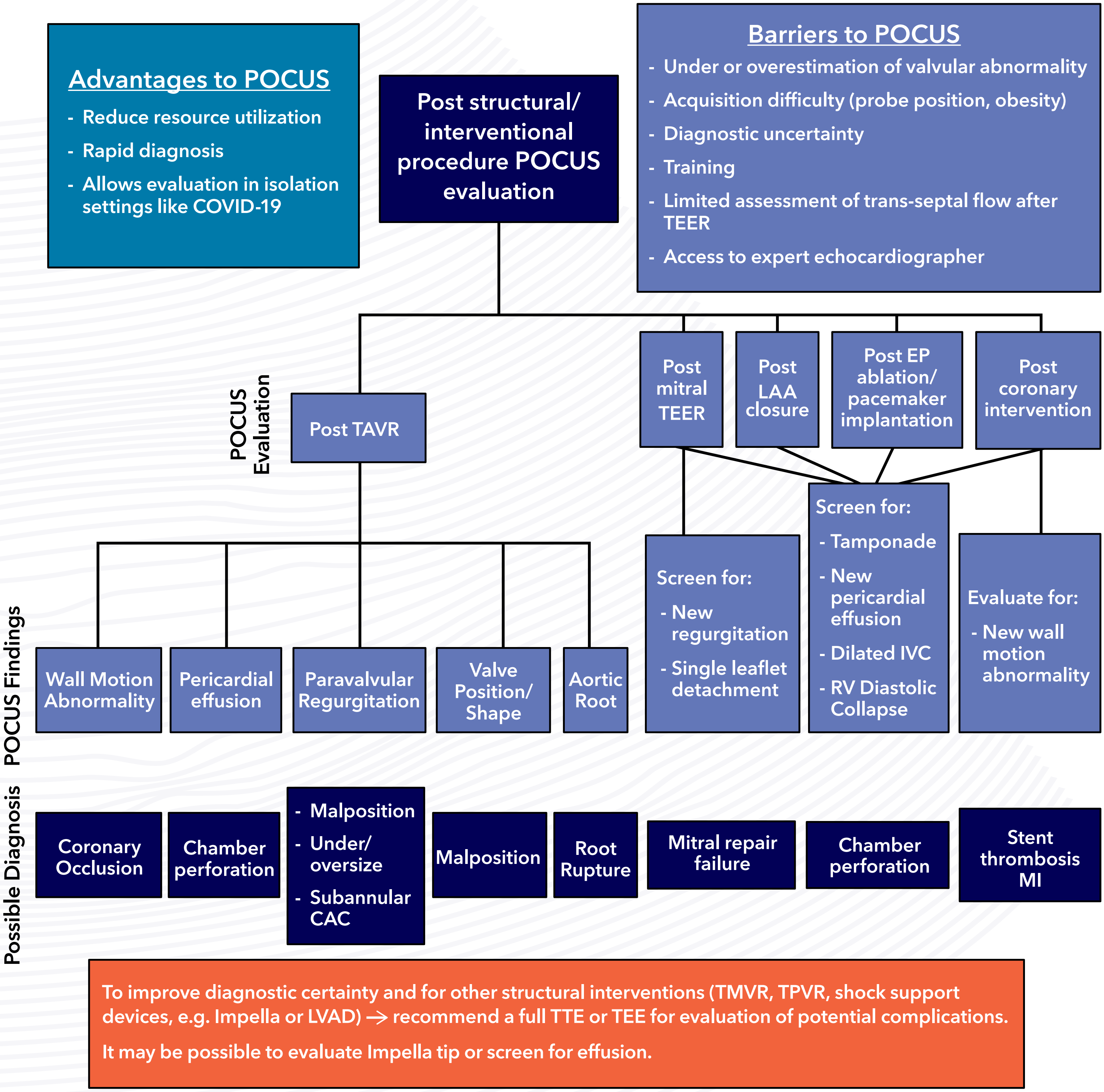
Figure 1



ED = emergency department; LV = left ventricle; PLAX = parasternal long axis view; PSAX = parasternal short axis view; A4C = apical four chamber; RV = right ventricle; AV = aortic valve; CF = color flow; S = spectral; MV = mitral valve; TAPSE = tricuspid annular plane systolic excursion; IVC = inferior vena cava; CAD = coronary artery disease; MI = myocardial infarction; PE = pulmonary embolism; HTN = hypertension; HD = heart disease; TTE = transthoracic echocardiogram
* = if available

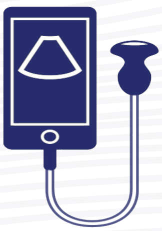
Figure 2



TEER = transcatheter edge-to-edge repair; TAVR = transcatheter aortic valve replacement; LAA = left atrial appendage; EP = electrophysiology; IVC = inferior vena cava; RV = right ventricle; CAC = coronary artery calcification; MI = myocardial infarction; TMVR = transcatheter mitral valve replacement; TPVR = transcatheter pulmonary valve replacement; LVAD = left ventricular assist device; TTE = transthoracic echocardiogram; TEE = transesophageal echocardiogram

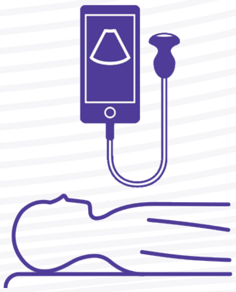
HOW TO PERFORM A CARDIOVASCULAR POCUS: A STEPWISE APPROACH *(FIGURE 3)*

1 Instrumentation and Machine Preparation:



- Pocket probes include those manufactured by Butterfly Network, Inc (Burlington, MA), Clarius Mobile Health Corp. (Vancouver, BC), EchoNous (Redmond, WA), GE Healthcare (Chicago, IL), Philips (Amsterdam, The Netherlands); SonoQue (Yorba Linda, CA), TENS Pros (St. Louis, MO), etc.
- Unique probe technology that uses a silicon chip array instead of piezoelectric crystals allows images to be displayed in various formats. Previously, this would have required separate probes.
- Image quality is reasonably good when used by a trained provider, but it may still be limited by body habitus.
- Harmonic imaging is a feature of many systems. Color flow Doppler is widely available, while spectral Doppler is available on some systems. Other systems have implemented measurement packages and applications.
- Wireless and Bluetooth technology now facilitates transducer recognition, battery charging, and image transfer.
- Touch screen technology is standard, and screen sizes have become so small that they either fit in a pocket or utilize a display application on a cell phone.
- Besides low initial cost and maintenance, these pocket probes offer telecommunication over a cloud-based platform for remote viewing of acquired images to allow distant peer evaluation.

2 Patient Preparation:



- Patients could either be lying supine or sitting upright on the exam table during the inpatient or outpatient visit.
- If performed at home, the patient could be lying supine or sitting upright in a comfortable place while a trained family member helps obtain the images.
- A focused and goal-directed ultrasound examination should be performed to answer a specific clinical question based on the patient's presentation.

3 Storage

- After images are acquired, the transmission of POCUS images to a cloud-based service allows an expert cardiologist echocardiographer to rapidly interpret the images and aid in immediate management decisions and therapies.
- A challenge in this area is that the infrastructure required for POCUS storage and PACS systems may represent an element of infrastructure duplication within a hospital network. This may require careful consideration and resolution.
- Access to archived POCUS images facilitates a complete patient imaging record for medicolegal and clinical quality assurance purposes. However, patient privacy and security must be carefully considered.

4 Interpretation and Reporting

- If hospital-based ultrasound systems are used for POCUS, the clinician should possess a method for recording data onto a media format that allows for offline review and archiving. The ultrasound examination interpretation should be documented within the medical record.

- For non-hospital based POCUS, the report may be incorporated as an extension of physical assessment and reported in the consultation note or history and physical assessment.

- A trained clinician should interpret the studies in POCUS, and findings should be reported in the provider's note.

- Official reports should be consistent with the real-time interpretation provided. A notification of substantive changes should be forwarded to medical records and the patient and/or the patient's physicians as appropriate. Reports should include the following[6]:

  i. Date and time of study
  ii. Name and hospital ID number of patient
  iii. Patient age, date of birth, and gender
  iv. Indication for study
  v. Name of the person who performed the study
  vi. Findings
  vii. Limitations and recommendations for additional studies
  viii. Impression
  ix. Name of the person who interpreted the study
  x. Date and time the report was signed
  xi. Mode of archiving the data

- In new clinically significant pathology cases, follow-up with a complete comprehensive transthoracic echocardiogram or transesophageal echocardiogram is recommended as deemed necessary and should be performed under the direction of an expert cardiologist echocardiographer to clarify and confirm the findings.

- A complete echocardiography study is generally recommended to improve diagnostic certainty for other structural interventions (e.g., transcatheter mitral valve replacement, cardiogenic shock support devices such as an Impella, or left ventricular assist device). (n.b.: It may be possible to evaluate the tip of a percutaneous mechanical support device or screen for pericardial effusion from POCUS if adequate windows can be obtained in the post-procedural setting).[1]

HOW TO PERFORM A CARDIOVASCULAR POCUS

Machine preparation

Smart device
i. Unlock the smart device.
ii. Connect your smart device to Wi-Fi.
iii. Login with your credentials.

Home
i. Patient lying supine or sitting in comfortable location.
ii. Trained family member/relative helps obtain images.

Telemedicine
i. Patient in front of the camera allowing visualization of the area of interest by the provider.

Patient preparation
Associate the patient with study

Inpatient/Outpatient
i. Patient lying supine or sitting on exam table.
ii. Examiner to the left of the patient.

Home
i. Patient lying supine or sitting in comfortable location.
ii. Trained family member/relative helps obtain images.

Telemedicine
i. Patient in front of the camera allowing visualization of the area of interest by the provider.

Recommended sequences
Cardiac protocol ±
Volume protocol ±
Vascular protocol

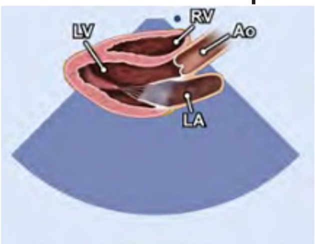
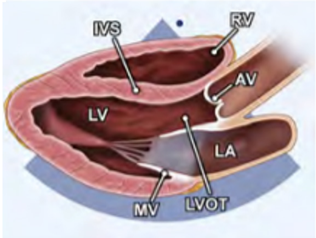
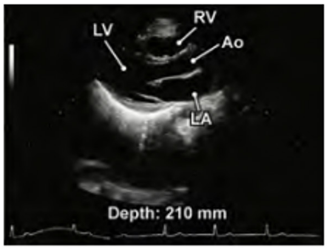
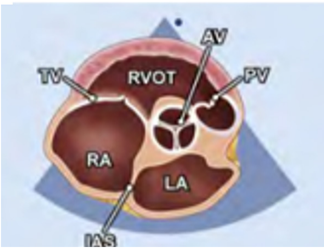
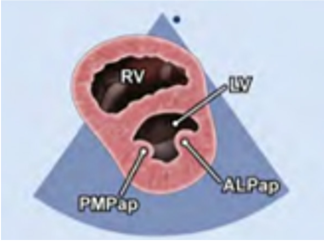
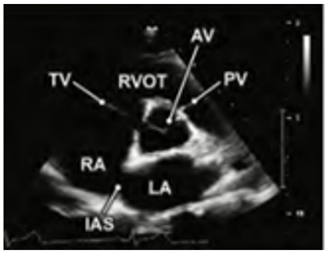
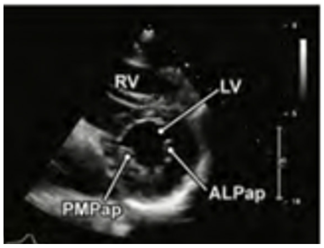
Storage
i. Clean the probe after each exam.
ii. Disconnect the probe from the smart device.
iii. Upload images in to the cloud.

Interpretation and reporting
i. To be interpreted by a physician trained in POCUS.
ii. Findings related to the diagnosis sought in protocol.

PERFORMING A CARDIAC POCUS: VIEWS AND PROTOCOLS

The common views used for adequately imaging the cardiac structures, along with their purpose, appropriate patient positioning, and probe positioning, are described in detail in *Table 2*. A combination of different views (as described in *Figure 1*) can be used for a more comprehensive approach to diagnosis based on purpose of the study. *Figures 1* and *2* also describe the possible POCUS findings and the diagnosis associated with those findings.

Steps for Image Acquisition and Views Obtained During Cardiac POCUS[7]

PLAX View:	**Anatomic Image**	**2D TTE Image**
Purpose: To assess the size and function of the left ventricle, any gross abnormalities of the aortic valve, mitral valve, or ascending aorta, and the presence of pericardial effusion. **Patient positioning:** Left lateral decubitus position **Probe positioning:** The transducer is placed in the third or fourth intercostal space to the left of the sternum, with the index marker pointed to the patient's right shoulder at approximately the 9 to 10 o'clock position.	**PLAX increased depth**  **PLAX left ventricle** 	 
PSAX View:	**PSAX (level great vessels) focus on AV**	
Purpose: Several anatomic structures are imaged by tilting the transducer first superiorly and then progressively inferiorly to multiple levels (aortic valve, papillary muscle, and apex levels). **Patient positioning:** Left lateral decubitus position **Probe positioning:** The transducer is rotated 90 clockwise from the PLAX view to position the beam perpendicular to the long axis of the left ventricle.	 **PSAX (level of papillary muscles)** 	 

PLAX = parasternal long axis view; TTE = transthoracic echocardiogram; PSAX = parasternal short axis view; AV = aortic valve

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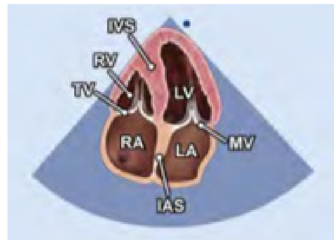
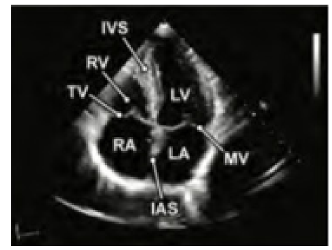
(continued)

<table>
<tr><th>Apical Four Chamber (A4C) View:</th><th>Anatomic Image</th><th>2D TTE Image</th></tr>
<tr><td rowspan="6">

Purpose: This view can be used for visual assessment of the LV, RV, LA, RA, as well as the mitral and tricuspid valves. It can also be used to look for evidence of pericardial effusion.

Patient positioning: Left lateral decubitus position

Probe positioning: The transducer is placed at the palpated apical impulse with the index marker oriented toward the bed. Optimize the depth setting to focus on the LV apical 4C view. Rotate the transducer to maximize the RV area.

</td><td colspan="2">A4C</td></tr>
<tr><td>
</td><td>
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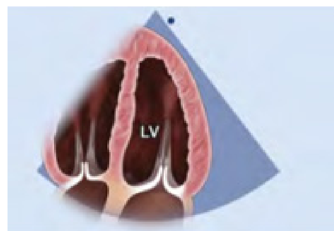
<tr><td colspan="2">A4C zoomed left ventricle</td></tr>
<tr><td>
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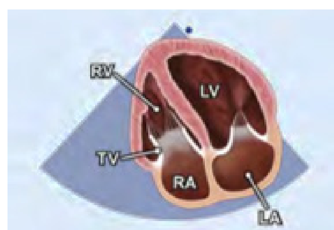
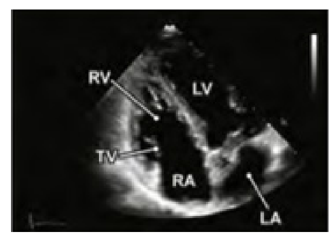
<tr><td colspan="2">A4C RV-focused</td></tr>
<tr><td>
</td><td>
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<tr><th>Right Ventricle-Focused View:</th><td colspan="2">A4C RV-focused</td></tr>
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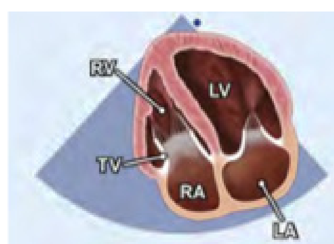
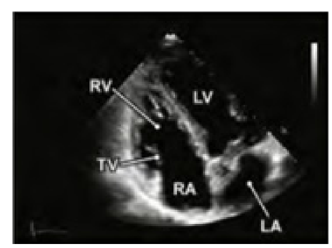
Purpose: Visual assessment of the RA, RV and tricuspid valve for size, function, and any other gross pathology.

Patient positioning: Left lateral decubitus position

Probe positioning: The transducer is rotated slightly counterclockwise from the A4C view while keeping it at the apex to maximize the RV area in this view.

</td><td>
</td><td>
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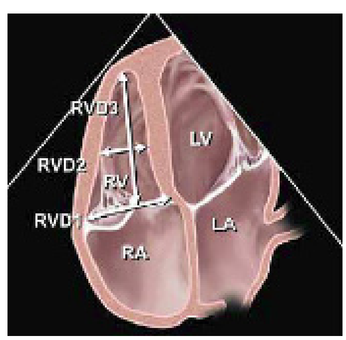
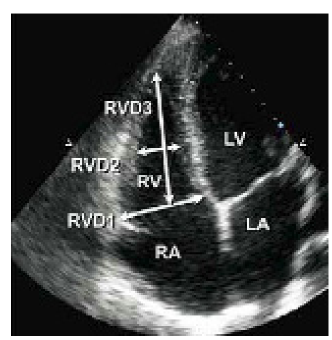
<tr><td>
</td><td>
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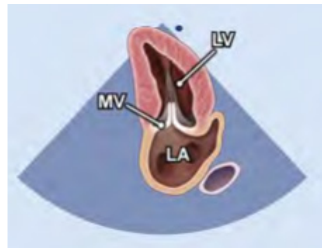
A4C = apical four chamber; TTE = transthoracic echocardiogram; LV = left ventricle; RV = right ventricle, LA = left atrium; RA = right atrium

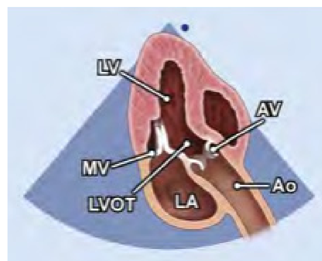
Table 2

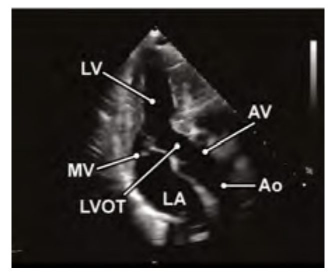
(continued)

Apical 2 Chamber View:	Anatomic Image	2D TTE Image
Purpose: In this view, the left atrium, MV, and left ventricle are demonstrated. **Patient positioning:** Left lateral decubitus position **Probe positioning:** From the full A4C view, the transducer is rotated approximately 60^0 counterclockwise to demonstrate the apical two-chamber (A2C) view. 2C Optimized to fill sector, apex up.	A2C	

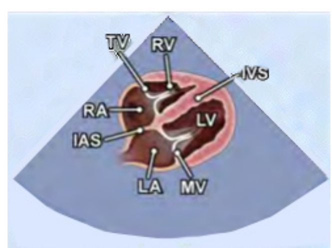


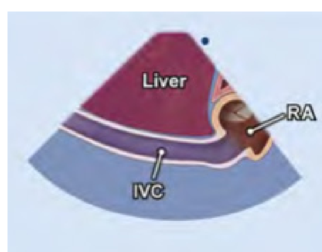
Apical 3 Chamber View/ Apical Long-Axis View:	
Purpose: The apical long-axis view demonstrates the left atrium, MV, left ventricle, AV, and aorta. **Patient positioning:** Left lateral decubitus position **Probe positioning:** Rotate 60^0 counterclockwise from apical 2C view.	Apical long axis





Subcostal View:	
Purpose: - Measure IVC with and without sniff to estimate the RA pressures. - Look for presence of pericardial effusion and RV collapse in the presence of pericardial effusion. Patient positioning: Supine Probe positioning: Transducer at subxiphoid position, orientation index marker pointing toward the patient's left shoulder. *Reprinted with permission from Elsevier. Mitchell C, Rahko PS, Blauwet LA, et al. Guidelines for performing a comprehensive transthoracic echocardiographic examination in adults: recommendations from the American Society of Echocardiography. J Am Soc Echocardiogr 2018;32:1-64.*	SC 4C SC long axis IVC





A2C = apical two chamber; TTE = transthoracic echocardiogram; MV = mitral valve; AV = aortic valve; SC = subcostal; IVC = inferior vena cava; RA = right atrial; RV = right ventricle

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Cardiac POCUS Key Takeaways:

- Cardiac POCUS provides rapid bedside diagnosis of important cardiovascular pathology.
- Cardiac POCUS involves a limited imaging protocol to detect or characterize specific findings or to facilitate serial assessments in a timely fashion *(Figure 1 and 2)*.
- The most significant value of cardiac POCUS is as an adjunct to the history and physical examination to provide more rapid and appropriate patient management in the early phases of their presentation.
- It is impractical to enumerate the specific clinical settings or patient conditions in which cardiac POCUS-assisted physical examination might be helpful. Instead, general clinical settings are described in which (1) a POCUS trained clinician needs to assess a patient at the bedside, (2) POCUS would improve the clinician's assessment over the tools that would otherwise be available, such as a stethoscope and one's hands, and (3) echocardiography is not available, not available quickly enough, or impractical. For patients undergoing telemedicine visits *(Figure 1)*, POCUS represents an opportunity for clinicians to evaluate real-time cardiovascular structure and function while allowing patients to stay in their home environment.

VOLUME ASSESSMENT

POCUS for targeted assessment of volume status can be obtained by combining an evaluation of the lungs (B-lines) with the size and collapsibility of the inferior vena cava (IVC) *(Table 3)*. The goal is (a) to differentiate cardiogenic from non-cardiogenic causes of dyspnea, e.g., cardiogenic vs. non-cardiogenic pulmonary edema, (b) to monitor the response to diuresis/dialysis[8,9,10] and (c) to provide with the estimate of the right atrial pressure (specific to the IVC). Assessment of the IVC comprises of evaluation of its size (dilated vs. normal) and its collapsibility with respiration ("sniff test"; collapsible vs. not). In certain cases, assessment of either the lungs, the IVC or both, may be challenging *(Table 4)*.

(A) Lungs - B-Lines

- B-lines are linear, vertical echogenic artefacts/reverberations – semi quantitative signs of pulmonary interstitial fluid
- Etiology of B-lines: contrast between air (alveoli) and water (edema), due to their opposite properties of acoustic impedance[11]
- Normal presentation: very few B-lines
- Pulmonary edema is characterized by progressive thickening of the interlobular septa and collection of alveolar water resulting in B-lines[12]

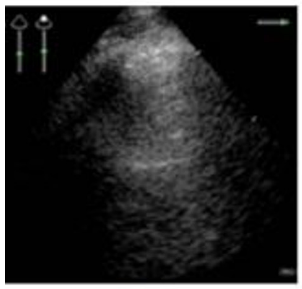
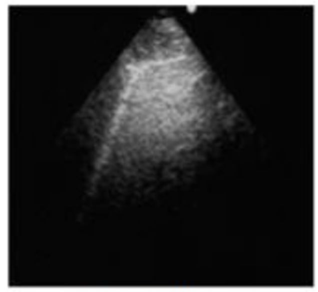
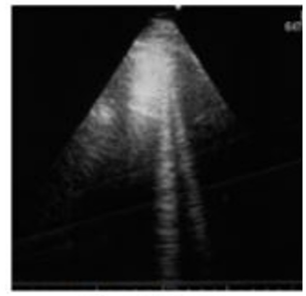
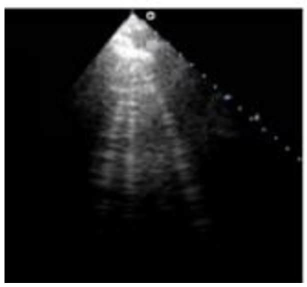
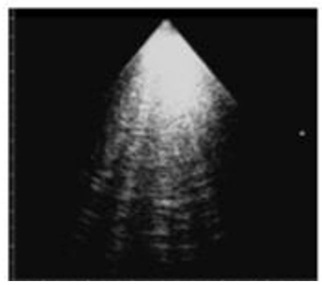
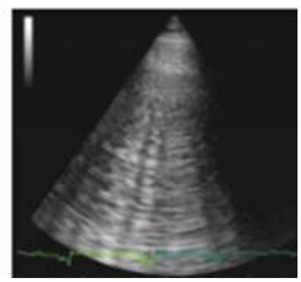
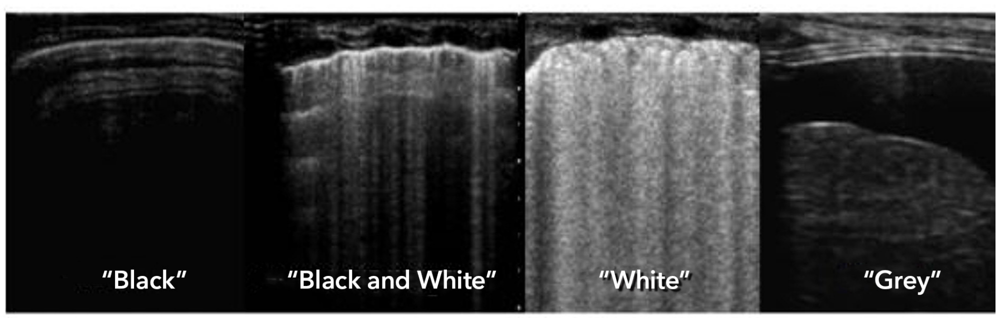
(B) IVC

- An assessment of IVC provides the most evidence-based surrogate of volume status compared to other large veins[13]
- Evaluation entails assessing both the size and collapsibility with respiration[14]
- Presence of collapsibility (>50%) shown to correlate with fluid responsiveness[13]

Advantages of POCUS assessment of the lungs and the IVC:

- Qualitative
- Easy to do (no need for color or spectral Doppler)

POCUS EVALUATION OF THE LUNGS AND THE IVC:
How to Perform and What to Look For

Lungs[15]:	**B-lines**
Purpose: To differentiate cardiogenic from non-cardiogenic causes of pulmonary edema. **Patient positioning:** Sitting, supine or near-supine **Probe positioning:** anterior and lateral chest on the left and right hemithorax from the 2nd to the 4th (on the left) and 2nd to 5th (on the right) intercostal spaces and from the parasternal to the axillary line. *Reprinted with permission from BioMed Central Ltd. Gargani L. Lung ultrasound: a new tool for the cardiologist. Cardiovasc Ultrasound 2011;9:6.*	 No B-lines  One B-line  Two B-lines  Three B-lines  Five B-line  Full white screen = 10 B-lines  Normal / Mild/moderate Interstitial edema / Severe Interstitial edema/ alveolar edema / Consolidation

(Table 3 will continue in the next page)

AMERICAN COLLEGE of CARDIOLOGY

Table 3

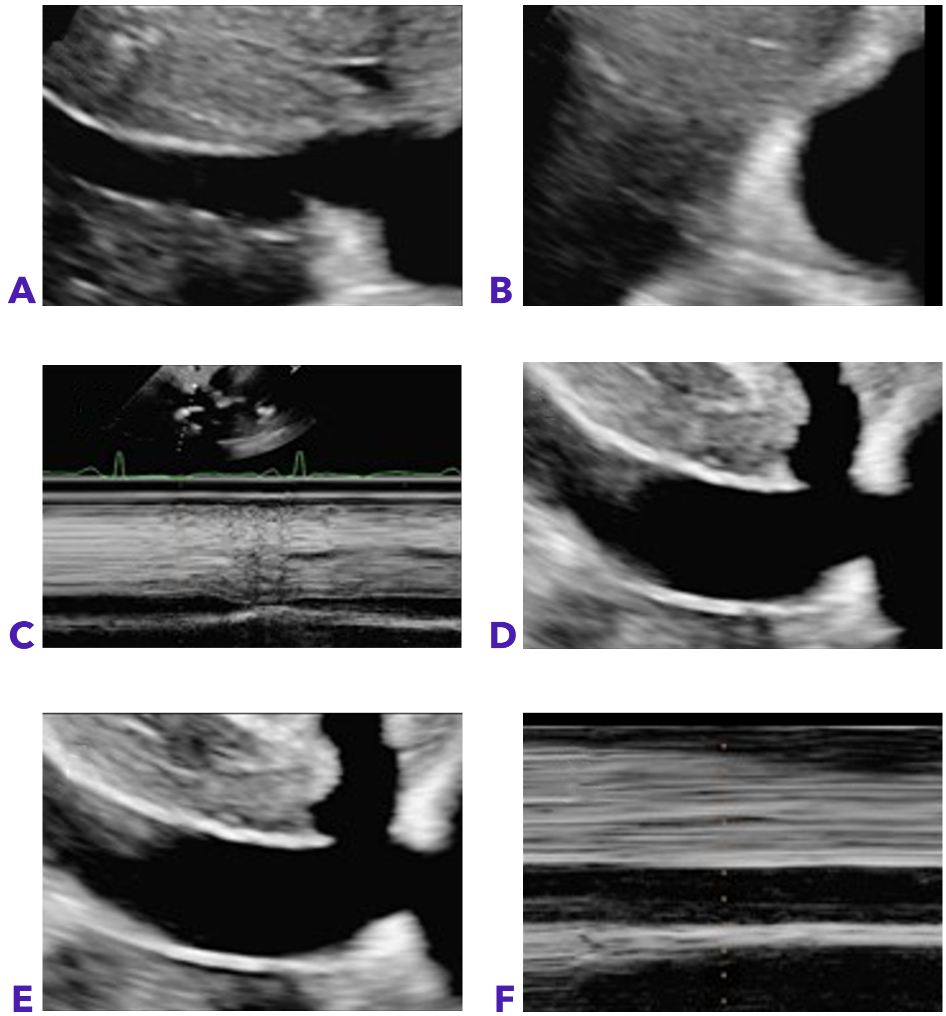
(continued)

Inferior Vena Cava (IVC)[16]:

Purpose: To assess the diameter of the IVC at inspiration and expiration and its collapsibility to estimate the right atrial (RA) pressure. In ventilated patients, the change in IVC diameter in response to changes in intrathoracic pressure during ventilation can be helpful.

Patient positioning: Supine

Probe positioning: subcostal window angling the transducer to the patient's right to visualize the IVC in a longitudinal view at the IVC–RA junction level. The IVC diameter is measured on inspiration and expiration at approximately 1-2 cm distal to the IVC–RA junction. B-mode or M-mode imaging.



A and B: normal size IVC with normal collapsibility (>50%, by visual estimate). **C:** M-mode of sniff test showing normal sized IVC with normal collapsibility (>50% by visual estimate). **D and E:** dilated IVC with reduced collapsibility (<50%, by visual estimate). **F:** M-mode of sniff test showing dilated IVC with reduced collapsibility (<50%, by visual estimate).

IVC = inferior vena cava, RA = right atrial

Table 4

CHALLENGING SCENARIOS WHEN PERFORMING IVC AND LUNG POCUS IMAGING

- Obesity
- Prominent ribs
- Surgical dressings over the chest or upper abdomen
- Chest wounds
- Open chest following cardiac surgery
- Devices, e.g., defibrillator pads
- Mechanical ventilation
- Subcutaneous emphysema (specific to assessment of the lungs)
- Emphysematous lungs (specific to assessment of the lungs)
- Prominent bowel gas (specific to assessment of the IVC)

IVC = inferior vena cava

Volume Assessment Key Takeaways:

- POCUS assessment of the lungs and IVC aims at differentiating cardiogenic from non-cardiogenic causes of dyspnea (lungs) and to monitor response to diuresis/dialysis.
- Easy and quick without need for color/spectral Doppler.
- Beware of challenging cases which may preclude imaging of diagnostic quality.

VASCULAR ASSESSMENT

Much of the vascular system, both arteries and veins, can be imaged by ultrasound, so there are multiple clinical situations where vascular assessment is an important component to cardiovascular POCUS *(Table 5)*. In symptomatic patients, aortic or deep vein pathology can be evaluated. In a comprehensive cardiovascular exam, detection of vascular atherosclerosis or aortic pathology can guide care. POCUS can also be used to guide vascular access.

- In patients presenting with chest pain or shortness of breath, vascular diagnoses (e.g., aortic aneurysm/dissection, DVT may be the underlying cause.[4,6,17,18]
  - Aorta: Evaluation of the ascending aorta for aneurysm/dissection is recommended, especially when aortic valve pathology is detected.[19] Studies have also shown high accuracy for abdominal aortic aneurysm (AAA) detection by POCUS in symptomatic patients. The pooled operating characteristics of seven studies of emergency department POCUS for the detection of AAA were sensitivity 99% and specificity 98%.[20]
  - DVT: POCUS has shown high accuracy for diagnosing acute proximal DVT. Metanalyses on the topic have consistently shown POCUS has a sensitivity between 90–95% and specificity between 91–98%.[21,22]
- In outpatients, vascular POCUS can detect pathology (e.g., carotid plaque, AAA) as part of a comprehensive cardiovascular examination and risk assessment.
  - Atherosclerosis: Carotid plaque detection may provide incremental information for ASCVD risk assessment.[23-26]
  - Aorta: AAA assessment may aid early detection and risk management, though it should not supplant formal United States Preventive Services Task Force (USPSTF)-recommended screening.[27]
- POCUS is well-recognized as a valuable aid to guiding vascular access procedures.[5]
  - POCUS-guided venous access: internal jugular, subclavian, femoral, and peripheral veins
  - POCUS-guided arterial access: radial, brachial, axillary, femoral, and dorsalis pedis arteries

STEPS FOR IMAGE ACQUISITION AND VIEWS OBTAINED DURING VASCULAR POCUS

<table>
<tr>
<td>Aorta:</td>
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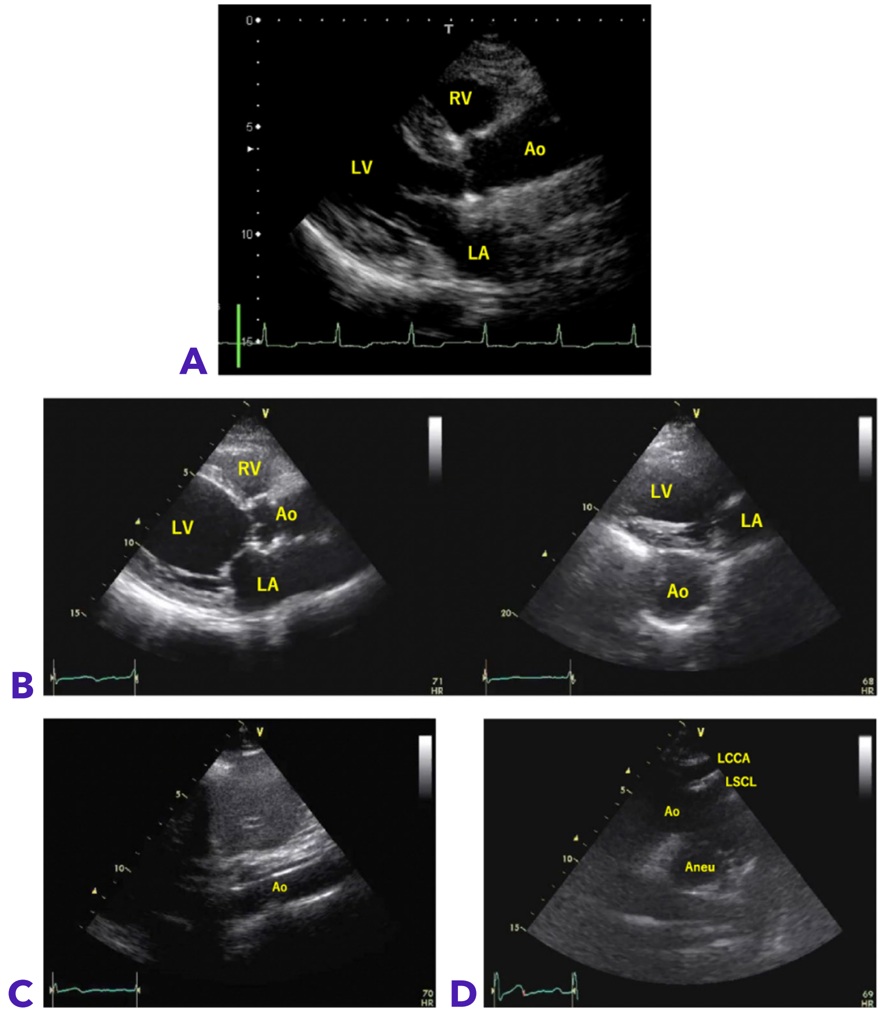

A: PLAX view from the superior intercostal space showing the proximal to mid-portion of the ascending aorta. B: Making the scale of the depth smaller (left to right) visualizes an aneurysm of the descending aorta under the LV. C: Sub-xiphoid approach illuminating the distal descending aorta to the abdominal aorta. D: Supra-sternal view disclosing a saccular aneurysm of the aortic arch.[19]
</td>
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<tr>
<td>
Purpose: Assess for pathology in the thoracic and abdominal aorta.

Patient positioning: Supine

Probe positioning: High parasternal long-axis for the ascending aorta, suprasternal notch for the aortic arch, and subxiphoid for the abdominal aorta.

Reprinted with permission from Springer. Nishigami K. Use of aortic point-of-care ultrasound in conventional and emergent echocardiography. J Med Ultrason (2001) 2022;49:655-661.
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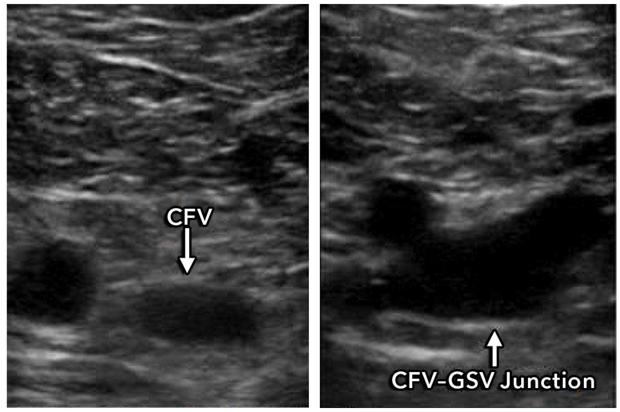
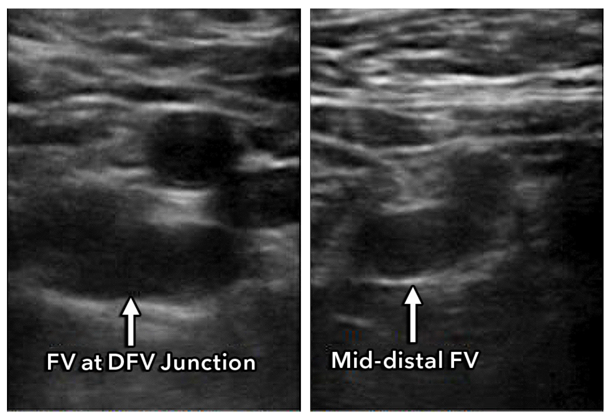
PLAX = parasternal long axis view; LV = left ventricle

(Table 5 will continue in the next page)

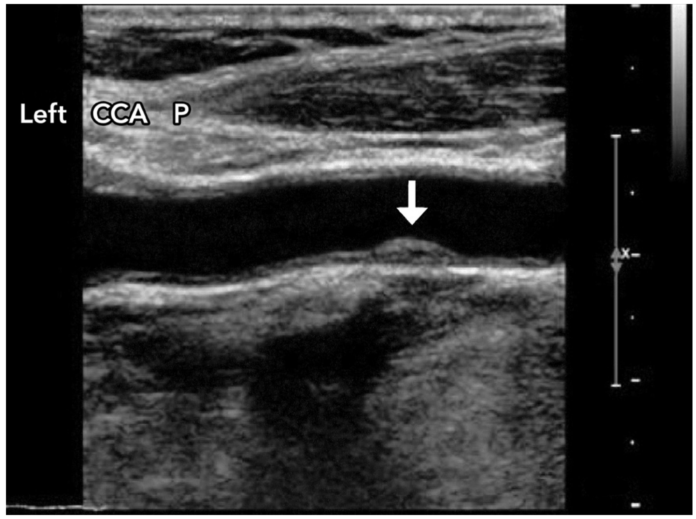
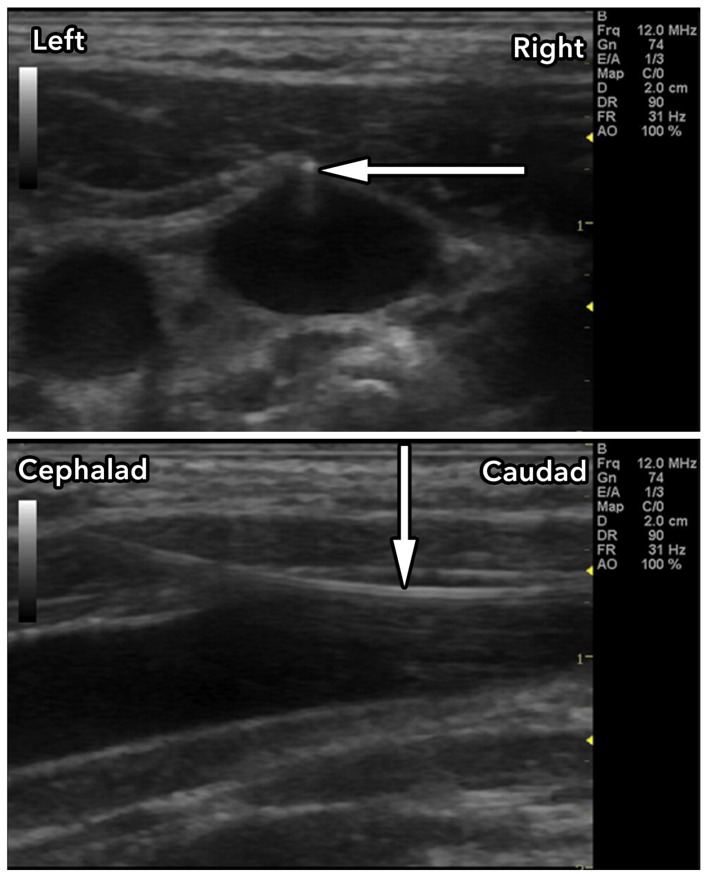
(continued)

Deep Veins:	
Purpose: Assess for acute proximal DVT. **Patient positioning:** Supine with head elevated 30 deg plus hip and knee in "frog leg" position **Probe positioning:** Imaging of multiple locations from the common femoral to popliteal veins for thrombus and compressibility, per "2-point" or "3-point" protocol. *Reprinted with permission from MDPI. Varrias D, Palaiodimos L, Balasubramanian P, et al. The use of point-of-care ultrasound (POCUS) in the diagnosis of deep vein thrombosis.J Clin Med 2021;10:3903.*	 Point 1: Common femoral vein (CFV) and junction of CFV with great saphenous vein (GSV).  Point 2: Femoral vein (FV) at deep FV (DFV) junction, as well as mid-distal FV. 2-point POCUS technique for evaluation of acute proximal DVT in the right lower extremity.[21]

DVT = deep vein thrombosis, CFV = common femoral vein; GSV = greater saphenous vein; FV = femoral vein; DFV = deep femoral vein

(Table 5 will continue in the next page)

(continued)

Carotid: **Purpose:** Assess for presence of carotid plaque. **Patient positioning:** Supine with neck rotated away from probe. **Probe positioning:** Short- and long-axis scanning of common carotid, bulb, and internal carotid artery. *Reprinted with permission from BioMed Central Ltd. Park TH. Evaluation of carotid plaque using ultrasound imaging. J Cardiovasc Ultrasound 2016;24:91-95.*	 Carotid ultrasound showing an asymptomatic single plaque (arrow) on the far wall of the proximal common carotid artery (CCA).[26]
Vascular Guidance: **Purpose:** Guide venous or arterial cannulation **Patient positioning:** Depends on access site. **Probe positioning:** Depends on access site. *Reprinted with permission from Elsevier. Troianos CA, Hartman GS, Glas KE, et al. Guidelines for performing ultrasound guided vascular cannulation: recommendations of the American Society of Echocardiography and the Society of Cardiovascular Anesthesiologists. J Am Soc Echocardiogr 2011;24:1291-1318.*	 Cannulation of the right internal jugular vein in short-axis (top) and long-axis (bottom) views showing guidewire (arrow).[5]

CCA = common carotid artery

Table 6

CHALLENGING SCENARIOS WHEN PERFORMING VASCULAR ASSESSMENT

- Obesity limiting vascular imaging
- Imaging of ascending aorta, arch, and descending aorta often incomplete
- Focused 2D imaging of the carotids may not detect all vascular plaques
- Bedside AAA measurement not as accurate as formal vascular ultrasound

AAA = abdominal aortic aneurysm

Vascular Assessment Key Takeaways:

- Vascular POCUS of the aorta and deep veins can help in the emergent diagnosis of symptomatic patients.
- POCUS of vascular plaque and aneurysms can enhance comprehensive cardiovascular risk assessment.
- Vascular POCUS can aid arterial and venous access procedures.

OTHER CLINICAL SCENARIOS

TASK	POCUS Finding	POCUS Diagnosis
Pre-operative	- LV size / function - RV size / function - focused valvular assessment - venous structures for vascular access	- cardiomyopathy - abnormal LV chamber size / function - LV regional wall motion abnormalities - dilated or hypokinetic RV - reduced opening / restrictive AV or MV leaflets - significant aortic or mitral insufficiency - correct (or incorrect) placement of arterial or venous lines
Post-Cardiac Arrest	- LV size / function - RV size / function - assess for pericardial effusion - focused valvular assessment - venous structures for vascular access	- LV regional wall motion abnormalities - cardiomyopathy - abnormal LV chamber size / function - dilated or hypokinetic RV - pericardial effusion - reduced opening / restrictive AV or MV leaflets - significant aortic or mitral insufficiency - correct (or incorrect) placement of arterial or venous lines - IVC size and collapsibility

LV = left ventricle, RV = right ventricle, AV = aortic valve, MV = mitral valve, IVC = inferior vena cava

STRENGTHS, LIMITATIONS, AND FUTURE INNOVATIONS

1. Strengthening the Appropriateness of Imaging and Downstream Testing

- Multiple studies have modeled potential POCUS cost savings by reducing downstream testing of the standard echocardiography.[28,29,30]
- POCUS may serve as a gatekeeper for echocardiography requests, including those deemed "rarely appropriate" by Appropriate Use Criteria.[31]
- POCUS may identify essential pathology even in rarely appropriate indications. In one study of POCUS for such patients, 25% of total requests had new significant abnormalities on standard echocardiography that may have been missed if canceled. At the same time, the use of POCUS to screen rarely appropriate requests led to a 59% reduction in the standard echocardiography.[32]
- POCUS may reduce the time to scan when compared to the standard echocardiogram.[32]

2. Limitations of Goal-Directed POCUS

- The workgroup acknowledges significant knowledge gaps still remain with this POCUS innovation model.
- While most studies have evaluated major structural findings, subtle changes in cardiac structure may not be well evaluated by POCUS (as evidenced by the reduced sensitivity with inexperienced operators) and are compounded by acquisition challenges with inexperienced users.
- Quality assurance measures will need to be developed to allow for continuous feedback for POCUS users.
- Recent literature has found that structures such as the inferior vena cava, valvular and vascular assessment have not yet been well assessed by lay patients or by AI/ML approaches compared to left ventricular assessment.

BARRIERS TO CARDIOVASCULAR POCUS

Barriers	Solutions
POCUS skill set is not uniform	• Integrate throughout medical school education from anatomy to physiology to physical exam. • Dedicated training within primary care/internal medicine residency and cardiology/critical care fellowship programs. • In-clinic training and certification for practitioners; online training is not very practical (according to a recent study, only 26% of academic faculty could get appropriate training by using online resources or in-person proctored sessions due to difficulties finding time to schedule for them).[33] • "Teleguidance" help service for practitioners.
Availability of the technology (institutions have varying policies on the use of POCUS)	• Incorporate POCUS accreditations and certifications programs to improve CV care processes and patient outcomes.
Quality of devices and imaging	• Equipment institutional committee should develop diagnostic imaging equipment standards. • Quality audit processes should be integrated into the POCUS program and closely tied to education.
No uniform agreement on documentation	• Physicians should document scan findings either in their clinical notes, a procedure note, or as a separate document.
Reimbursement, added time to an encounter	• POCUS may be billed under CPT 93308 only by providers who have both competency and institutional privileges to read a transthoracic echocardiogram. Providers may consider including the time spent with the patient in clinical documentation.
Storage/Cloud/Internet security issues	• Develop institutional committees and resources to regularly assess the storage needs, cybersecurity, and privacy risk.

3. Innovative Approaches to Cardiovascular POCUS:

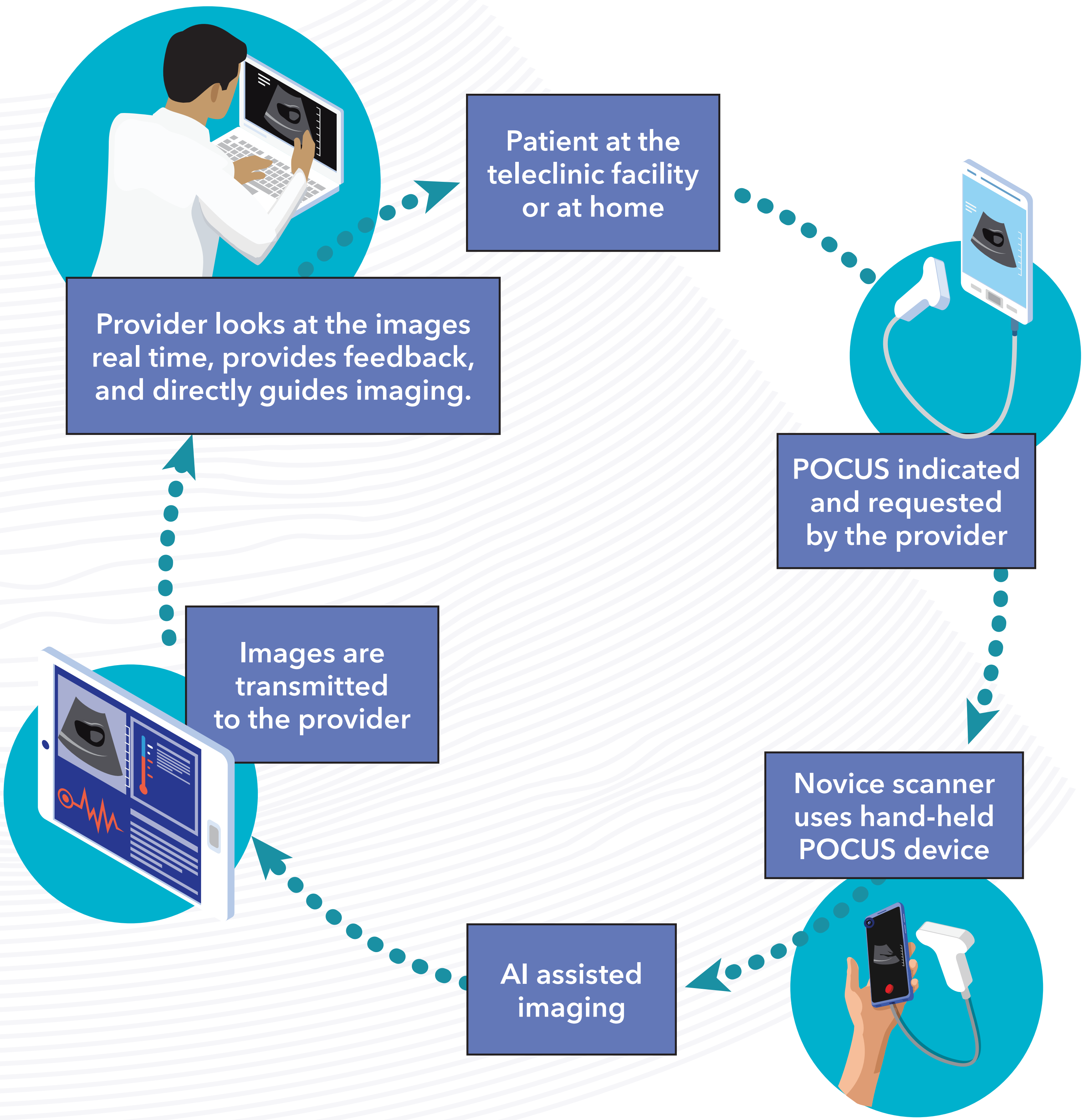
- Innovative acquisition approaches include 1) the training of clinicians involved in the care of patients with congestive heart failure/coronary artery disease/valvular heart disease/vascular disease, 2) traveling technologists with expertise in echocardiography, or 3) primary care clinicians with an emphasis on home visits, or 4) advanced practitioners and non-clinician health care professionals trained in POCUS.
- In addition, another innovative care model allows "lay patients" (persons without prior medical training but are closely associated with the patient, such as a family member) to perform POCUS with adequate training. This would require significant education, support, and a potential to integrate AI for image acquisition.
- As a frame of reference, tele-echocardiography, guided by family members, has been utilized in specialized pediatric echocardiography environments where access to care may be limited due to geographic considerations.[28,34] One example is the Stanford Children's Center.[35]
- Chen et al. evaluated 15 parent-patient pairs with unrepaired Marfan's Syndrome aortopathy trained to assess the aorta via POCUS.[34] They found similar measurements between parental-acquired POCUS with remote interpretation and clinically acquired echocardiography of the aortic root.[34] Similarly, Dykes, et al. evaluated pediatric patients who underwent heart transplantation living a median distance of 131 miles from the main echocardiography center with challenging access to routine pediatric echocardiography. Here, parents received 1-hour training with POCUS and performed image acquisition at home. In the small (N=15) cohort, 100% reported they were moderately comfortable using POCUS. The qualitative assessment of LV function was adequate in 100% of home POCUS, but the quantitative evaluation of home POCUS was limited to 43% of the cohort.[36]

- In a recent meta-analysis of 33 studies with >6,000 participants, Jenkins et al. found that using POCUS, trained echocardiographers were able to detect cardiac LV abnormalities with reasonable sensitivity (85%–89%) and specificity (91%–98%), as opposed to inexperienced users (e.g., nurses, medical students, general practitioners, and cardiology trainees) (60-80% reduction in sensitivity between experienced and non-experienced users).[37] Therefore, while inexperienced users may acquire images for the foreseeable future, the final interpretation would require images relayed to trained providers for interpretation.
- **As noted previously, to reference the previous section on image acquisition, as part of a novel paradigm, the following recommendations are provided for acquisition during a telehealth visit:** during a visit, the patients should be positioned on their back for a cardiac exam or seated upright for a lung scan so that the supervising clinician or technologist can see the area of interest to guide the scan remotely. The bedside scanner can place video calls from the app, and providers can evaluate the POCUS acquisition directly from their computer either in real-time or at a future time *(Figure 4)*.

4. AI for Guiding POCUS Acquisition

- AI techniques are being increasingly adopted into POCUS. The instrumentation using AI techniques has been used for technology-assisted image acquisition for less experienced users. These steps may aid standardized image scanning, improve image quality, and automate measurements and interpretation.
- AI represents an emerging approach to augmenting the training of home-based, "lay" providers and clinicians inexperienced with echocardiography *(Figure 4)*.
- The workgroup proposes the potential use of AI to guide novice users as a strategy for POCUS acquisition with appropriate validation.
- Using validated machine learning (ML) algorithms to guide probe positioning may improve diagnostic quality through instantaneous user feedback on image quality.
- Narang et al. have recently tested deep learning convolutional neural networks to estimate correct probe positioning for nurses without prior ultrasound training.[38] In a prospective, multi-center study of adult patients, AI-guided nurses achieved high diagnostic quality for left ventricular size and function and the presence of a pericardial effusion for >98% of scans and high diagnostic quality for right ventricular size and position in >92%, which persisted across the BMI categories.
- Qualitative visual assessments of the aortic and mitral valves were also of high diagnostic quality. Inferior vena cava size assessment was modest with 58% adequate quality.[38]
- AI/ML learning-based approaches have been further tested to achieve safe image acquisition during the COVID-19 pandemic in the intensive care environment.[39,40]

Figure 4


Patient at the teleclinic facility or at home
POCUS indicated and requested by the provider
Novice scanner uses hand-held POCUS device
AI assisted imaging
Images are transmitted to the provider
Provider looks at the images real time, provides feedback, and directly guides imaging.

SUMMARY STATEMENT

- Cardiovascular POCUS may be used in outpatient and inpatient settings. It has distinct advantages in the emergency department, in critically ill patients, and in pre-procedural risk assessment before surgery, interventions or post-cardiac arrest.
- A goal-directed approach to the evaluation of cardiovascular structures via POCUS is recommended to allow for screening of cardiac structure changes, as well as an initial rapid (<10 minutes) evaluation for important inpatient post-cardiac procedural complications.
- POCUS may serve as a gatekeeper for echocardiography requests while identifying important pathology even in rarely appropriate indications.
- While most studies have evaluated major structural findings, subtle changes in cardiac structure may not be well evaluated by POCUS (as evidenced by the reduced sensitivity with inexperienced operators) and are compounded by acquisition challenges with inexperienced users.
- For patients undergoing telemedicine visits, POCUS represents an opportunity for clinicians to evaluate real-time cardiac structure and function while allowing the patient to stay in their home environment. The application of POCUS in virtual settings, however, is still in development and needs further refinement for routine application.
- Innovative acquisition approaches include: 1) the training of clinicians involved in the care of patients with congestive heart failure/coronary artery disease/valvular heart disease/vascular disease; 2) traveling technologists with expertise in echocardiography; 3) primary care clinicians with an emphasis on home visits; or 4) advanced practitioners and non-clinician health care professionals trained in POCUS.
- AI represents an emerging approach to augment the training of home-based, “lay” providers and clinicians inexperienced with echocardiography.
- The workgroup proposes the potential use of AI to guide novice users as a strategy for POCUS acquisition with appropriate validation.

Author Disclosures

Dr. Sengupta is a consultant for Echo IQ and RCE Technologies. Dr. Andrikopoulou is an advisory board member for Mpirik. Dr. Choi reports equity in Cleerly, Inc.; and is a consultant for Siemens Healthineers. Dr. McConnell is an employee at identifeye HEALTH; a medical advisory board member of 4Catalyzer Corp; and a previous employee (until 2022) at Google Health. All other authors have reported that they have no relationships relevant to the contents of this workbook to disclose.

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