MAYO CLINIC

REVIEW

Point-of-Care Ultrasonography for Primary Care Physicians and General Internists

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Abstract

Point-of-care ultrasonography (POCUS) is a safe and rapidly evolving diagnostic modality that is now utilized by health care professionals from nearly all specialties. Technological advances have improved the portability of equipment, enabling ultrasound imaging to be executed at the bedside and thereby allowing internists to make timely diagnoses and perform ultrasound-guided procedures. We reviewed the literature on the POCUS applications most relevant to the practice of internal medicine. The use of POCUS can immediately narrow differential diagnoses by building on the clinical information revealed by the traditional physical examination and refining clinical decision making for further management. We describe 2 common patient scenarios (heart failure and sepsis) to highlight the impact of POCUS performed by internists on efficiency, diagnostic accuracy, resource utilization, and radiation exposure. Using POCUS to guide procedures has been found to reduce procedure-related complications, along with costs and lengths of stay associated with these complications. Despite several undisputed advantages of POCUS, barriers to implementation must be considered. Most importantly, the utility of POCUS depends on the experience and skills of the operator, which are affected by the availability of training and the cost of ultrasound devices. Additional system barriers include availability of templates for documentation, electronic storage for image archiving, and policies and procedures for quality assurance and billing. Integration of POCUS into the practice of internal medicine is an inevitable change that will empower internists to improve the care of their patients at the bedside.

 ■ Mayo Clin Proc. 2016;91(12):1811-1827

Point-of-care ultrasonography (POCUS) is a safe and rapidly evolving diagnostic modality. Traditionally, ultrasonography has been used by imaging specialists, such as radiologists and cardiologists; however, it is now utilized by health care professionals from nearly all specialties. Technological advances have improved portability and miniaturization of equipment, allowing ultrasound imaging at the bedside to make timely diagnoses and guide procedures. Over the past several years, there has been emerging interest in the routine use of POCUS to potentially expedite and provide cost-efficient, high-value care.[1]

This technology has been touted as the "visual stethoscope" of the 21st century.[2,3] The stethoscope, developed 200 years ago, is the classic icon for the traditional diagnostic physical examination and is still the most widely used tool to examine patients at the bedside. It is interesting to note, however, that the stethoscope is truly a "stethophone" because it allows only listening to the human body (steth = chest, phone = sound), rather than truly looking inside the body (scope = to look in). However, as true "scopes," portable ultrasound devices can generate high-quality images revealing the structure and function of organs.[4] The traditional bedside physical examination has been on the decline within internal medicine for several years for various reasons.[5-9] This increase in ambiguity in diagnosis is potentially unsettling to internal medicine physicians who see a variety of complex presentations and want to "do no harm." Globally, medical education still emphasizes teaching traditional physical examination; however, no patient outcomes data justify application of physical examination techniques learned for commonly encountered clinical conditions. As an example, little data exist regarding an evaluation of central venous pressure using jugular venous distention in a morbidly obese patient. Moreover, many

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important cardiopulmonary abnormalities that are easily and rapidly detected by POCUS, such as pericardial fluid, left ventricular (LV) systolic dysfunction, and pleural effusion, are often missed by traditional physical examination. It is conceivable that patients' increasingly complex medical conditions, physicians' declining physical examination skills, and society's expectation for higher standards of medical care are all leading to increased utilization of POCUS for more accurate bedside assessments of patients.

POCUS can immediately narrow the differential diagnosis by building on clinical information revealed by the history and physical examination[10,11] and refine clinical decision making for further work-up and treatment.[12] Recent studies have found that clinical management involving the early use of POCUS accurately guides diagnosis, significantly reduces physicians' diagnostic uncertainty, and also changes management and resource utilization.[13] From a patient perspective, "very low" discomfort was reported during POCUS of the heart, lungs, and deep veins, and most patients agreed to be evaluated with POCUS in an emergency department.[14] Additionally, use of POCUS in the emergency department has been reported to improve patient satisfaction and short-term health care resource utilization.[15-17]

LITERATURE REVIEW AND CLINICAL APPLICATIONS

POCUS can be helpful in a variety of common clinical conditions by quickly identifying abnormalities that may not be revealed by a traditional physical examination.[2] For instance, consider the evaluation of a patient presenting with unexplained dyspnea. In these patients, POCUS of the lungs can rapidly detect pleural effusions, pulmonary edema (B lines, a type of comet tail artifact),[18] pneumonia (consolidation with dynamic air bronchograms),[19] or pneumothorax (absence of pleural sliding and presence of a lung point sign).[20]

Other conditions readily detected with POCUS include abdominal aortic aneurysms,[21] deep venous thromboses,[22] and peritoneal free fluid.[23] Central venous pressure can be estimated by assessing the inferior vena cava (IVC) or internal jugular vein size and collapsibility.[24] Focused cardiac ultrasonography can expeditiously assess global LV and right ventricular function and detect the presence of a pericardial effusion.[25] Other common POCUS applications include vascular, musculoskeletal, sinus, ocular, nerve, thyroid, gallbladder, liver, spleen, renal, testicular, and bladder imaging (Figure 1).

Several medical and surgical subspecialties have adopted POCUS protocols to rule in or rule out certain conditions using an algorithmic approach. Common protocols include BLUE (Bedside Lung Ultrasound in Emergency) for acute respiratory failure,[26] FAST (Focused Assessment with Sonography in Trauma) for peritoneal free fluid,[27] RUSH (Rapid Ultrasound for Shock and Hypotension) for shock,[28,29] and CLUE (Cardiovascular Limited Ultrasound Examination) for heart failure.[30] These protocols offer a logical POCUS workflow for specific clinical scenarios and provide a foundation to integrate POCUS findings into clinical decision making.

POCUS is not simply a diagnostic algorithm but rather a tool used by a skilled clinician at the bedside to guide clinical decision making in real time. Although almost any diagnostic evaluation can be aided by POCUS (Figure 1, Table), we will describe 2 common patient scenarios to highlight the impact of POCUS on efficiency, diagnostic accuracy, resource utilization, radiation exposure, and patient satisfaction.

CASE 1

A 41-year-old man with hypertension, type 2 diabetes mellitus, and asthma presented to the outpatient clinic with worsening shortness of breath. The shortness of breath had begun abruptly while the patient was at work in a cabinet woodworking shop. He had been evaluated in an urgent care clinic 1 week before presentation and treated with a short course of corticosteroids and inhaled albuterol. His symptoms improved initially but subsequently worsened. He reported frequent ankle swelling that had recently increased. A review of systems revealed loud snoring at night but no angina, orthopnea, paroxysmal nocturnal dyspnea, recent travel/immobilization, or infectious symptoms.

Traditional Physical Examination

Traditional physical examination revealed the following:

Mayo Clin Proc. ■ December 2016;91(12):1811-1827 ■ http://dx.doi.org/10.1016/j.mayocp.2016.08.023
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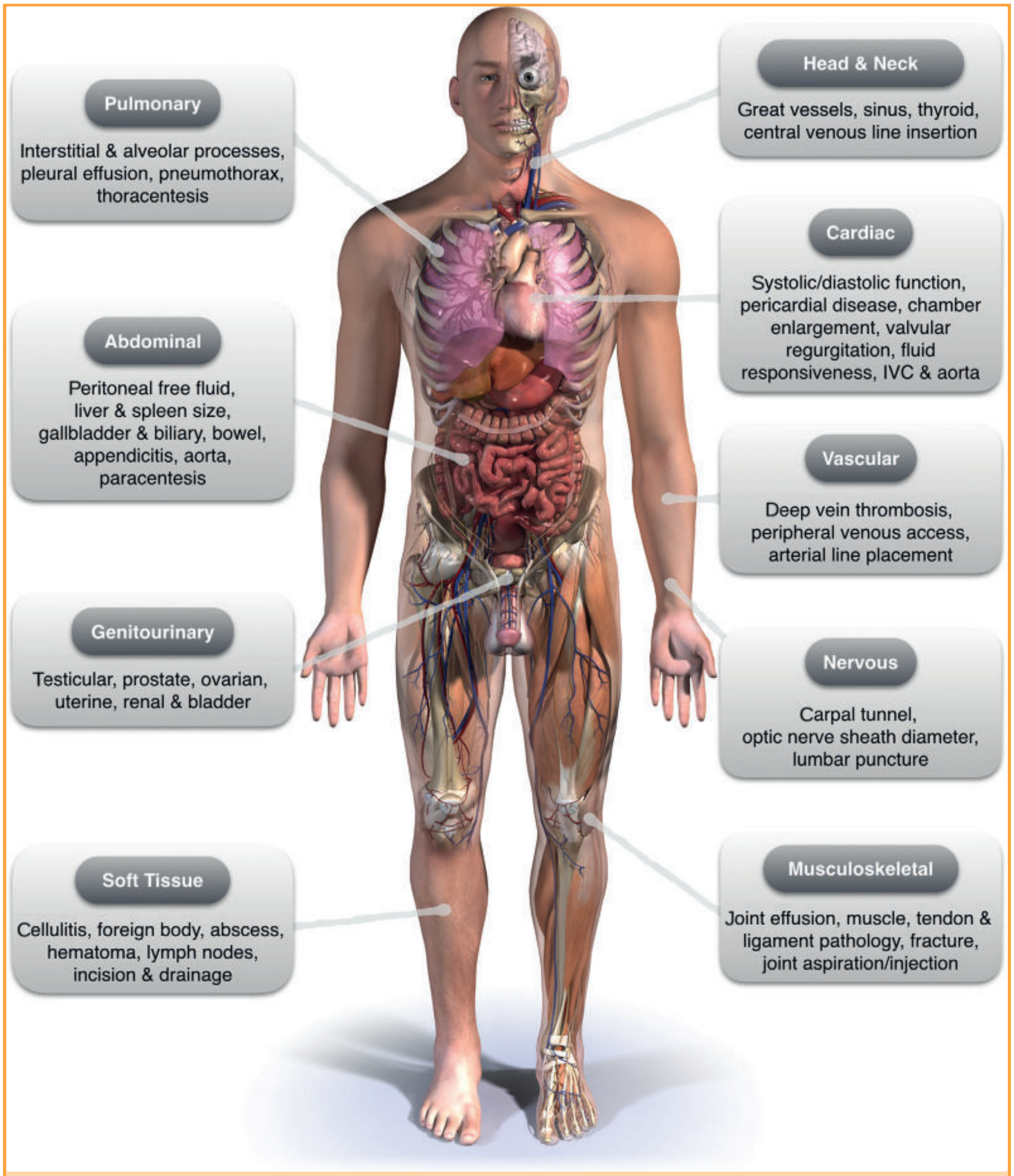

FIGURE 1. Internal medicine point-of-care ultrasonography applications. IVC = inferior vena cava.

- Vital signs: Temperature, 36.2°C; pulse rate, 90 beats/min; blood pressure, 128/85 mm Hg; respiratory rate, 15 breaths/min; oxygen saturation, 95%; body mass index (calculated as weight in kilograms divided by height in meters squared), 31 kg/m^2
- Head, ears, eyes, nose, and throat: Mild bilateral tenderness on percussion over maxillary sinuses
- Pulmonary: Distant lung sounds, occasional expiratory wheezing bilaterally
- Cardiovascular: Distant heart sounds, no murmur, neck veins not visible, mild bilateral edema of the ankles
- Abdomen: Protuberant, no palpable hepatosplenomegaly, no shifting dullness or fluid wave
- Skin: No abnormalities

Differential Diagnosis. On physical examination, the differential diagnosis includes asthma exacerbation, congestive heart failure, allergic

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TABLE. Test Characteristics of Physical Examination vs Point-of-Care Ultrasonography

	Physical examination[31]					Point-of-care ultrasonography				
Test characteristics	Finding	Sensitivity	Specificity	LR+	LR−	Finding	Sensitivity	Specificity	LR+	LR−
Pulmonary										
Pleural effusion	Percussion dullness	89%	81%	4.8	0.1	Pleural fluid visualization[32]	93%	96%	23	0.07
	Decreased breath sounds	88%	83%	5.2	0.1					
Pulmonary edema	Crackles	19%-64%	82%-94%	3.4	NS	B lines (bilateral)[33]	94%	92%	10.4	0.06
Pneumonia	Bronchial breath sounds	14%	96%	3.3	NS	Consolidation pattern[34,35]	94%-95%	90%-96%	13.5	0.06
	Egophony	4%-16%	96%-99%	4.1	NS					
	Crackles	19%-67%	36%-94%	1.8	0.8					
Cardiac										
Elevated LV filling pressures	4th Heart sound	37%-71%	50%-70%	NS	NS	PCWP ≥17 if				
						IVC >2.0[36]	75%	83%	4.4	0.3
						IVCCI <45%[36]	83%	71%	2.9	0.24
Elevated CVP >8 cm H_2O	Neck vein inspection	47%-92%	93%-96%	9.7	0.3	For CVP >10 mm Hg:				
						IVC size >2 cm[37]	73%	85%	4.9	0.32
						with IVCCI <50%[38]	87%	82%	4.8	0.16
						For CVP <10 mm Hg:				
						IVC <2 cm[39]	85%	81%	4.4	0.2
						with IVCCI >50%[39]	47%	77%	2.1	0.7
						IJV aspect ratio for CVP <8[40]	78%	77%	3.5	0.3
Reduced ejection fraction <50%	3rd Heart sound	11%-51%	85%-98%	3.4	0.7	LV systolic dysfunction[41-43]	84%-91%	85%-88%	6.5	0.14
Congestive heart failure	Crackles	12%-23%	88%-96%	NS	NS	B lines, bilateral[26]	97%	95%	19.4	0.03
	Elevated JVP	10%-58%	96%-97%	3.9	NS	For CVP >10 mm Hg:				
						IVC size >2 cm[37]	73%	85%	4.9	0.32
						with IVCCI <50%[38]	87%	82%	4.8	0.16
	Abdominojugular test	55%-84%	83%-98%	8.0	0.3					
	Edema	10%	93%-96%	NS	NS	CVP <10 mm Hg:				
						IVC <2 cm[39]	85%	81%	4.4	0.2
						with IVCCI >50%[39]	47%	77%	2.1	0.7

Continued on next page

TABLE. Continued

Test characteristics	Physical examination[31]					Point-of-care ultrasonography				
	Finding	Sensitivity	Specificity	LR+	LR−	Finding	Sensitivity	Specificity	LR+	LR−
Abdomen										
Hepatomegaly	Percussion	61%-92%	30%-43%	NS	NS	Hepatomegaly (≤13 or ≥15.5 cm)[44]	82%	90%	8.2	0.2
	Palpation	39%-71%	56%-85%	1.9	0.6					
Splenomegaly	Percussion	25%-85%	32%-94%	1.7	0.7	Splenomegaly[45]	100%	74%	3.8	0
	Palpation	18%-78%	89%-99%	8.5	0.5					
Bladder volume >400 mL	Palpation	82%	56%	1.9	0.3	US bladder volume >600 mL (transverse diameter >9.7 cm)[46]	96%	75%	3.84	0.05
Ascites	Bulging flanks	73%-93%	44%-70%	1.9	0.4	Ascites visualization[47]	96%	82%	32	0.04
	Flank dullness	80%-94%	29%-69%	NS	0.3					
	Shifting dullness	60%-87%	56%-90%	2.3	0.4					
	Fluid wave	50%-80%	82%-92%	5.0	0.5					
Vascular										
Lower extremity DVT	Calf swelling >2 cm	61%-67%	69%-71%	2.1	0.5	Compression venous ultrasonography[48]	96%	97%	32	0.04
	Homans sign	10%-54%	39%-89%	NS	NS					
	Wells score (high probability)	38%-87%	71%-99%	6.3	NA					

CVP = central venous pressure; DVT = deep vein thrombosis; IJV = internal jugular vein; IVC = inferior vena cava; IVCCI = IVC collapsibility index; JVP = jugular venous pressure; LR+ = positive likelihood ratio; LR− = negative likelihood ratio; LV = left ventricle; NA = not applicable; NS = not significant; PCWP = pulmonary capillary wedge pressure; US = ultrasound.

pneumonitis secondary to wood dust, pneumonia, and pulmonary hypertension due to obstructive sleep apnea.

Plan With Traditional Physical Examination Alone. For patients with the aforementioned findings on traditional physical examination, the following steps would be taken:

- Outpatient chest radiography
- Addition of inhaled glucocorticoid and continuation of albuterol for asthma
- Follow-up in 3 to 5 days if no improvement noted

POCUS-Assisted Physical Examination

POCUS-assisted physical examination revealed the following:

- Head, ears, eyes, nose, and throat: No fluid level present in either maxillary sinus (Figure 2, A)
- Pulmonary: Lung sliding bilaterally throughout (Supplemental Video 1, available online at http://www.mayoclinicproceedings.org), multiple bilateral B lines ($\geq$3 per interspace) in upper and lower lung fields (Figure 2, B; Supplemental Video 1), small bilateral pleural effusions with associated atelectasis (Figure 2, C; Supplemental Video 2, available online at http://www.mayoclinicproceedings.org)
- Cardiovascular: Measurement of IVC was 2.8 cm with less than 50% collapse on inspiration (Figure 2, C; Supplemental Video 2), no pericardial effusion, LV wall thickness of 2 cm septal and 1.9 cm posterior, LV systolic function severely reduced (Figure 2, D; Supplemental Video 3, available online at http://www.mayoclinicproceedings.org), no major mitral or tricuspid regurgitation, right ventricle difficult to view but does not appear substantially enlarged

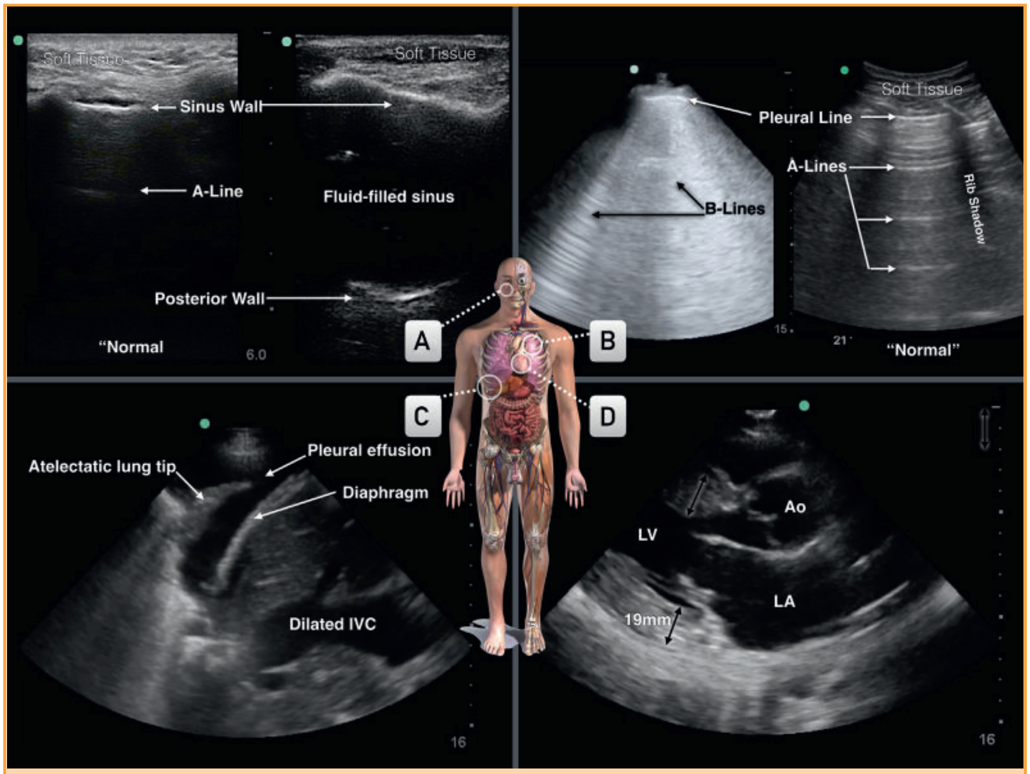

FIGURE 2. Case 1. Point-of-care ultrasonographic images. A, Normal maxillary sinus (left) compared with abnormal, fluid-filled maxillary sinus (right). B, Pulmonary images showing normal lung (right) and abnormal lung with pulmonary edema (left). C, View at the level of the right diaphragm with pleural effusion and dilated inferior vena cava (IVC). D, Parasternal long-axis view of the heart showing thickened left ventricular (LV) walls, left atrium (LA), and ascending aorta (Ao).

- Abdomen: Liver span and spleen size normal, no ascites visible

Differential Diagnosis. Based on POCUS examination findings of a plethoric IVC, bilateral B lines, pleural effusions, and severely reduced LV systolic function, the primary diagnosis in the differential is acute decompensated systolic heart failure with pulmonary edema and elevated central venous pressure. Asthma exacerbation, allergic pneumonitis, pneumonia, and pulmonary hypertension with obstructive sleep apnea are highly unlikely based on the POCUS examination findings.

Plan With POCUS-Assisted Physical Examination. For patients with the aforementioned findings on POCUS-assisted physical examination, the following steps would be taken:

- Admit to hospital from clinic
- Comprehensive transthoracic echocardiography to evaluate LV function and pericardial effusion the next morning
- Cardiac ischemic work-up
- Intravenous diuresis

Discussion

The identification of elevated central venous pressure (IVC dilation with minimal collapse),[38,49-53] pulmonary edema (bilateral interstitial syndrome B lines),[54-56] and pleural effusions combined with an unanticipated reduction in LV systolic function[25,41,57-64] dramatically changed this patient's evaluation and management. During his inpatient work-up, isolated LV noncompaction was diagnosed after cardiac magnetic resonance imaging and coronary angiography.

Shortness of breath entails a broad differential, and the addition of POCUS in real time at the bedside can tremendously help mitigate delay in appropriate testing and diagnosis.[26,33,34,65-74] The presence of B lines on the initial pulmonary ultrasonography in this patient focuses the differential on heart failure, pneumonia, interstitial lung disease, and potentially pulmonary embolism.[26,55,56,74-76] The distribution of B lines is helpful in further narrowing the differential diagnosis.[26] The presence of bilateral diffuse B lines makes cardiogenic pulmonary edema, viral pneumonia, and other causes of diffuse interstitial lung abnormalities most likely. The differential diagnosis is further narrowed by focused cardiac ultrasonography to assess LV systolic function[57,58,60,77] and an IVC examination to estimate the central venous pressure.[78] In the absence of cardiac findings suggestive of cardiogenic pulmonary edema, a focused work-up or empirical treatment of pneumonia would have ensued.

The following workflow may be employed. (1) The lack of B lines on pulmonary ultrasonography rules out dyspnea from hydrostatic cardiogenic pulmonary edema.[26,54] (2) The lack of consolidation or B lines reduces the likelihood of pneumonia considerably; in a patient with a low pretest probability of pneumonia, the diagnosis can be ruled out (note that although the sensitivity of POCUS for pneumonia is high in critically ill patients, central pneumonia can be missed, especially in less severe cases frequently seen in outpatient presentations).[19,26,34,66,70,71,74,79-81] (3) The differential diagnosis now includes obstructive lung disease and pulmonary vascular disease that can be difficult to distinguish with basic POCUS applications.[19,26,34,66,70,71,74,79-81] (4) Auscultation at this point may be valuable if findings of obstructive lung disease, such as decreased breath sounds and wheezing, are present. (5) If findings of obstructive lung disease are not present, a combination of venous and focused cardiac ultrasonography can further narrow the differential diagnosis to improve efficiency of further work-up (Figure 3).

CASE 2

A 69-year-old man with cirrhosis secondary to alcohol abuse, benign prostatic hypertrophy, type 2 diabetes mellitus, and nephrolithiasis was admitted to the hospital with lethargy, confusion, increased abdominal distention, and a subjective fever over the preceding 24 hours. He reported minimal oral intake and a mild productive cough for the past 2 weeks. A syncopal episode while getting out of bed prompted transport to the emergency department. Initial laboratory tests in the emergency department revealed acute renal failure (ARF), leukocytosis, thrombocytopenia, and elevated troponin T level. Electrocardiography revealed sinus tachycardia with 1- to 2-mm lateral ST-segment depression.

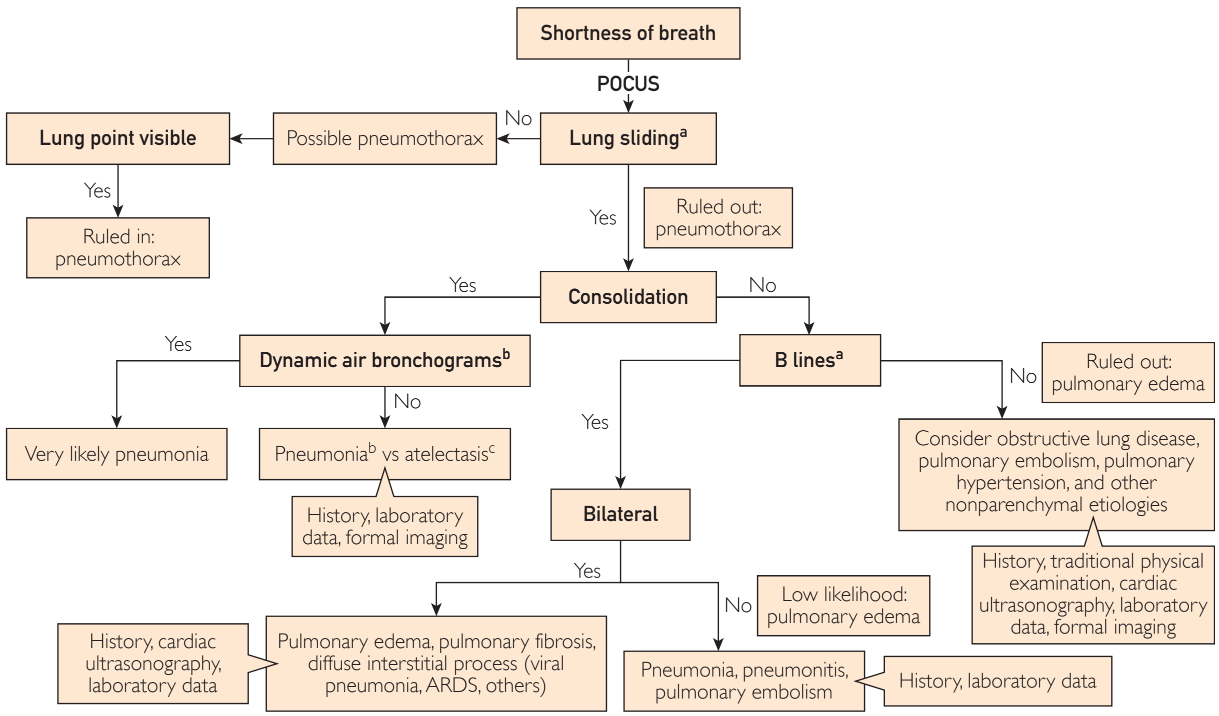

FIGURE 3. Typical point-of-care ultrasonography (POCUS)—integrated approach to a patient presenting with shortness of breath. ARDS = acute respiratory distress syndrome; a = Supplemental Video 1; b = Supplemental Video 6; c = Supplemental Video 2. Supplemental videos are available online at http://www.mayoclinicproceedings.org.

Traditional Physical Examination

Traditional physical examination revealed the following:

- Vital signs: Temperature, 37.7°C; pulse rate, 110 beats/min; blood pressure, 72/32 mm Hg; respiratory rate, 28 breaths/min; oxygen saturation, 91%; body mass index, 18 kg/m^2
- Pulmonary: Decreased lung sounds bilaterally at the bases, intermittent bibasilar crackles
- Cardiovascular: Tachycardia, regular rhythm, no murmur, neck veins not visible, warm bilateral lower extremities with mild edema to the shin (right greater than left)
- Abdomen: Protuberant abdomen with bulging flanks and dullness to percussion, moderate diffuse tenderness on palpation without acute peritoneal signs, liver and spleen examination limited due to abdominal distention and pain, no costovertebral angle tenderness
- Skin: No jaundice, dilated venous pattern on abdomen, palmar erythema, no rash

Differential Diagnosis. (1) Hypotension and tachycardia secondary to (a) sepsis due to spontaneous bacterial peritonitis (SBP), pneumonia, or biliary process, (b) cardiogenic shock due to alcoholic cardiomyopathy or ischemia, (c) obstructive shock from cardiac tamponade or pulmonary embolism, or (d) hypovolemic shock from diuretics and reduced intake; and (2) ARF secondary to (a) prerenal etiologies, including hypotension vs hepatorenal physiology, or (b) postrenal etiologies, such as benign prostatic hypertrophy or nephrolithiasis.

Plan With Traditional Physical Examination Alone. For patients with the aforementioned findings on traditional physical examination, the following steps would be taken:

- Chest radiography to evaluate for possible pulmonary infiltrate
- Blood and urine cultures, urinalysis, and liver biochemical tests
- Abdominal ultrasonography to evaluate for possible obstructive biliary process and

ascites, followed by diagnostic paracentesis performed in the radiology department
- Central venous catheter (CVC) placement for central venous pressure monitoring, fluid resuscitation, and possible vasopressor support
- Initiation of empirical broad-spectrum antibiotics to cover potential pulmonary and abdominal sources of sepsis
- Comprehensive transthoracic echocardiography to evaluate LV function and pericardial effusion the next morning
- Renal ultrasonography in the radiology department to evaluate for hydronephrosis
- Bladder scan or empirical urinary catheter placement to measure postvoid residual urine volume
- Serial laboratory measurements of lactate and troponin levels with fluid resuscitation

POCUS-Assisted Physical Examination

POCUS-assisted physical examination revealed the following:

- Pulmonary: Bilateral lung sliding noted throughout, bilateral elevated hemidiaphragm to tip of scapula with small bilateral pleural effusions and few B lines in both dependent lung fields associated with mild bilateral atelectasis
- Cardiovascular: Focused cardiac ultrasonography revealed trace pericardial effusion, normal right ventricle size with increased contractility, hyperdynamic LV with "kissing" endocardium (Supplemental Video 3, available online at http://www.mayoclinicproceedings.org), IVC less than 1 cm in diameter with 100% collapse except during expiration (Supplemental Video 4, available online at http://www.mayoclinicproceedings.org). Lower extremity vascular assessment revealed complete compression of saphenous veins, common/deep/superficial femoral veins, and popliteal veins bilaterally
- Abdomen: Moderate ascites throughout (Figure 4, A; Supplemental Video 5, available online at http://www.mayoclinicproceedings.org), small liver (8-cm midclavicular span) with scalloped cortex, enlarged spleen (19 cm in long axis and 8 cm in short axis) (Figure 4, B), minimally distended bladder (Figure 4, C), and no hydronephrosis (Figure 4, D). Gallbladder was noted to be normal with no sonographic Murphy sign

Differential Diagnosis. Based on the POCUS findings of a collapsed IVC, hyperdynamic LV, ascites, splenomegaly, and cirrhotic liver, the differential diagnosis was narrowed to hypovolemia secondary to sepsis syndrome due to SBP or possible biliary process and ARF due to a prerenal/renal etiology.

Plan With POCUS-Assisted Physical Examination. For patients with the aforementioned findings on POCUS-assisted physical examination, the following steps would be taken:

- Bedside paracentesis with ultrasound guidance to evaluate for SBP (Supplemental Video 5)
- Immediate volume resuscitation
- Serial bedside POCUS of LV, IVC, and lungs during fluid resuscitation to monitor for early signs of pulmonary edema with low threshold for transfer to critical care unit for vasopressor and fluid support
- Empirical broad-spectrum antibiotics to cover possible SBP and biliary source of sepsis
- Blood and urine cultures, urinalysis, and liver biochemical tests
- Consider right upper quadrant ultrasonography for possible obstructive biliary process
- Serial laboratory testing including lactate and troponin levels with fluid resuscitation
- Comprehensive transthoracic echocardiography to evaluate LV function and pericardial effusion the next morning

Discussion

Bedside ultrasound-guided paracentesis has been reported to be safe and effective when performed by nonradiologists[82-84] and can quickly identify the source of sepsis. Volume resuscitation guided by POCUS includes discontinuation of intravenous fluids when the POCUS examination reveals early signs of pulmonary edema[74,85] or when minimal change in stroke volume occurs with a passive leg raise.[86-91] This patient was transitioned to the intensive care unit for initiation of early vasopressor support. The ARF normalized

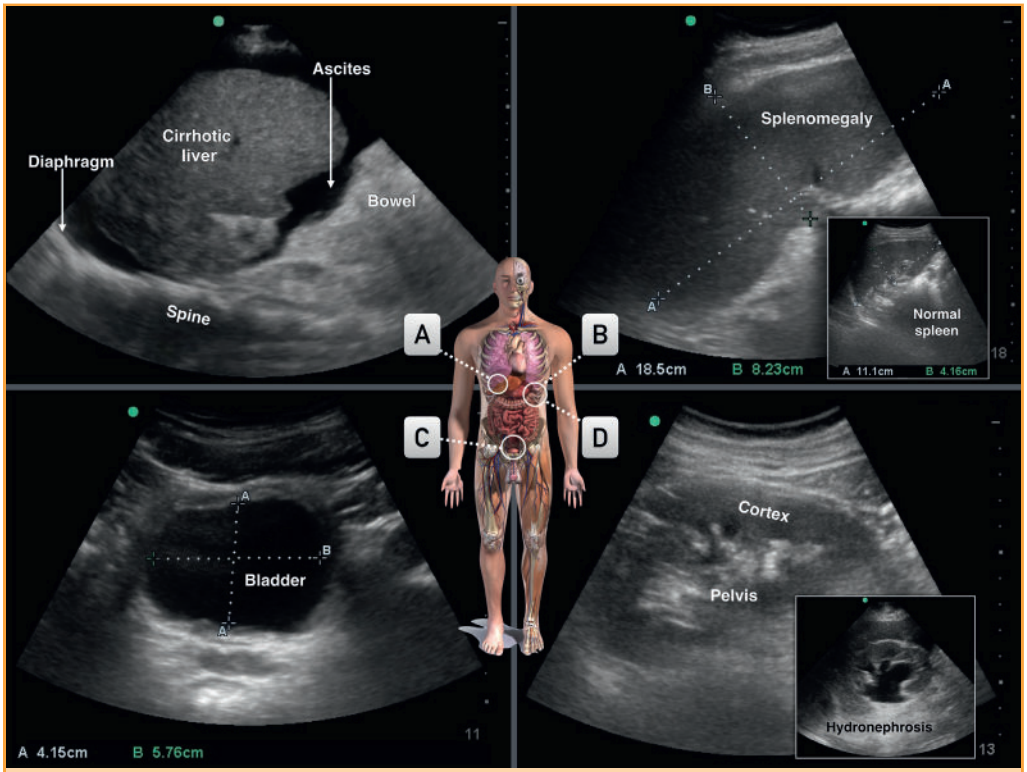

FIGURE 4. Case 2. Point-of-care ultrasonographic images. A, Cirrhotic liver with surrounding ascites. B, Enlarged spleen measuring 18.5×8.2 cm compared with a normal sized spleen (inset). C, Minimally distended bladder in transverse plane with approximately 75 mL of urine. D, Normal kidney without hydronephrosis compared with kidney with moderate hydronephrosis (inset).

over the next 48 hours with fluid resuscitation and vasopressor support.

Hypotension has a broad differential diagnosis, as in this case, and poses a diagnostic and therapeutic challenge to internists. POCUS of the heart, lungs, abdomen, and peripheral vascular system can expedite evaluation for potential etiologies of hypovolemic, distributive, cardiogenic, or obstructive shock.[29,66,92-97] Serial POCUS can be used to monitor ongoing fluid resuscitation and help determine the need for vasopressor support.[85,98]

Acute renal failure is common in the inpatient setting and often creates a diagnostic dilemma. A POCUS examination of the kidneys has been found to rapidly and effectively rule out hydronephrosis and guide the need for urinary catheterization.[99] POCUS of the lungs and cardiovascular system supplements the renal examination by providing information on hemodynamics to assess renal perfusion.[100-103]

CHALLENGES AND PITFALLS

Despite the several undisputed advantages of utilizing POCUS, there are several barriers and pitfalls to consider. First, there are challenges relating to equipment and technology. POCUS can be performed with a variety of available equipment: full-sized traditional machines, laptop-sized devices, and pocket-sized devices. Even ultrasound transducers that can be plugged directly into handheld computers are now available. Although many physicians generally prefer compact ultrasonography devices for portability, these devices have limited ability to adjust image quality. Concerns have been raised about small handheld systems with regard to their narrow sector, smaller field of view, lower resolution, and simplified transducer technology.[25,104,105] Although

Mayo Clin Proc. ■ December 2016;91(12):1811-1827 ■ http://dx.doi.org/10.1016/j.mayocp.2016.08.023
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studies have documented that small ultrasonography devices can be used to answer focused questions,[18,61,106-115] operators must be aware of their limitations.

From an operator and training perspective, studies have found that the utility of a POCUS examination depends on the experience and skills of the operator.[42,48,116-120] Operator training is crucial for POCUS to be utilized correctly in patient care, and studies have revealed that barriers to POCUS adoption include insufficient faculty training, high cost of ultrasonography machines, and time required to train physicians.[45,121] The relatively high level of operator dependency compared with other diagnostic testing is reasonably expected, given the multiple skills required to perform a POCUS examination. First, a POCUS examination begins with formulation of a specific clinical question and a decision to utilize POCUS to answer this question.[122] Next, acquisition of images requires knowledge of sonographic windows, ultrasound physics, and hand-eye-brain coordination to manipulate the transducer to optimize image quality.[122] Interpretation of POCUS images requires skills that are independent from physical examination skills, and operators must recognize artifacts that are encountered during image acquisition and interpretation.[122] Most importantly, POCUS findings must be interpreted and integrated with other clinical data to effectively guide clinical decision making.[122] Failure during any step of this multistep process may undermine the true value of using POCUS.

The skills needed to perform POCUS examinations have not been uniformly taught in undergraduate or graduate medical education. Although a movement to integrate POCUS education into medical schools or internal medicine residency programs has been gaining momentum over the past decade,[43,121,123-129] there is no consensus on the training required to reach adequate POCUS competency levels in general internal medicine.[25,104,110,111,130-133] It is generally agreed that training must include basic knowledge of ultrasound physics and supervised image acquisition and interpretation practice.[25,104,110,111,130-133]

Other potential challenges include the availability of templates for documentation, electronic storage for image archiving, and policies and procedures for quality assurance and billing. Emergency medicine societies have addressed these issues and assisted physicians in understanding correct and compliant coding for the past 2 decades.[37,39,40] In terms of billing, POCUS can potentially influence the evaluation and management code by affecting the complexity of medical decision making (*Current Procedural Terminology*).[112-115] Some believe that reimbursement is essential to cover the substantial cost of POCUS education and equipment purchasing and maintenance.[112-115] Conversely, others view POCUS as an extension of the physical examination, which raises concerns that a heavy focus on billing may block the routine use of POCUS.[116-118] Future reimbursement systems that capture an "episode of care," also known as "bundling," will likely change the perspectives on POCUS billing, documentation, and image archiving.[112,117] As the workflow for POCUS in internal medicine matures, medical practices will be required to provide the administrative infrastructure needed to meet these evolving standards of care for use of POCUS.[25,104,116]

For effective integration of POCUS into clinical care, quality assurance is an important consideration. Although quality assurance has been emphasized to avoid misinterpretation of images, most malpractice cases related to POCUS in emergency medicine have been due to failure to perform a POCUS examination in a timely manner, rather than misinterpretation or misdiagnosis with the use of POCUS.[76] The extent to which quality assurance will be needed in internal medicine and other specialties is yet to be determined because increased legal risks may occur with either failure to use POCUS or misinterpretation of POCUS images.

FUTURE RESEARCH

Early POCUS research focused on diagnostic accuracy to establish that health care professionals with focused training in ultrasonography can acquire and interpret images accurately. The diagnostic accuracy of frontline physicians performing POCUS examinations has been compared with imaging acquired by full-time sonographers and interpreted by imaging specialists, primarily radiologists or cardiologists. Several published studies have proven that POCUS has diagnostic accuracy similar to that of criterion standard imaging studies for specific findings, such as pneumothorax,[67,119] pericardial effusion,[42,120] or lower extremity deep venous thrombosis.[48] However, few studies have compared the diagnostic accuracy of POCUS vs the traditional diagnostic approach using history and physical examination. Interestingly, these studies have clearly confirmed the superiority of POCUS. For instance, half as many major cardiac findings were missed when a cardiac physical examination performed by experienced cardiologists was supplemented with a focused cardiac ultrasonographic examination.[121] Although a fairer comparison may be to compare the diagnostic accuracy of POCUS to that of physical examination, rather than criterion standard imaging studies, few comparative studies of internist-performed physical examinations, with or without the addition of POCUS, have been published.[45]

During the past 15 years, POCUS research has shifted focus from diagnostic accuracy to demonstration of improved health outcomes. Use of POCUS to guide bedside procedures has been reported to reduce procedure-related complications, including arterial punctures during central venous catheterization,[134] postthoracentsis pneumothorax, and postparacentesis bleeding complications, along with the costs and lengths of stay associated with these complications.[123,124] However, few randomized trials have been published, and a paucity of data exists supporting the routine use of POCUS for diagnostic evaluations.[15,69,77,125-127] Only one randomized trial with internal medicine–trained physicians has been published comparing routine focused cardiac ultrasonography vs standard care in hospitalized general medicine patients. This study found a potential reduction in length of stay with the use of POCUS in the cohort of patients with heart failure.[43] Thus, comparative studies evaluating the clinical and health services outcomes of usual care with and without the routine use of POCUS by internists for different conditions are needed.

Another interesting facet of POCUS research is whether the higher-priority focus is physician training or clinical outcomes. A fundamental question has yet to be answered: How do we effectively train health care professionals, ranging from medical students to senior attending physicians, to utilize POCUS? Experts generally agree that the use of POCUS requires basic knowledge of ultrasonography, image acquisition and interpretation skills, and an understanding of integration of POCUS findings into clinical decision making. If we believe that the focus should be outcomes research rather than training, then we are relegated to performing studies with a few experts performing all POCUS examinations, which may be biased toward benefit because the experts' skill level is beyond what may be achievable by a physician with average POCUS skills. On the contrary, if we believe training should be the focus, then medical institutions, including medical schools, hospitals, and health care systems, will have to invest in training physicians in basic POCUS applications before large effectiveness trials can be undertaken to evaluate the impact of POCUS on clinical outcomes. As this debate has continued, medical schools have begun to invest heavily in integrating POCUS training into clinical skills education, and positive student reviews and publicity continue to drive this integration in medical school curricula. Meanwhile, practicing internists are feeling growing pressures to acquire basic POCUS skills because their trainees may have more advanced POCUS skills than they do.

From a health care system perspective, the field of POCUS is ripe for health services research because an increasing number of POCUS applications are recommended by evidence-based guidelines. For example, consider the use of ultrasound guidance to place CVCs. Since the early 2000s, ultrasound guidance for placement of CVCs has been recommended by national patient safety and quality organizations on the basis of several randomized trials and meta-analyses[128,129,135]; however, the use of ultrasound guidance to insert CVCs has not been universally adopted in clinical practice. Investigations using methods from implementation science may reveal barriers to adoption of POCUS use for CVC insertion. Lessons learned from studying this implementation gap may guide future implementation of POCUS use within the practice of internal medicine.

Certain POCUS applications with well-proven benefits, such as use of ultrasound

Mayo Clin Proc. ■ December 2016;91(12):1811-1827 ■ http://dx.doi.org/10.1016/j.mayocp.2016.08.023
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guidance for insertion of CVCs, are primed for system-wide implementation. However, a diversified approach to POCUS research is needed in view of the varying levels of evidence supporting different POCUS applications. For known POCUS applications that are not yet the standard of care, such as evaluation of acute dyspnea with POCUS, additional clinical outcomes and health services research will likely be needed to confirm benefit and assess the effect on health care costs, length of stay, and patient experience. For other newer, novel POCUS applications, such as elastography and 3-dimensional ultrasound imaging, diagnostic accuracy studies are needed to establish their role in clinical medicine. Underlying this broad spectrum of clinical research needs is the need for educational research to help us understand how to effectively train physicians to use POCUS. Educational research will help us define the scope of training, identify resources needed (equipment, faculty/staff time), and set realistic goals for training programs.

CONCLUSION

Empowering internists to assess patients using POCUS is an inevitable change in the practice of internal medicine that has already begun to disseminate. The ability to visualize pathophysiologic features in real time using POCUS can provide expedited, high-quality, safe, and cost-conscious patient care. As new clinical and educational research emerges, our understanding of how to integrate POCUS into clinical practice will improve, and routine use of POCUS in clinical practice will establish new standards of care.

SUPPLEMENTAL ONLINE MATERIAL

Supplemental material can be found online at http://www.mayoclinicproceedings.org. Supplemental material attached to journal articles has not been edited, and the authors take responsibility for the accuracy of all data.

Abbreviations and Acronyms: **ARF** = acute renal failure; **CVC** = central venous catheter; **IVC** = inferior vena cava; **LV** = left ventricular; **POCUS** = point-of-care ultrasonography; **SBP** = spontaneous bacterial peritonitis

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