

Review Article

Basic point-of-care ultrasound framework based on the airway, breathing, and circulation approach for the initial management of shock and dyspnea

Toru Kameda¹  and Akio Kimura²

¹Department of Emergency Medicine, Red Cross Society Azumino Hospital, Nagano, and ²Department of Emergency and Critical Care, Center Hospital of the National Center for Global Health and Medicine, Tokyo, Japan

Ultrasound (US) carried out and interpreted by clinicians at the bedside is now called point-of-care US (POCUS). Clinical studies on POCUS have been carried out based on the ideas of “creation”, “extraction”, and “combination”. “Creation” refers to findings for the upper airway and lung being obtained at the bedside. “Extraction” refers to findings suitable for POCUS being extracted from comprehensive US, including echocardiography, abdominal US, and whole-leg US. “Combination” refers to these POCUS applications being combined for the comprehensive assessment of patients with trauma, shock, or dyspnea. Emergency and critical care physicians have many opportunities to encounter trauma or non-trauma patients with shock, dyspnea, or both. Furthermore, the scope of POCUS includes many diseases and injuries that present with both shock and dyspnea. Therefore, we propose a basic POCUS framework based on the systematic airway, breathing, and circulation approach for the initial management of shock and dyspnea in adult patients. In this article, we update and review each application of POCUS and their combination in this framework. Furthermore, we propose the practical usage of the framework based on clinical presentations to improve the management of shock and dyspnea.

Key words: Dyspnea, emergency department, point of care, shock, ultrasonography

INTRODUCTION

ULTRASONOGRAPHY (US) CARRIED out and interpreted by clinicians at the bedside is now called point-of-care US (POCUS).¹ The concept of POCUS has spread worldwide due to the advent of portable US machines with high quality and numerous clinical studies supporting its utility. Clinical studies on POCUS have been carried out based on the ideas of “creation”, “extraction”, and “combination”.² “Creation” refers to findings for the upper airway and lung being obtained at the bedside, which are not generally evaluated in radiology or laboratory settings. “Extraction” refers to findings suitable for POCUS being extracted

from established comprehensive US, including echocardiography, abdominal US, and whole-leg US. “Combination” refers to these POCUS applications being combined for the comprehensive assessment of patients with trauma, shock, or dyspnea (Fig. 1).

Several protocols for the combined POCUS application are widely accepted. Focused assessment with sonography for trauma (FAST)^{3,4} and extended FAST (EFAST)⁵ including the assessment of pneumothorax are carried out in the initial management of trauma patients.⁶ Rapid US in shock is a more comprehensive POCUS designed to recognize distinctive shock etiologies.⁷ The bedside lung US in emergency protocol is designed as a diagnostic tool of acute respiratory failure in intensive care units.⁸ However, emergency and critical care physicians have many opportunities to encounter trauma or non-trauma patients with shock, dyspnea, or both. Furthermore, the scope of POCUS includes many diseases and injuries that present with both shock and dyspnea, such as (tension) pneumothorax, hemothorax, cardiac tamponade, left ventricular systolic dysfunction, and

Corresponding: Toru Kameda, MD, PhD, Department of Emergency Medicine, Red Cross Society Azumino Hospital, 5685 Toyoshina, Azumino-city, Nagano, 399-8292, Japan. E-mail: kamekame@pb3.so-net.ne.jp.

Received 18 Nov, 2019; accepted 18 Dec, 2019

Funding Information

No Funding information provided.

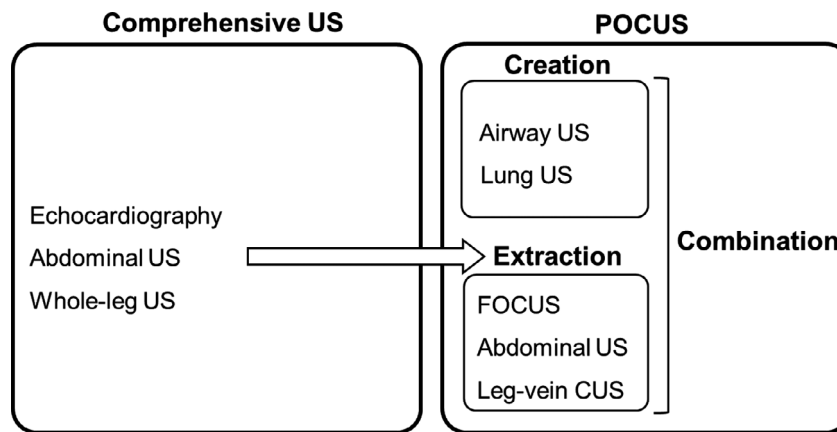


Fig. 1. Concept of clinical studies on point-of-care ultrasound (POCUS). FOCUS, focused cardiac ultrasound; CUS, compression ultrasound.

	Shock/Hypotension	Dyspnea
Airway	Airway ultrasound Confirmation of endotracheal intubation Identification of the cricoid membrane for cricothyrotomy	
Breathing	Lung ultrasound Pneumothorax Hemothorax, Pleural effusion, Empyema (sepsis), Drainage Pulmonary edema	
Circulation	Focused cardiac ultrasound Pericardial effusion/Cardiac tamponade, Drainage Left ventricular systolic function (hypokinesia, hyperkinesia) Right ventricular dilatation/Systolic dysfunction IVC diameter and collapsibility	
	Abdominal ultrasound Hemoperitoneum Abdominal aortic aneurysm Hydronephrosis (sepsis) Acute cholecystitis (sepsis)	
	Leg-vein compression ultrasound Deep venous thrombosis (pulmonary embolism)	
	Ultrasound-guided vascular access Intravenous line placement, REBOA, ECMO	

Fig. 2. Framework of point-of-care ultrasound based on the airway, breathing, and circulation (ABC) approach for the initial management of shock/hypotension and dyspnea in adult patients. ECMO, extracorporeal membrane oxygenation; IVC, inferior vena cava; REBOA, resuscitative endovascular balloon occlusion of the aorta.

pulmonary embolism (PE). Therefore, we propose a basic POCUS framework based on the systematic airway, breathing, and circulation (ABC) approach for the initial management of shock/hypotension and dyspnea in adult patients (Fig. 2).

In this article, we update and review each application of POCUS and their combination in this framework. Furthermore, we propose the practical usage of the framework based on clinical presentations to improve the management of shock and dyspnea.

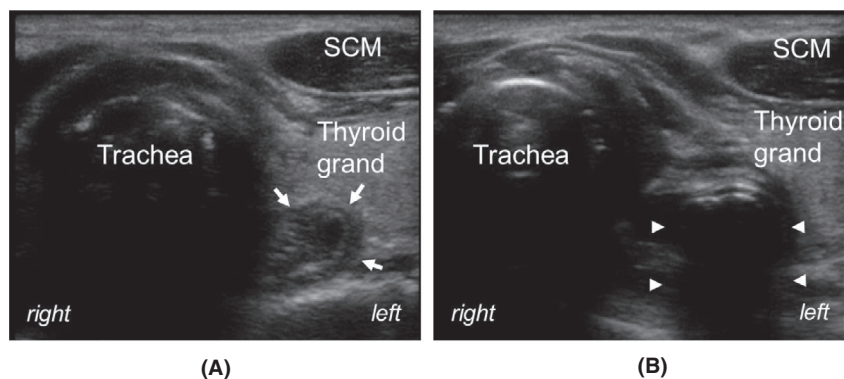


Fig. 3. Transverse views of the neck before intubation (A) and after esophageal intubation showing double tract sign (B). Arrows and arrowheads indicate an empty esophagus and the acoustic shadow caused by a tube in the esophagus, respectively. SCM, sternocleidomastoid muscle. (Permission for reproduction obtained from Kameda and Taniguchi (2015))²

AIRWAY

Airway US

Confirmation of endotracheal tube placement

TO CONFIRM endotracheal tube placement, it is recommended to undertake capnography in addition to visual inspection and auscultation. However, capnography requires ventilation for confirmation, which can lead to gastric distention and aspiration if the tube has been incorrectly placed in the esophagus.

In recent years, many studies have shown the usefulness of POCUS for verifying endotracheal tube placement. This method can be carried out quickly without ventilation.⁹ Several findings can be used for the confirmation of placement. In tracheal intubation, one air–mucosa interface with acoustic shadowing is seen, whereas in esophageal intubation,

two air–mucosa interfaces (double tract sign) are detected simultaneously (Fig. 3).¹⁰ In tracheal intubation, movement of the tube within the trachea,⁹ tracheal dilation by cuff inflation with air,¹¹ and hyperechoic lines of the tube can also be detected.¹² A systematic review and meta-analysis (SR/MA) of 17 prospective studies involving 1,595 patients found that POCUS was 99% sensitive (95% confidence interval [CI], 98–99%) and 97% specific (95% CI, 92–99%) for the confirmation of tube placement. These results show that POCUS should be considered, especially when capnography is unavailable or unreliable.⁹

Identification of the cricothyroid membrane for cricothyrotomy

Difficult airways remain a major challenge that can lead to serious adverse outcomes. In such serious situations,

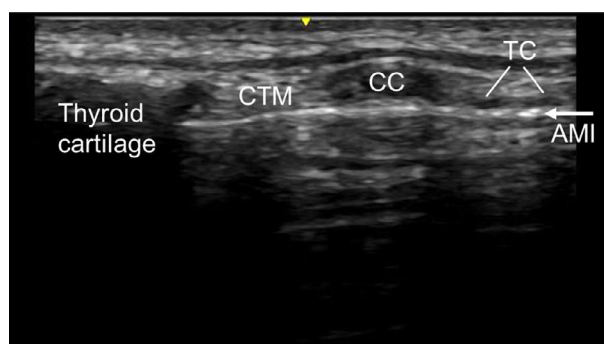


Fig. 4. Longitudinal view of the upper airway to identify the cricothyroid membrane. AMI, air–mucosa interface; CC, cricoid cartilage; CTM, cricothyroid membrane; TC, tracheal cartilage.

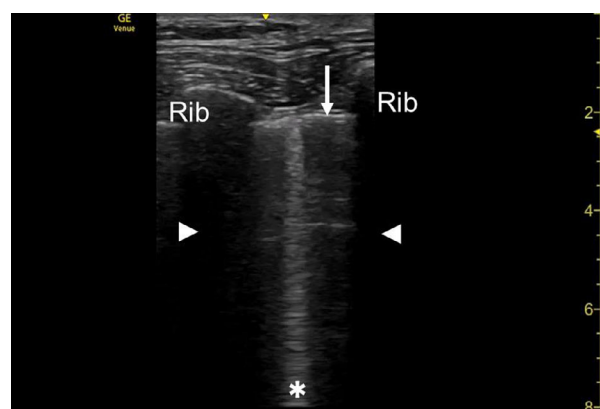


Fig. 5. Longitudinal view of the anterior chest. Arrow and arrowheads indicate the pleural line and acoustic shadows from the ribs, respectively. A single B-line (asterisk) is shown.

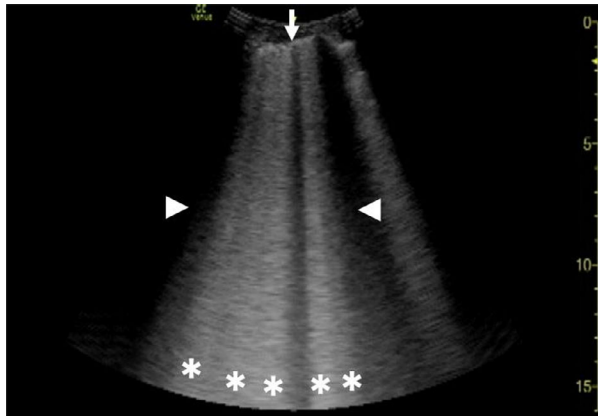


Fig. 6. Ultrasound image of cardiogenic pulmonary edema. Multiple B-lines (asterisks) are shown between two ribs in a longitudinal plane. Arrow and arrowheads indicate the pleural line and acoustic shadows from the ribs, respectively.

emergency cricothyrotomy is a critical option. When undertaking this life-saving procedure, the first step is to palpate and correctly identify the cricothyroid membrane. However, the accurate localization of the cricothyroid membrane with palpation is challenging in some patients, such as those with obesity or anatomical abnormalities. Several studies have shown the superiority of POCUS over landmark palpation for identifying the cricothyroid membrane in controlled situations (Fig. 4).^{13–15} However, the usefulness of identification using POCUS has not been proven in actual emergency situations.¹⁵

BREATHING

Lung US

Pneumothorax

THE UTILITY OF US for diagnosing pneumothorax has been demonstrated mainly in traumatic patients. Chest X-ray is carried out in a supine position for the initial evaluation if patients are immobilized, considering the risk of cervical spine injury or injuries affecting the vital signs. However, nearly half of all traumatic pneumothoraces are undetectable on supine chest X-ray. The supine position is actually ideal for a US diagnosis of pneumothorax, and many studies have shown that the sensitivity is higher than that of chest X-ray.¹⁶

Pneumothorax is mainly assessed in the anterior chest regions. The pleural line, a horizontal hyperechoic line just below the surface of the ribs, can easily be identified (Fig. 5). The presence of lung sliding, a to-and-fro movement of the visceral pleura against the parietal pleura observed at the pleural line during respiration, indicates contact between these pleurae (Movie S1A). The lung pulse, which is the movement of heart beats transmitted through the lung parenchyma, can be identified at the pleural line when lung sliding is not observed during respiratory pause (Movie S1B) or in patients with apnea, bullous emphysema, or pleural adhesion. In addition, the presence of B-lines or comet tail artefacts, vertical hyperechoic artefacts arising just below the visceral pleura, indicates the contact between

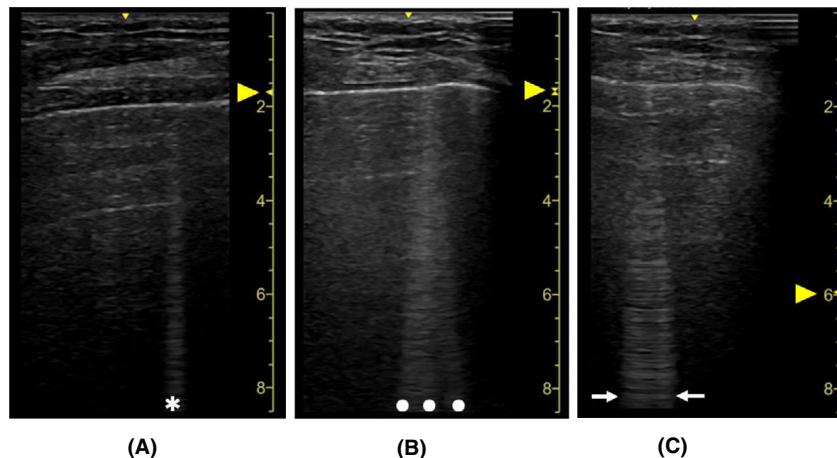


Fig. 7. A, Narrow B-line (asterisk) arises from the point of the pleural line when spatial compound imaging is turned off and the focal zone (arrowhead) is set at or near the level of the pleural line. B, With spatial compound imaging enabled, the single B-line changes to multiple lines (dots) radiating from the same point of the pleural line. C, As the focal zone is moved from the level of the pleural line to deeper levels, the B-line becomes wider (arrows). For the proper evaluation of B-lines, spatial compound imaging should be turned off to avoid counting B-lines erroneously. The focal zone is also recommended to be set at or near the level of the pleural line to keep each B-line narrow for the identification.

the pleurae (Fig. 5). Thus, the absence of these signs suggests the existence of air interposed between the visceral and parietal pleurae, representing pneumothorax (Movie S2A, B). Lung point, the alternation of the presence and absence of lung sliding at the same point, is specific for pneumothorax (Movie S2C).¹⁷ An SR/MA of 13 prospective studies involving 2,965 hemithoraces found that POCUS was 81% sensitive (95% CI, 71–88%) and 98% specific (95% CI, 97–99%) for the diagnosis of traumatic pneumothorax.¹⁶

Hemothorax, pleural effusion, and empyema

Chest X-ray is carried out in the supine or semi-Fowler position in critically ill or injured patients for the evaluation of pleural effusion, hemothorax, or empyema. Under such conditions, the accuracy of POCUS is superior to that of X-ray for the evaluation.^{18–21} An SR/MA of three prospective studies involving 449 hemithoraces found that POCUS was 60% sensitive (95% CI, 31–86%) and 98% specific (95% CI, 94–99%) for the diagnosis of traumatic hemothorax. Despite the low sensitivity, most false-negative results involved small or non-significant hemothoraces.¹⁶ Empyema usually presents as capsulated or homogeneously echogenic effusion.²¹

It is recommended that thoracentesis and chest drain insertion be carried out under US guidance,²² as this increases the success rate of the thoracentesis and decreases the risk of complications.^{23,24}

Pulmonary edema

In lung US, the presence and severity of pulmonary edema are evaluated using vertical hyperechoic artifacts known as B-lines that arise from the pleural line and extend to the bottom of the screen without fading.¹⁷ B-lines are thought to originate from thickened interlobular septa and the accumulation of fluid just below the visceral pleura. However, the US–pathologic correlation has not been elucidated clearly.²⁵ Multiple B-lines refer to the presence of three or more B-lines in a longitudinal plane between two ribs. In patients with dyspnea due to cardiogenic pulmonary edema (CPE), multiple B-lines are usually distributed bilaterally and diffusely (Fig. 6). The finding is useful for distinguishing CPE with acute exacerbation of chronic obstructive pulmonary disease and asthma. However, diffuse multiple B-lines, which are not specific for CPE, are also observed in patients with acute respiratory distress syndrome, interstitial pneumonia, pulmonary fibrosis, and bilateral bacterial pneumonia.¹⁷ A multicenter, prospective cohort study found that the implementation of lung US with the initial standard assessment improved the diagnostic accuracy for CPE.²⁶

Therefore, diffuse multiple B-lines should be interpreted in clinical context with the history and findings of physical examination, electrocardiogram, and blood tests.

When interpreting the B-lines, we should be aware that the visualization of B-lines is affected by the settings of US machines, such as spatial compound imaging and the focal zone. Spatial compound imaging should be turned off to avoid counting B-lines erroneously, and the focal zone should be set at or near the level of the pleural line in order to keep each B-line narrow for identification (Fig. 7).²⁵

CIRCULATION

Focused cardiac US

FOCUSED CARDIAC US (FOCUS) is a simplified, clinician-performed application extracted from comprehensive transthoracic echocardiography. It collects the information essential for clarifying the causes of shock and dyspnea in time-sensitive situations. Focused cardiac US does not require the execution of all echocardiography views. The standard views of FOCUS include the subcostal four-chamber view, subcostal inferior vena cava (IVC) view, parasternal long-axis view, parasternal midpapillary short-axis view, and apical four chamber view.²⁷ On a FOCUS examination, target pathological findings with physiological changes are detected, and the consistency between them is evaluated in patients with shock and dyspnea (Table 1).⁷ There are many large observational and randomized studies showing that FOCUS improves diagnostic accuracy and positively influences changes in clinical management.²⁷

Pericardial effusion/cardiac tamponade

Pericardial effusion is the presence of an excess of fluid in the pericardial cavity. The symptoms depend on the rate of fluid accumulation, ranging from mild dyspnea to shock due to cardiac tamponade. Cardiac tamponade physiology occurs when the pericardial pressure exceeds the pressure of the cardiac chambers. Diastolic collapse of the right ventricle with pericardial effusion is a specific finding of cardiac tamponade (Fig. 8).²⁸ An initial study showed that emergency physicians detected pericardial effusion with a sensitivity of 96% (95% CI, 90–99%) and specificity of 98% (95% CI, 96–99%).²⁹ An SR/MA of nine studies involving 1,031 penetrating trauma patients found that FOCUS was 91% sensitive (95% CI, 87–94%) and 94% specific (95% CI, 92–96%) for the detection of pericardial effusion.⁶

Ultrasound-guided pericardiocentesis is the current technique of choice, showing a higher rate of success and lower rate of major complications than the landmark method. To

Table 1. Target pathological findings and physiological changes on focused cardiac ultrasound

Type of shock	Cardiogenic	Obstructive	Hypovolemic	Distributive
Pericardial effusion		Present (CA)		
Left ventricle	Hypokinetic Dilated (acute on chronic) Normal ID (acute)	Hyperkinetic D-shaped (PE)	Hyperkinetic Reduced ID	Hyperkinetic
Right ventricle		Dilated (PE) Collapsed (CA)		
Inferior vena cava	Dilated	Dilated	Collapsed	Normal or small

CA, cardiac tamponade; ID, internal diameter; PE, pulmonary embolism.

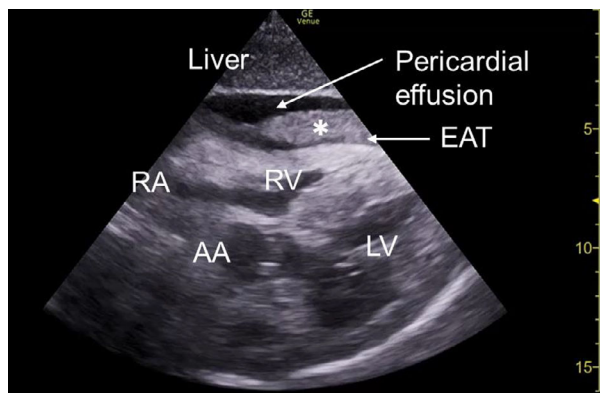


Fig. 8. Subcostal view in a patient with cardiac tamponade complicating type A aortic dissection. Diastolic collapse of the right ventricle (RV) is shown. The asterisk indicates a clot in the pericardial effusion. AA, ascending aorta; EAT, epicardial adipose tissue; LV, left ventricle; RA, right atrium.

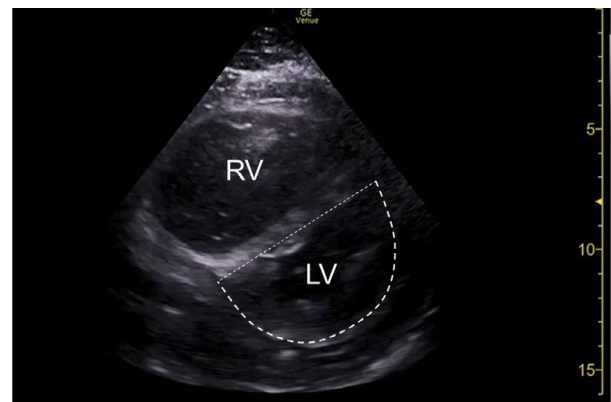


Fig. 9. Parasternal short-axis view in a patient with acute pulmonary embolism. The size of the right ventricle (RV) is greater than that of the left ventricle (LV). Deviation of the interventricular septum toward the LV is shown as a D-shaped LV.

improve the success and safety of these procedures, US enables us to select needle entry sites with a shorter distance to the pericardium and more accumulated pericardial fluid, including apical and parasternal sites.^{30,31}

Left ventricular systolic function

Focused cardiac US accurately detects left ventricular (LV) systolic dysfunction, LV dilatation, and LV hypertrophy.²⁷ There has been good evidence that clinicians can be trained in the global assessment or visual estimation of the LV systolic function.^{32,33} In the setting of shock or dyspnea, FOCUS can accurately assess the global LV systolic function.²⁷ One common cause of acute decompensated heart failure is an acute exacerbation of chronic LV systolic dysfunction with a dilated LV internal diameter (LVID), which

can be detected with FOCUS without difficulty. It also reveals a hypokinetic LV with a normal LV internal diameter in some patients with cardiogenic shock due to acute myocardial infarction or fulminant myocarditis. Hyperkinetic LV on FOCUS is observed in patients with hypovolemic and distributive shock.^{7,27} However, hypovolemic patients with chronic LV dysfunction may not show hyperkinetic LV. Furthermore, hyperkinetic LV might also be observed in patients with acute mitral regurgitation due to chordae tendineae rupture, papillary muscle rupture, or infective endocarditis.³⁴ Advanced FOCUS, including assessments with color Doppler or standard echocardiography undertaken by specialists, should be considered when patients could have such conditions.²⁷ There are no recommendations regarding the incorporation of the assessment of the LV diastolic function into guidelines for FOCUS application.²⁷

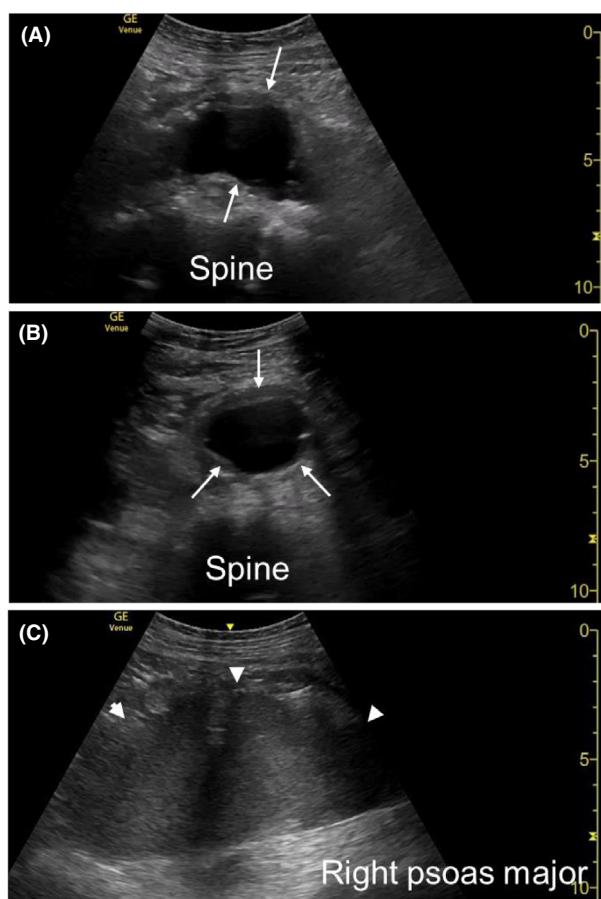


Fig. 10. Ultrasound images of ruptured abdominal aortic aneurysm (AAA). A, Longitudinal view of AAA (arrows). B, Transverse view of AAA (arrows). C, Coronal view from the right side showing retroperitoneal hematoma (arrowheads). Although the retroperitoneal hematoma is detected occasionally, ruptured AAA is usually diagnosed based on the history, physical examination findings, and presence of AAA.

Right ventricular dilatation/systolic dysfunction

Right ventricular (RV) dilatation and systolic dysfunction are commonly observed in patients with PE. The presence of RV dilatation can be visually detected on FOCUS when the size of the RV is greater than that of the LV. In such cases, deviation of the interventricular septum toward the LV is observed as a D-shaped LV from the parasternal short-axis view (Fig. 9).³⁵ The RV size is considered an intrinsic element of the RV systolic function.²⁷ The presence of RV systolic dysfunction itself can be visually detected by observing a decrease in the longitudinal movement of the tricuspid annulus toward the apex during systole from an apical four-

chamber view.^{35,36} This movement measured with M-mode is called tricuspid annular plane systolic excursion and shows good correlation with the parameters used to estimate the RV global systolic function.³⁷

We should keep in mind that other acute and chronic diseases also show RV dilatation. For example, RV infarction sometimes represents RV dilatation with shock, which seems to indicate massive PE. Right ventricular pressure overload due to chronic pulmonary hypertension shows RV dilatation accompanied by thickening of the RV free wall. Right ventricular volume overload due to atrial septal defect shows RV dilatation with a septal shift in diastole.³⁸

A prospective observational study involving 149 patients with a moderate to high pretest probability of PE found that RV dilatation on FOCUS carried out by emergency physicians had a sensitivity of 50% (95% CI, 32–68%) and a specificity of 98% (95% CI, 95–100%).³⁶ The sensitivity is expected to be higher in patients with shock or hypotension.³⁹ Mobile thrombus in the right cardiac chambers, which is observed less commonly, can be a specific finding for the diagnosis of PE.³⁹

Inferior vena cava diameter and collapsibility

An SR/MA of five studies found that the average maximal IVC diameter was significantly smaller under hypovolemic conditions than euvoletic conditions, with a mean difference of 6.3 mm (95% CI, 6.0–6.5 mm).⁴⁰ Collapsed IVC with hyperkinetic LV in patients with shock strongly suggests hypovolemia and justifies fluid resuscitation. The combination of the IVC diameter and its respiratory collapsibility is well known to be useful for estimating the right atrial pressure.³⁷ A dilated IVC with reduced collapsibility, indicating a high right atrial pressure, is observed in patients with cardiogenic or obstructive shock.⁷

Abdominal US

Hemoperitoneum

Focused assessment with sonography for trauma provides a quick overview of the peritoneal cavity to detect free fluid, which is a direct sign of hemoperitoneum in trauma patients.³ An SR/MA of 35 prospective and 17 retrospective studies involving 19,666 patients found that FAST was 74% sensitive (95% CI, 73–76%) and 98% specific (95% CI, 97–98%) for the identification of intraabdominal free fluid.⁶ The sensitivity of FAST might be higher in patients with shock due to hemoperitoneum than in non-shock patients with hemoperitoneum, and the time needed to undertake FAST could be

shorter in patients with a positive finding of hemoperitoneum than in those with a negative finding.⁴¹ In non-trauma patients, the etiology of spontaneous hemoperitoneum can vary, and the causes are classified as gynecologic, hepatic, splenic, vascular, or coagulopathic. It is also reasonable to consider carrying out a FAST examination for the rapid detection of spontaneous hemoperitoneum, even though few original studies have explored its use.⁴²

Abdominal aortic aneurysm

Ruptured abdominal aortic aneurysm (AAA) is a vascular emergency with a high morbidity and mortality. The use of POCUS to diagnose AAA has been well studied prospectively with great accuracy (Fig. 10). An SR/MA of seven prospective studies involving 655 patients found that POCUS was 99% sensitive (95% CI, 96–100%) and 98% specific (95% CI, 97–99%) for the detection of AAA in symptomatic patients.⁴³ Aortic dissection, which extends to the abdominal aorta in one-third of cases, is also detected occasionally on abdominal POCUS.⁴⁴

Hydronephrosis

Urosepsis is mainly a result of obstructive uropathy of the upper urinary tract, with ureterolithiasis being the most common cause. Delayed management can lead to high mortality, so rapid assessment and intervention to release the obstruction are needed. As obstruction of the upper urinary tract is the main cause of urosepsis, and POCUS for the evaluation of hydronephrosis is a good first imaging method in septic patients.^{45–47} Chen *et al.*⁴⁸ showed that POCUS was able to detect significant abnormalities, such as hydronephrosis, polycystic kidney disease, renal abscess, and emphysematous pyelonephritis, in 40% of patients finally diagnosed with acute pyelonephritis. The absence of hydronephrosis could rule out a urinary tract infection resulting from obstructive uropathy.

Acute cholecystitis

Acute cholecystitis is usually diagnosed when the inflammation is localized to the gallbladder. However, if left undetected, acute cholecystitis will likely lead to serious complications, including perforation, septic shock, multiorgan failure, and death.⁴⁹ When performing POCUS for the evaluation of acute cholecystitis, the presence of gallstones, gallbladder wall thickening, pericholecystic fluid, and sonographic Murphy sign provide diagnostic information.⁵⁰ Summers *et al.*⁵¹ reported in a prospective observational

study of 164 patients that the test characteristics of POCUS for the detection of acute cholecystitis had a sensitivity of 87% (95% CI, 66–97%) and specificity of 82% (95% CI, 74–88%).

Leg-vein compression US

Deep venous thrombosis

Pulmonary embolism and deep venous thrombosis (DVT) are considered a continuum of the same clinical entity. Most cases of pulmonary emboli arise from lower-extremity DVT.⁵² In patients with suspected DVT, an SR/MA revealed that both two-point (common femoral and popliteal vein) and three-point (common femoral, femoral, and popliteal vein) compression US (CUS) undertaken by emergency physicians showed an excellent performance for the diagnosis of DVT.⁵³ In patients with suspected PE, another SR/MA of 15 prospective studies involving 6,991 patients found that proximal CUS, including two-point CUS, was 41% sensitive (95% CI, 36–46%) and 96% specific (95% CI, 94–98%).⁵⁴ Proximal CUS has a high specificity but a low sensitivity for PE, so it may not be routinely performed in undifferentiated shock patients. However, it remains a useful technique in addition to FOCUS for improving the diagnostic accuracy in shock patients with suspected PE.⁵⁵

Ultrasound-guided vascular access

Peripheral i.v. line placement is a common procedure in emergency departments (EDs). Real-time US guidance has been found to improve the success rates and reduce the number of complications, especially in patients who have difficulty in undergoing cannulation by the standard method.^{56,57} Several studies reported that US-guided placement of peripheral i.v. catheters in the internal jugular vein can be carried out without increasing the risk of complications, such as blood stream infection.^{58,59}

Resuscitative endovascular balloon occlusion of the aorta (REBOA) has been introduced in many countries for temporary hemorrhagic controls following massive hemorrhaging due to abdominopelvic trauma, ruptured abdominal aortic aneurysm, and miscellaneous causes.⁶⁰ The initial step in REBOA involves common femoral artery cannulation. The use of US guidance for the cannulation decreases life-threatening vascular complications and improves the first-pass success rate.⁶¹ In addition, abdominal POCUS is useful for confirming the position of the guidewire and the occlusion balloon in the aorta.^{62,63} Additionally, POCUS-guided cannulation of extracorporeal membrane oxygenation is a useful strategy over landmark-guided cannulation in terms of avoiding cannula misplacement.⁶⁴

MULTIORGAN POCUS

THE UTILITY OF combined POCUS applications or multiorgan POCUS has been evaluated for advanced management in ED patients with undifferentiated shock/hypotension^{55,65–71} or dyspnea^{72–79} in prospective studies (Table 2).

In patients with shock/hypotension, diagnostic studies found that the type of shock or diagnosis determined by multiorgan POCUS, including lung US, FOCUS, and abdominal US with or without leg-vein CUS, showed substantial or excellent agreement with the final diagnosis.^{66–69,71} However, the accuracy decreased in patients with distributive or mixed-typed shock.^{69,71} Nazerian *et al.*⁵⁵ reported that, in shock patients with suspected PE, FOCUS showed a suboptimal diagnostic performance to rule in and rule out PE; however, the combination of FOCUS and leg-vein CUS dramatically improved the specificity. A randomized controlled trial showed that immediate multiorgan POCUS in addition to standard care showed significantly fewer viable diagnostic etiologies of illness and more accurately reported the correct final diagnosis among the potential diagnostic etiologies than standard care alone.⁶⁵ As mentioned above, multiorgan POCUS has early diagnostic accuracy for specific pathologies in patients with undifferentiated shock/hypotension. However, another randomized controlled trial did not find any benefits for the survival,

length of stay, rates of CT scanning, inotrope use, or fluid administration. The authors mentioned that a larger study including more POCUS-sensitive diagnoses is required to confirm these findings.⁷⁰

In patients with dyspnea, several diagnostic studies showed that integration of multiorgan POCUS, including lung US and FOCUS with or without leg-vein CUS, detected life-threatening conditions missed at the primary assessment⁷³ and showed an improved diagnostic accuracy compared to the assessment before or without multiorgan POCUS.^{74,75} When adding a FOCUS finding (LV systolic dysfunction or non-collapsible dilated IVC) to lung US, the specificity improved in the diagnosis of CPE.^{72,76} Papanagnou *et al.*⁷⁸ reported that multiorgan POCUS improved physicians' confidence with their leading diagnosis despite not improving the diagnostic accuracy in dyspneic patients with mild-to-moderate disease. The largest study involving 2,683 consecutive patients with dyspnea indicated that the average time needed to make a diagnosis at the initial assessment with multiorgan POCUS, including lung US and FOCUS, was significantly shorter than that required with the standard ED diagnostic methods (24 ± 10 min vs. 186 ± 72 min; $P = 0.025$). Interestingly, diagnoses with multiorgan POCUS and the standard methods showed good overall concordance ($k = 0.71$). The initial assessment with multiorgan POCUS was significantly more sensitive for the diagnosis of CPE, whereas the standard methods performed

Table 2. Prospective studies on multiorgan point-of-care ultrasound (US)

Research	N	Lung US	FOCUS	Abd US	Leg-vein CUS
Shock/hypotension					
Jones <i>et al.</i> (2004) ⁶⁵	184	–	Included	Included	–
Volpicelli <i>et al.</i> (2013) ⁶⁶	108	Included	Included	Included	Included
Bagheri-Hariri (2015) ⁶⁷	25	Included	Included	Included	Included
Shokoohi <i>et al.</i> (2015) ⁶⁸	118	Included	Included	Included	–
Ghane <i>et al.</i> (2015) ⁶⁹	77	Included	Included	Included	Included
Nazerian <i>et al.</i> (2017) ⁵⁵	105	–	Included	–	Included
Atkinson <i>et al.</i> (2018) ⁷⁰	273	Included	Included	Included	–
Rahulkumar <i>et al.</i> (2019) ⁷¹	130	Included	Included	Included	Included
Dyspnea					
Anderson <i>et al.</i> (2013) ⁷²	101	Included	Included	–	–
Laursen <i>et al.</i> (2013) ⁷³	139	Included	Included	–	Included
Laursen <i>et al.</i> (2014) ⁷⁴	320	Included	Included	–	Included
Mantuani <i>et al.</i> (2016) ⁷⁵	57	Included	Included	–	–
Sforza <i>et al.</i> (2017) ⁷⁶	68	Included	Included	–	–
Zanobetti <i>et al.</i> (2017) ⁷⁷	2,683	Included	Included	–	–
Papanagnou <i>et al.</i> (2017) ⁷⁸	115	Included	Included	–	–
Bekgoz <i>et al.</i> (2019) ⁷⁹	383	Included	–	–	Included

–, not included; Abd, abdominal; CUS, compression US; FOCUS, focused cardiac US.

better in the diagnosis of chronic obstructive pulmonary disease/asthma and PE.⁷⁷ The addition of leg-vein CUS into multiorgan POCUS might improve the diagnostic accuracy in dyspneic patients with suspected PE.⁷⁹

PRACTICAL USE OF THE POCUS FRAMEWORK

AS OUTLINED ABOVE, the POCUS applications in the framework shown in Figure 2 are powerful techniques for either confirming or ruling out the presence of life-threatening diseases and injuries for physicians trained in POCUS. There are several reasons for proposing this framework based on the ABC approach. The scope of POCUS includes many diseases and injuries that can present shock, dyspnea, or both. In addition, multiorgan POCUS has a better diagnostic accuracy for some diseases, such as CPE and PE, than single POCUS.^{55,72,76} Furthermore, the ABC approach was established for the management or resuscitation of critically ill and injured patients. Thus, it is reasonable and more practical to integrate POCUS into the ABC approach and interpret POCUS findings in line with the clinical context for the improvement of patient care.

The framework can be used in various ways according to the observed clinical presentations. In general, one or several POCUS applications can be selected from the framework according to the clinical presentation after taking the patient history and carrying out a physical examination, either with or without any other clinical tests. For example, abdominal US should be selected first for the evaluation of ruptured AAA in elderly smokers who present with shock accompanied by lower back pain. Likewise, lung US should be selected first for the evaluation of pneumothorax in young patients who present with dyspnea accompanied by decreased breath sounds on the right chest. However, in patients with undifferentiated shock/hypotension, dyspnea or both, the framework can be used as a protocol or algorithm as follows: if tracheal intubation is needed, airway US can be carried out quickly for the verification of tube placement. Lung US is carried out followed by FOCUS to clarify the causes of shock and dyspnea. In patients with suspected hypovolemic or septic shock, abdominal US is the subsequent technique of choice. In patients with suspected PE, the addition of leg-vein CUS can improve the diagnostic accuracy. The appropriate US-guided procedures at each step should be considered when landmark approaches are deemed unhelpful or improved safety is sought.

CONCLUSION

WE PROPOSED A basic POCUS framework based on the ABC approach for the initial management of

shock and dyspnea. The POCUS applications in this framework are powerful techniques for evaluating life-threatening diseases and injuries for physicians trained in POCUS. In general, one or several POCUS applications can be selected from the framework according to the clinical presentation after taking the patient history and carrying out a physical examination, either with or without any other clinical tests. In patients with undifferentiated shock/hypotension, dyspnea, or both, the framework can be used as a protocol or algorithm.

DISCLOSURE

Approval of the research protocol: N/A.

Informed consent: Written informed consent was obtained from the healthy models and patients.

Registry and the registration no. of the study/trial: N/A.

Animal studies: N/A.

Conflict of interest: None.

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SUPPORTING INFORMATION

Additional Supporting Information may be found in the online version of this article at the publisher's web-site:

Movie S1A. Ultrasound movie showing lung sliding in a healthy model.

Movie S1B. Ultrasound movie showing lung pulse during respiratory pause in the healthy model.

Movie S2A. Ultrasound movie showing the absence of lung sliding, lung pulse and B-line in the right anterior chest in a patient with right pneumothorax.

Movie S2B. Ultrasound movie showing the presence of lung sliding in the left anterior chest in the patient.

Movie S2C. Ultrasound movie showing the presence of lung point in the right lateral chest in the patient.