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REVIEW ARTICLE

Guidance for clinical practice using emergency and point-of-care ultrasonography

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Abstract
Owing to the miniaturization of diagnostic ultrasound scanners and their spread of their bedside use, ultrasonography has been actively utilized in emergency situations. Ultrasonography performed by medical personnel with focused approaches at the bedside for clinical decision-making and improving the quality of invasive procedures is now called point-of-care ultrasonography (POCUS). The concept of POCUS has spread worldwide; however, in Japan, formal clinical guidance concerning POCUS is lacking, except for the application of focused assessment with sonography for trauma (FAST) and ultrasound-guided central venous cannulation. The Committee for the Promotion of POCUS in the Japanese Association for Acute Medicine (JAAM) has often discussed improving the quality of acute care using POCUS, and the "Clinical Guidance for Emergency and Point-of-Care Ultrasonography" was finally established with the endorsement of JAAM. The background, targets for acute care physicians, rationale based on published articles, and integrated application were mentioned in this guidance. The core points include the fundamental principles of ultrasound, airway, chest, cardiac, abdominal, and deep venous ultrasound, ultrasound-guided procedures, and the usage of ultrasound based on symptoms. Additional points, which are currently being considered as potential core points in the future, have also

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been widely mentioned. This guidance describes the overview and future direction of ultrasonography for acute care physicians and can be utilized for emergency ultrasound education. We hope this guidance will contribute to the effective use of ultrasonography in acute care settings in Japan.

KEYWORDS
acute care physician, core items, ultrasound education

CHAPTER 1: OVERVIEW

Introduction

Ultrasonography was introduced into clinical practice approximately 40 years ago, and systematic ultrasonography methods have been established for each area, with high-quality ultrasonography being performed by experts in the field for a long time. However, the miniaturization of ultrasound equipment has made it possible to use it easily at the bedside, and it is now being actively utilized in emergency situations regardless of the field. In recent years, ultrasonography performed by medical personnel at the bedside to improve clinical decisions and techniques has been called point-of-care ultrasonography (POCUS), as opposed to images recorded by a sonographer and interpreted later, and the concept has been widely shared internationally.[1] In Europe and the United States, many clinical studies on POCUS have been conducted, and various guidelines have been developed based on these findings,[2–4] along with systematic education. However, in Japan, the consensus was limited to focused assessment with sonography for trauma (FAST), extended FAST (EFAST), and ultrasound-guided central venous catheterization as ultrasound examinations that should be performed by acute care physicians.

The Committee for the Promotion of Point-of-Care Ultrasonography of the Japanese Association for Acute Medicine was established in January 2019. The committee has been actively engaged in ongoing discussions to improve the quality of emergency care through ultrasonography. The proposed learning goals of POCUS for acute care physicians were established, and a training course based on these goals was developed. The Board of Directors approved the outline of the course in February 2020; however, due to the spread of the new coronavirus infection, the course has not been held as originally planned.

This time, the "Clinical Guidance for Emergency and Point-of-Care Ultrasonography" was established with the endorsement of the Japanese Association for Acute Medicine. In this document, we provide information on the background, goals for acute care physicians, rationale based on published articles, and integrated applications. The focus of the guidance is the "core items" in the learning goals, but to facilitate future development of POCUS in emergency medicine, "adjunct items" are also broadly defined. It is important to note that this guidance does not correspond to a guideline that shows the level of evidence or recommendation based on systematic reviews but rather outlines the direction and approach for acute care physicians, considering validation articles on existing ultrasound examinations or POCUS in emergency medicine and the current situation of dissemination of POCUS in emergency medicine in Japan. Although this guidance is not mandatory for the training of emergency medicine residents, it should be regarded as a guide for ultrasound education and training in emergency medicine.

In publishing this guidance, we would like to emphasize that POCUS can be regarded as a "part of medical examinations," owing to its ease of use. However, it is important to note that POCUS does not replace a physical examination. There may be cases where POCUS as a focused examination can be performed and interpreted appropriately in a short period of time, but only after performing an appropriate physical examination. It should be recognized that there is a risk of inappropriate use of POCUS if a physical examination is omitted or if incorrect diagnostic inferences are made due to inappropriate performance of physical examinations.

Owing to space limitations, ultrasound images were not included in this guidance, except in some cases. For detailed information on each item and ultrasound images, please refer to the articles listed in this guidance and the existing books. We hope that this guidance will be valuable for acute care physicians, in the education of emergency medicine residents, and in conducting seminars. Furthermore, we hope that this guidance will contribute to the effective use of ultrasonography in the field of emergency medicine in Japan and encourage related clinical studies.

Of note, this guidance does not require the approval of an ethics committee and does not require anonymization based on the Human Information Protection Law.

Learning goals of POCUS for board-certified acute care physicians

The learning goals of POCUS for acute care physicians (committee drafts) were selected in the following manner: during the first meeting of the Committee for the Promotion of POCUS, each area (fundamentals of ultrasound, airway, thorax, heart, abdomen, deep vein, skin and soft tissue/musculoskeletal system, guided procedures, and symptoms) was assigned to committee members. The committee members reviewed the original articles and review articles in each area and selected the items they considered "essential" and "desirable" as learning goals of

POCUS for acute care physicians. The definition of "essential" was set as "acute care physicians can perform it when necessary". Specific examples include cases where access to ultrasound performed by specialists is difficult (e.g. focused cardiac ultrasound), cases where the procedure is not easily performed by conventional methods (e.g. guided puncture of an artery that is difficult to palpate), cases where transport to a computed tomography (CT) room is difficult because of the patient's condition, and cases of sudden deterioration in a hospital ward. FAST and ultrasound-guided puncture "must be performed" in the primary assessment of trauma and when securing the central venous catheterization, respectively, which differ from the definition of "essential."

At the second meeting, the committee members explained the items in their areas of responsibility based on evidence, and then all committee members voted for each item. The chairperson tabulated the voting results and provided feedback to the committee members. Based on these opinions, each committee member reconsidered and submitted a revised draft. At the third meeting, the revised draft was discussed, and the committee draft of the learning goals of POCUS was finalized.

Finally, the committee decided to set the "core items" as the levels at which POCUS could be performed when necessary (Table 1). Items that are expected to become more important in the future for emergency POCUS are designated "adjunct items" (Table 2). The standard for each item is divided into "core items" and "adjunct items" to indicate the level of proficiency required, but since this is a transitional period, please consider the educational system of each institution when using this guidance.

Off-the-job training, such as hands-on seminars, is desirable for the education of emergency medicine residents. It is especially effective in facilities where the educational environment is insufficient for on-the-job POCUS training. According to the ultrasound guidelines of the American College of Emergency Physicians (ACEP), proficiency in POCUS typically requires experience and a review of 25–50 cases in each area, with five cases for each guided procedure. The overall experience for POCUS is recommended to be 150–300 cases,[2] and these numbers are also considered reasonable for skill acquisition in Japan. Certification and quality assurance are topics that need to be discussed in the future.

Fundamentals of ultrasound [Core item]

For acute care physicians to perform ultrasonography accurately, interpret the findings correctly, and apply them to medical treatment, basic knowledge of ultrasonography in general (fundamentals of ultrasound) is essential. Table 3 provides an overview of the ultrasound basics that should be recognized by acute care physicians. Medical professionals specializing in ultrasonography, such as ultrasound specialists, are expected to have a greater level of knowledge than these fundamentals. For detailed information on the basics of ultrasound, please refer to textbooks dedicated to ultrasonography.

Although ultrasonography use is generally considered safe, the intensity of ultrasonic waves may have adverse effects on the human body. Ultrasound has two indices for assessing acoustic safety: the mechanical index (MI) and thermal index (TI). The MI is associated with the mechanical effects of ultrasonic waves on organisms and reflects the potential for cavitation, a phenomenon in which bubbles are activated by pressure changes. However, the TI is related to the thermal effects of ultrasonic waves on the tissue. The principle of "as low as reasonably achievable" (ALARA) should be followed in the use of ultrasonic waves, meaning using the lowest power level that allows for an adequate examination and the shortest possible duration.[5]

Infection control measures are essential for the safe and effective use of ultrasonography and should be implemented in accordance with conventional infection control measures and measures against emerging infectious diseases, such as the coronavirus disease 2019 (COVID-19). In general, bedside maintenance of ultrasound equipment is often inadequate, posing a risk of spreading infection. After the examination,

TABLE 1 Learning goals of POCUS for acute care physicians: Core items (can be performed when necessary).

Fundamentals	1. Acoustic engineering, 2. Probe handling and visualization, 3. Handling of the main unit of the device and optimization of the image, 4. Artifacts, 5. Patient safety
Airway	1. Normal, 2. Tracheal/esophageal intubation
Thorax	1. Normal, 2. Pneumothorax, 3. Pulmonary edema, 4. Pneumonia and atelectasis, 5. Pleural effusion and hemothorax
Heart	1. Normal, 2. Reduced left ventricular contractility, 3. Right ventricular dilatation (pulmonary thromboembolism), 4. Pericardial effusion (cardiac tamponade), 5. Hypovolemia, 6. Intracardiac masses (thrombi, vegetations, tumors), 7. Chronic changes (atrial/ventricular enlargement, wall thickening, severe valvular disease)
Abdomen	1. Normal, 2. Intra-abdominal fluid retention (bleeding, ascites), 3. Acute cholecystitis, 4. Abdominal aortic aneurysm, 5. Urolithiasis (hydronephrosis)
Deep veins	1. Normal, 2. Deep vein thrombosis of the lower extremity (2-region ultrasonography)
Ultrasound-guided procedures	1. Central venous access, 2. Peripheral venous access, 3. Arterial access, 4. Pericardiocentesis, 5. Thoracentesis, 6. Paracentesis
Integrated applications	1. Shock, 2. Dyspnea, 3. Trauma (FAST, EFAST), 4. Cardiac arrest

TABLE 2 Learning goals of POCUS for acute care physicians: Adjunct items (expected to become more important in the future).

Airway	1. Identification of the cricothyroid ligament
Thorax	1. Noncardiogenic pulmonary edema (ARDS)
Heart	1. Acute coronary syndrome, 2. Acute aortic dissection (ascending aorta)
Abdomen/Genital organs	1. Aortic dissection (abdominal), 2. Intussusception (children), 3. Bowel obstruction, 4. Acute appendicitis, 5. Acute scrotum, 6. Normal pregnancy
Skin and soft tissue/Musculoskeletal system	1. Fractures, 2. Synovial fluid, 3. Tendon/ligament injury
Ultrasound-guided procedures	1. Peripheral nerve block (femoral nerve, distal sciatic nerve, brachial plexus, radial/median/ulnar nerves)

Abbreviation: ARDS, acute respiratory distress syndrome.

TABLE 3 Fundamentals of ultrasound [Core item].

Acoustic engineering
Pulse wave and continuous wave
Acoustic impedance, reflection and transmission
Frequency and spatial resolution (axial and lateral resolution) and attenuation
Probe handling and visualization
Probe selection (linear, convex, microconvex, and sector)
Visualization arrangements (general and radiological fields, cardiovascular field)
Orientation (probe marker, screen marker)
How to hold and move the probe (sliding, rotating, tilting, rocking, compression)
Maintenance and management of probes (delicate probe handling, disinfection methods, etc.)
Handling of the main unit of the device and optimization of the image
Mode selection (B mode, M mode, and the Doppler mode)
Preset selection (cardiac, lung, abdominal, superficial, etc.)
Depth, gain, focus, adjustment of STC
Spatial compound imaging (influence on B-line morphology)
Freeze, cine operation, still image capture, and movie capture
Maintenance and management of the main unit of the device (power supply, etc.)
Artifacts
Acoustic shadow
Multiple reverberations
Mirror image
Patient safety
Biological effects and safety of ultrasound (the MI, TI, ALARA)
Infection control

Abbreviations: ALARA, as low as reasonably achievable; MI, mechanical index; STC, sensitivity time control; TI, thermal index.

it is important not only to wipe off the echo gel adhering to the probe but also to decontaminate any body fluids and blood in accordance with the facility policies. It should be noted that some types of disinfectants may damage ultrasound equipment and probes, and there is no universally recommended disinfectant for all ultrasound equipment. Therefore, when selecting a disinfectant, it is necessary to refer to the device manual or contact the manufacturer. Portable ultrasound devices, which have gained popularity in recent years, are easy to use for treating COVID-19 due to their ease of cleaning and ability to be used with a cover.[6–8]

CHAPTER 2: ORGAN-SPECIFIC APPLICATIONS

Airway

Introduction

The use of ultrasonography for airway management was first reported in the 1980s and has since evolved with the POCUS trend. The ACEP published guidelines on ultrasonography in emergency medicine, and the guidelines updated in 2017 lists airway management as 1 of 12 areas of practice.[2] POCUS for airway management mainly serves to confirm tracheal intubation and identify the cricothyroid ligament during surgical airway management. Given that these airway management skills are vital for emergency physicians, this committee designated them as essential components.

Basic scans and normal images [Core item]

The anatomical structures relevant for airway management in the neck include the following, listed from the head to the lower extremities: the thyroid cartilage, cricoid cartilage, and first and second tracheobronchial cartilages. These cartilages are interconnected by ligaments, and the space between the thyroid and cricoid cartilages is known as the cricothyroid ligament, which is crucial for emergency surgical airway management. The esophagus is located on the left dorsal aspect of these structures. The thyroid gland is located anteriorly and inferiorly to the thyroid cartilage, whereas the common carotid arteries and internal jugular veins are positioned laterally in the neck.

Airway management using ultrasonography typically involves the use of a linear probe to obtain longitudinal and transverse views. Ensure that the left side of the image corresponds to the patient's head in the longitudinal view, whereas in the transverse view, make sure that the left side of the image corresponds to the patient's right side.

Owing to the significant difference in acoustic impedance between air in the airway and cervical tissues, ultrasound waves are almost entirely reflected at the boundary between the airway and cervical tissues. The longitudinal image clearly displays a hyperechoic line, known as the air-mucosal interface (AMI). It is essential to evaluate the image superficial to the AMI because artifacts appear posterior to it (in the lower portion of the image). Cartilage is depicted as hypoechoic structures, whereas the cricothyroid ligament appears as a hyperechoic structure (Figure 1). In the transverse view, the thyroid cartilage is represented as a triangular-shaped structure, whereas the cricoid and tracheal cartilages are shown as large and small arcuate structures, respectively. The inner space of these airway structures is depicted as hypoechoic, and on the left dorsal side, the esophagus is represented as a hypoechoic luminal image (Figure 2).

Confirmation of tracheal intubation [Core item]

Confirmation of tracheal intubation involves ensuring the correct placement of the tracheal tube. A previous study reported that 3.3% of emergency intubations resulted in esophageal intubation.[9] The most reliable method for confirming intubation is usually the measurement of partial pressure of end-tidal carbon dioxide ($PETCO_2$). However, in situations where $PETCO_2$ may yield unreliable results, such as in patients with cardiac arrest, alternative confirmation methods become necessary, and POCUS is one such method.[10] Given that the confirmation of tracheal intubation is the most fundamental and crucial skill in the field of emergency medicine, and recognizing the high reliability of POCUS, we have designated it as the "core item" in the learning goals.

First, a transverse view is taken at the suprasternal notch. It may be easier to find the esophagus if the field is slightly scanned from the left side. If tracheal intubation is performed correctly, the ultrasound image does not show any significant changes. However, if a tube is mistakenly inserted into the esophagus, a luminal structure resembling the trachea will be observed within the esophagus, which is referred to as the double tract sign. If the double tract sign is absent, tracheal intubation is properly performed. There are two methods to confirm the double tract sign: dynamic (real-time) and static (pre- and post-intubation assessment).[11] The dynamic technique involves real-time observation during tracheal intubation and offers the advantage of visualizing the tube's passage through the trachea.[11] The static method is employed immediately after intubation and offers the advantage of being a single-operator procedure, whereas the dynamic method requires multiple persons to perform. Although the esophagus is only rarely detected on the right side of the trachea, it is nevertheless still recommended to confirm the location of the esophagus before intubation when using the static method.[12,13] In addition, methods such as twisting the tracheal tube[14] and employing the color Doppler technique[15] are available. According to several recent meta-analyses, ultrasonography to confirm tracheal intubation exhibits a sensitivity of over 92%, a specificity of at least 97%, and confirms tracheal intubation in approximately 13 s, suggesting that POCUS is highly valuable for tracheal intubation.[10,16,17]

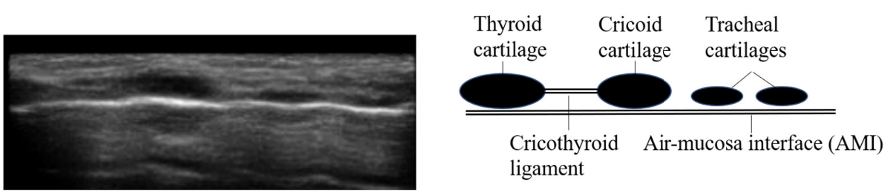

FIGURE 1 Longitudinal image of the neck (normal).

FIGURE 2 Transverse image of the neck (normal and successful intubation).

Another method for indirectly confirming tracheal intubation involves examining the anterior chest and observing bilateral pleural movements, known as lung sliding, with a sensitivity of 92%–100% and a specificity of 56%–100%. Lung sliding becomes visible only during forced ventilation in the absence of spontaneous breathing. If lung sliding is not observed on the left side of the chest, it suggests unintentional bronchial intubation in the right main bronchus, whereas bilateral absence suggests esophageal intubation. The use of lung sliding, in addition to the previously mentioned double tract sign, is believed to enhance the accuracy of intubation confirmation.[11]

Identification of cricothyroid ligament [Adjunct item]

Recent reports have indicated that cricothyrotomy is necessary in approximately 1% of airway management cases. Given this non-negligible frequency, airway management should always be performed with the possibility of intubation difficulties in mind.[9] However, palpation-based identification of the cricothyroid ligament shows accuracy rates of only 71% in nonobese patients and 39% in obese patients.[18] In contrast, when ultrasonography is employed, cricothyroid ligament identification accuracy improves significantly, being approximately 10 times more precise than the anatomical palpation approach in patients for whom locating the cricothyroid ligament is expected to be difficult.[19] Nevertheless, owing to the limited literature available regarding whether or not ultrasonography improves the success rate of cricothyrotomy in patients requiring surgical airway management, we have categorized this as an "adjunct item" within the learning goals.

For the accurate identification of the cricothyroid ligament, it is advisable to confirm its anatomical location using both longitudinal and transverse images. Hypoechoic thyroid cartilage and cricoid cartilage are identified in the longitudinal images. The slightly hyperechoic cricothyroid ligament is located between the two cartilages. In transverse images, the thyroid cartilage appears as a triangular structure, whereas the cricoid cartilage takes on an arcuate shape. The cricothyroid ligament can be recognized as a slightly luminous structure positioned between the two cartilages.

Thorax

Introduction

Dyspnea is a potentially fatal condition that occurs when the lungs, diaphragm, rib cage, intercostal musculature, and other organs responsible for lung movements are compromised. Obtaining an accurate patient history and findings in cases of dyspnea can be challenging, and often necessitate quick decision-making. Lung ultrasonography is drawing attention as a modality for quickly obtaining information beyond physical examinations at the bedside.

Although ultrasonography cannot capture normal lung structures with high air content, it has been employed in Japan since the late 1970s for assessing pleural and subpleural neoplastic lesions.[20] Lichtenstein et al., from France, introduced an algorithm for identifying the causes of acute respiratory failure (the BLUE protocol) in 2008, with a focus on the pleura and associated artifacts.[21] They used the concept that the inability to visualize lung structures with ultrasonography is indicative of high air content. In 2012, an international recommendation was issued for the utilization of lung ultrasonography in cases of respiratory failure, including pneumothorax, cardiogenic pulmonary edema, and pneumonia.[22] During the COVID-19 pandemic, the value of lung ultrasonography as a screening tool has been highlighted, with benefits in terms of cost-effectiveness and infection prevention.[23,24] It is not an overstatement to assert that lung ultrasonography has become an essential procedure for acute care physicians.

Basic scans and normal images [Core item]

In lung ultrasonography, we utilize findings pertaining to the pleura and the region just below it, along with any related artifacts. When positioning the probe along the midclavicle line along the long axis of the trunk, the following structures become visible: the skin and subcutaneous tissue, chest wall musculature, rib and cartilage, intercostal muscles, and pleural line. The pleural line constitutes a complex structure consisting of the parietal pleura, a physiologically trivial amount of pleural fluid covering the pleural surface, visceral pleura, and alveoli located just beneath the pleura. This intricate structure is also referred to as the pleural echo complex in Japan.[25] The line connecting the ribs to the pleural line is termed the "bat sign" due to its resemblance to a bat with outstretched wings, serving as the basic image of the landmark for the accurate identification of the pleural line (Figure 3).[26] Table 4 provides a summary of the findings in normal lungs based on this image.[22,26–28] As illustrated in Figure 3, it is recommended to assess four scanning areas on each side in accordance with internationally endorsed guidelines, resulting in a total of eight areas.[22]

Pneumothorax [Core item]

The importance of using ultrasonography to assess pneumothorax in the context of acute respiratory failure lies in the early diagnosis and prompt implementation of chest drainage.[21] According to a previous meta-analysis, the performance characteristics of ultrasonography for pneumothorax was reported to be 79% for sensitivity and 98% for specificity, which outperformed the sensitivity of 40% and specificity of 99% observed in chest X-rays.[29] Notably, supine chest X-rays are unable to detect an anterior pneumothorax known as an

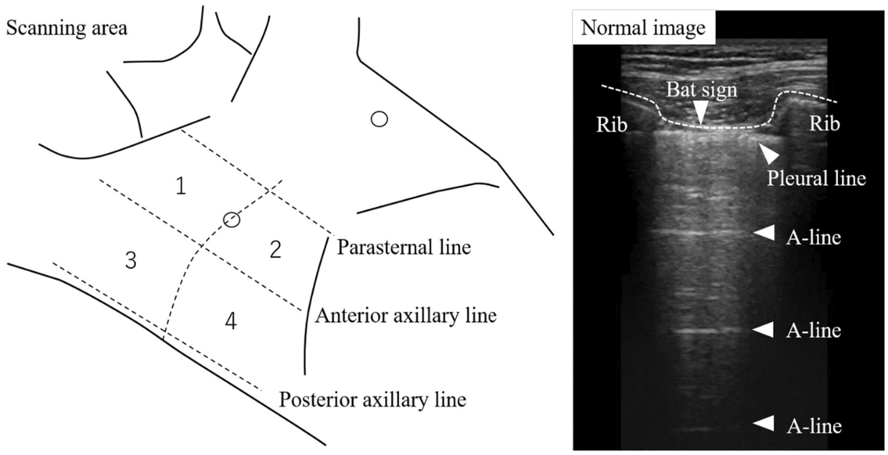

FIGURE 3 Scanning area and the normal image. Scanning areas: In the supine and semi-recumbent positions, the field is divided from the parasternal line to the anterior axillary line and from the anterior to the posterior axillary line, and then upper and lower at the level of the nipple (1 upper anterior area, 2 lower anterior area, 3 upper lateral area, 4 basal lateral area).

TABLE 4 Ultrasound findings in normal lungs.

Conditions/diseases	Assessment item (finding)	Description
Normal lung	A-line[26]	Multiple reverberations between the probe and the pleura, observed in well aerated lungs The finding is also observed in overdistended lung, including asthma/COPD, and pneumothorax
	B-line[22]	High-intensity linear artifact extending vertically from the pleural line without attenuation
	Lung sliding[26]	Respiratory movement of the visceral pleura against the parietal pleura, which is seen as a to-and-fro movement on the pleural line
	Lung pulse[27]	A finding in which the heartbeat is transmitted through the lung to the pleura and the pleural line moves vertically synchronized with the heartbeat
	Curtain sign[28]	A finding in which the subdiaphragmatic organs (liver and spleen) that are visualized during expiration are observed to be (partially) hidden by the lungs during inspiration

Abbreviation: COPD, chronic obstructive pulmonary disease.

"occult pneumothorax," where ultrasonography proves to be valuable.[30] It has been documented that emergency physicians can achieve an accurate pneumothorax diagnosis using ultrasonography after 2 h of intensive training, making it a skill that is easily attainable.[31] Table 5 shows the findings in pneumothorax.[27,32–34]

Pulmonary edema [Core item]

In acute respiratory failure, after excluding pneumothorax, the next step is to assess pulmonary edema. Among the numerous conditions that can lead to pulmonary edema, cardiogenic pulmonary edema caused by congestion stands apart from other forms owing to its positive response to noninvasive positive pressure ventilation and pharmacologic therapy, emphasizing the need for rapid identification.

As lung water density increases, B-lines, which are high-intensity linear artifacts extending vertically from the pleural line without attenuation and canceling out the A-lines, become more prominent.[33] In normal lungs, one or two B-lines per intercostal space can be observed, but three or more are called multiple B-lines and are considered a pathological finding.[33] It is crucial to accurately delineate B-lines. To properly depict and evaluate B-lines, the lung preset should be selected, or spatial compound imaging should be turned off, and the focus should be close to the pleural line.[35] The presence of multiple B-lines in two or more areas, among the four areas described in Figure 3, on both sides is called diffuse multiple B-lines.

Table 6 shows the findings of pulmonary edema.[21,33] Diffuse multiple B-lines may also appear in conditions such as noncardiogenic pulmonary edema, including acute respiratory distress syndrome (ARDS), and diffuse lung diseases such as interstitial pneumonia. Conversely, focal multiple B-lines, referred to as such, are commonly found in pneumonia, lung contusion, pulmonary infarction, malignancies, and more.[21] Acute care physicians should grasp the significance of multiple B-lines, assess their distribution, and distinguish them from other conditions.

Lung ultrasonography has been reported to be more effective than clinical symptoms or chest X-rays in diagnosing cardiogenic pulmonary edema in the emergency department. A meta-analysis of seven prospective clinical studies revealed a sensitivity of 94% and specificity of 92% for the diffuse multiple B-lines.[36,37] A different meta-analysis indicated that lung ultrasonography was useful not only for diagnosing cardiogenic pulmonary edema but also when combined with bedside echocardiography, was also valuable for the diagnosis.[38]

Pneumonia and atelectasis [Core item]

Lung ultrasonography is highly accurate in diagnosing pneumonia, with a sensitivity of 95% and specificity of 90%, whereas the sensitivity and specificity of chest X-ray are reported to be 77% and 91%, respectively.[39,40] Dorsal lesions in the lungs can be easily overlooked on chest X-ray, but lung ultrasonography reveals dorsal sonographic consolidation (Table 7), which often presents as hyperechoic dendritic structures corresponding to bronchi. When pneumonia is suspected, scanning the dorsal area meticulously is crucial to detect the lesions.[21,41] The presence of dynamic air bronchograms (Table 7), indicating respiratory changes in the dendritic structures, increases the likelihood of a pneumonia diagnosis.[42]

Pleural effusion and hemothorax [Core item]

In a comparison using CT as the gold standard for identifying pleural fluid, lung ultrasonography was reported to demonstrate 100% sensitivity and 100% specificity, while chest X-ray exhibited 65% sensitivity and 81% specificity.[43] Lung ultrasonography is valuable in identifying pleural effusion. When there is an accumulation of pleural effusion near the spine on the dorsal side, the spine, typically visible through solid organs in the abdominal cavity, becomes observable cephalad to the diaphragm. This finding is referred to as the "spine sign."[44] The spine sign is particularly beneficial for detecting small quantities of pleural fluid. The findings related to pleural effusion and hemothorax are shown in Table 8.

Pleural effusion is attributed to heart failure, pneumonia, and malignancies, accounting for 80% of the cases. Transudative pleural effusion, caused by increased

TABLE 5 Ultrasound findings in pneumothorax.

Conditions/diseases	Assessment item (finding)	Description
Pneumothorax	Absence of lung sliding[32]	The sensitivity of this finding is 90%. However, the absence of lung sliding is not specific to pneumothorax, as it can also be seen in massive bulla, pleural adhesions, and bronchial intubation
	Absence of B-line[33]	In pneumothorax, the visceral pleura is detached from the chest wall, so the B-line arising from just below the visceral pleura is not observed
	Absence of lung pulse[27]	In pneumothorax, the visceral pleura is detached from the chest wall, resulting in the absence of the lung pulse
	Lung point[34]	A transition point between the area where the visceral pleura contacts the chest wall and the area where it does not, where lung sliding repeatedly appears and disappears (specificity, 100%; sensitivity, 60%)

TABLE 6 Ultrasound findings in pulmonary edema.

Conditions/diseases	Assessment item (finding)	Description
Pulmonary edema	Multiple B-lines[33]	A finding of three or more B-lines in one intercostal space
	Diffuse multiple B-lines[21]	A finding where multiple B-lines are present on two or more areas on both sides, which suggests cardiogenic pulmonary edema, noncardiogenic pulmonary edema, or diffuse pulmonary disease

TABLE 7 Ultrasound findings in pneumonia/atelectasis.

Conditions/diseases	Assessment item (finding)	Description
Pneumonia/atelectasis	Focal multiple B-lines[21]	A finding of multiple B-lines in a localized area, suggesting pneumonia, pulmonary contusion, pulmonary infarction, malignant disease, etc
	Sonographic consolidation[41]	An abnormal finding due to decreased air content in the lungs. A condition in which the affected area of the lung shows hypoechoic or solid organ-like appearence (tissue-like sign)
	Dynamic air bronchogram[42]	A finding of respiratory changes of hyperechoic dendritic structures in the sonographic consolidation, which are not observed in resorptive atelectasis and indicate pneumonia

TABLE 8 Ultrasound findings in pleural effusion/hemothorax.

Conditions/ diseases	Assessment item (finding)	Description
Pleural effusion/ hemothorax	Absence of curtain sign[28]	In the presence of pleural effusion or hemothorax, the air content of the lungs decreases, and the curtain sign disappears
	Spine sign[44]	A finding in which the spine, which normally can only be observed via solid organs in the abdominal cavity, can also be observed on the cephalic side of the diaphragm via the pleural effusion

hydrostatic pressure due to heart failure or decreased colloid oncotic pressure due to hypoalbuminemia, often appears as an anechoic area due to the lack of cellular components and fibrins. In contrast, exudative pleural fluid resulting from infection or tumors appears turbid, displaying swirling dots within pleural effusion. In addition, exudative pleural effusion may exhibit fibrin septations or encapsulated components, contributing to its differentiation from transudative pleural effusions.

Ultrasonography is recommended for thoracentesis.[45] Prior to puncture, measuring the distance from the parietal pleura to the visceral pleura can help mitigate the risk of iatrogenic pneumothorax. After the puncture, it allows for the confirmation of pneumothorax or hemothorax and monitoring for the presence of re-expansion pulmonary edema (refer to Chapter 2, Ultrasound-guided procedures).

Noncardiogenic pulmonary edema (ARDS) [Adjunct item]

Noncardiogenic pulmonary edema, such as ARDS, can be distinguished from cardiogenic pulmonary edema by the irregularity and thickening of the pleura.[23,46,47] In addition, consolidations appear on the dorsal areas, and the curtain sign (Table 4) is absent.[28,41] Table 9 illustrates the findings observed in noncardiogenic pulmonary edema.

Severe cases of COVID-19 exhibit similarities to ARDS.[48] Although specific details are provided in a separate section [refer to Chapter 3, Coronavirus Disease 2019 (COVID-19)], CT reportedly often reveals ground-glass opacities and consolidations just below the pleura, which can also be captured by ultrasonography.[49,50] The findings associated with noncardiogenic pulmonary edema are outlined in Table 9.[46]

The heart

Introduction

In the field of cardiac POCUS, focused assessed transthoracic echocardiography (FATE),[51] introduced by Jensen et al. in 2004, and focused cardiac ultrasound examination (FoCUS), recommended by World Interactive Network Focused on Critical Ultrasound (WINFOCUS) and supported by multiple international societies, are well known.[52,53] FoCUS is a rapid, problem-oriented, goal-directed, bedside cardiac ultrasound examination performed by clinicians who may not necessarily specialize in echocardiography. FoCUS has been reported to be valuable in emergency and intensive-care settings for rapidly assessing clinical conditions, such as shock and dyspnea, as well as for safely performing invasive procedures, such as pericardiocentesis. FoCUS is employed to make decisions and promptly administer treatment to patients, making it crucial to understand the major patterns through the use of limited views. To enable any clinician to perform FoCUS quickly and easily, a visual estimation is the fundamental method, and the evaluation using the Doppler mode is not mandatory.[53] The focus cardiac ultrasound core curriculum and core syllabus of the European Association of Cardiovascular Imaging,[54] published in 2018, has seven assessment items and six scenarios (Table 10).

Cardiac POCUS has been described and basic evaluation criteria were proposed in various countries and societies. While the contents differ to some extent among them, their goal is to assess the condition of the heart with limited views and make a diagnosis in combination with the clinical history and symptoms.[2–4,54–57] In this guidance, the concept of FoCUS is adopted, and the "core items" and "adjunct items" in the field of cardiac POCUS are presented in Table 11.

Basic scans and normal images [Core item]

The heart is assessed using three windows and five cross-sectional views: parasternal long-axis and short-axis views from the left third or furth intercostal space, four-chamber view from the apex, and four-chamber and longitudinal inferior vena cava views from the subxiphoid area. Without using the Doppler mode, visual assessment is the fundamental method for making a comprehensive judgment in combination with the clinical course and symptoms. The goal is to evaluate the following items in order to recognize any abnormalities (Figure 4).

Reduced left ventricular contractility [Core item]

Left ventricular contractility is assessed using the left ventricular ejection fraction (LVEF). Although the biplane disk summation method (modified Simpson method) is currently the most strongly recommended approach for measuring LVEF in FoCUS, the evaluation is primarily conducted through a visual estimation based on the observed endocardial motion, without direct measurement. Normal ranges and severity partition cutoff values of LVEF in the recommendations published by the American Society of Echocardiography and the European Association of Cardiovascular Imaging in 2015 and a visual estimation based on the recommendations are shown in Table 12.[58]

TABLE 9 Ultrasound findings in noncardiogenic pulmonary edema.

Conditions/diseases	Assessment item (finding)	Description
Noncardiogenic pulmonary edema (ARDS, etc.)	Confluent B-lines/spared region	A finding of multiple B-lines fusing together and showing as a white area across the entire intercostal space as well as the presence of areas where no abnormality is observed
	Pleural line abnomarities	A finding of pleural irregularity and thickening due to inflammation
	Subpleural consolidation	A finding of consolidation just below the pleura
	Absence/decreae of lung sliding	A finding of the absence of or a decrease in lung sliding due to inflammation

Abbreviation: ARDS, acute respiratory distress syndrome.

TABLE 10 Assessment items and scenarios in FoCUS.

1. Seven assessment items in FoCUS
(1) Left ventricular systolic function
(2) Right ventricular systolic function
(3) Pericardial effusion, findings that suggest cardiac tamponade
(4) Intravascular volume, fluid responsiveness
(5) Chronic changes (ventricular enlargement, wall thickening, and atrial enlargement)
(6) Valvular abnormalities
(7) Large intracardiac masses (thrombi, vegetations, tumors)
2. Six scenarios in FoCUS
(1) Circulatory compromise/shock
(2) Cardiac arrest
(3) Chest pain/dyspnea
(4) Chest/cardiac trauma
(5) Respiratory compromise
(6) Syncope/presyncope

Abbreviation: FoCUS, focused cardiac ultrasound examination.

Multiple reports have highlighted the reliability of an LVEF evaluation through visual estimation by physicians who have received a certain level of training, suggesting comparability with evaluations conducted by specialists in echocardiography. For the evaluation of decreased left ventricular contractility, the sensitivity is reported to range from 74% to 97% and specificity from 57% to 99%.[59] The sensitivity and specificity of the visual estimation depend on the experience and skill of sonographers, with improvements noted after several hours of training.[60] In patients with respiratory failure in the emergency department, diagnosing a reduced LVEF through FoCUS reportedly has an accuracy of 81% for both the sensitivity and specificity.[38] A review published in 2020 reported that a series of observational studies showed FoCUS to have a sensitivity ranging from 74% to 97% and specificity from 57% to 99% for left ventricular dysfunction.[61]

Right ventricular dilatation [Core item]

The normal size of the right ventricle is typically approximately two-thirds the size of the left ventricle in the apical four-chamber view. Right ventricular dilation is confirmed when the size of the right ventricle is equal to or greater than the size of the left ventricle at end-diastole. When the right ventricle is enlarged and the interventricular septum is compressed and flattened toward the left ventricle in the parasternal short-axis view, the left ventricle appears D-shaped. Several diseases, such as pulmonary thromboembolism (PTE), acute right ventricular infarction, and primary pulmonary hypertension, can lead to right ventricular enlargement and dysfunction.

In FoCUS, several studies refer to the diagnosis of PTE based on the assessment of the right ventricle. In unstable patients suspected of having PTE in emergency departments, FoCUS, including the assessment of right ventricular dilation, McConnell's sign, flattened intraventricular septum, tricuspid regurgitation, and tricuspid annular plane systolic excursion (TAPSE), showed a sensitivity of 92% and specificity of 64%, as reported.[62] The guidelines from the European Society of Cardiology for the diagnosis and management of PTE state that hemodynamically unstable patients without right ventricular enlargement are unlikely to have PTE.[63] Recently, a diagnostic algorithm for PTE that integrates ultrasound findings with physical examinations and test results, such as D-dimer, has been proposed.[63]

Pericardial effusion (Cardiac tamponade) [Core item]

The normal volume of pericardial fluid is typically around 20 mL; however, confirming this value using ultrasonography can be challenging. An excess volume exceeding 50 mL is considered abnormal, with 50–100 mL categorized as a small volume, 100–500 mL as a moderate volume, and more than 500 mL as a large volume. Ultrasonography is employed for the semi-quantitative evaluation of the volume by measuring the widest dimension at end-diastole. In cases of a small volume, it may be observed posterior to the right atrium in the apical four-chamber view in the left lateral position. In accordance with the criteria for pericardial effusion introduced by the American Society of Echocardiography in 2013, we suggest a reference guide for evaluating pericardial effusion size (Table 13).[52]

An acute accumulation of even small amounts of pericardial fluid can result in cardiac tamponade. Conversely, in

TABLE 11 Assessment items in the field of cardiac POCUS (check sheet).

Core items	
Left ventricular contractility	□ Severely reduced □ Reduced □ Normal □ Hypercontractile
Right ventricular dilatation	□ Absent □ Present
Pericardial effusion	□ Absent □ Small □ Large
	□ No tamponade □ Tamponade
Intravascular volume	
Inferior vena cava	□ Collapsed □ Dilated
Left ventricular hypercontractility	□ Respiratory variation >50% □ Respiratory variation <50% □ Present □ Absent
Intracardiac masses (thrombi, vegetations, tumors)	□ Present □ Absent
Obvious abnormal changes that can be visually confirmed	□ Ventricular enlargement □ Atrial enlargement □ Wall thickening □ Severe valvular disease
Adjunct items	
Acute coronary syndrome	□ Wall motion abnormality □ Acute complication (cardiac rupture, acute mitral regurgitation)
Acute aortic dissection	□ Acute aortic regurgitation □ Flap

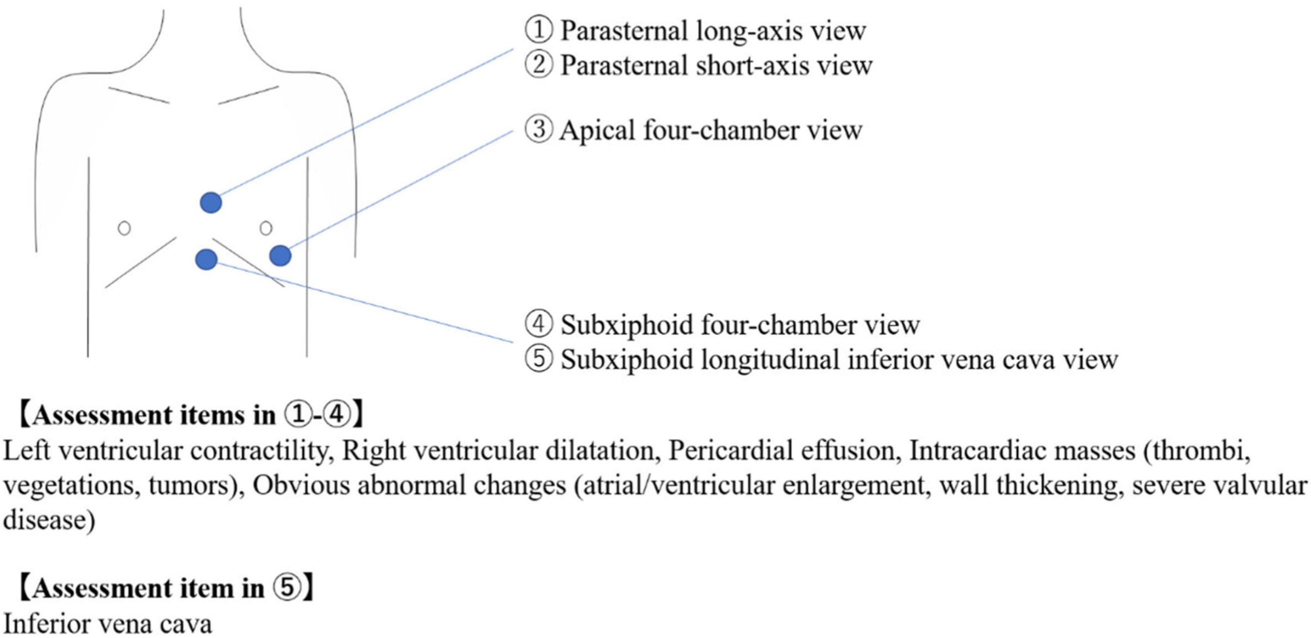

FIGURE 4 Scanning areas and items to be investigated in focused cardiac ultrasound examination.

cases of a slow accumulation despite the presence of substantial pericardial fluid, cardiac tamponade may not occur. It is important to note that localized pericardial fluid accumulation following open heart surgery has the potential to cause cardiac tamponade. The diagnosis of cardiac tamponade is typically based on the presence of circulatory impairments, such as decreased blood pressure or shock. In addition, ultrasound findings indicative of cardiac tamponade include (1) collapse of the right atrium or right ventricle, (2) dilatation of the inferior vena cava with reduced respiratory variation, and (3) pendulum-like movements of the heart in large pericardial effusion (swinging heart).[54,64] It has been reported that trained emergency physicians detected pericardial effusion using ultrasonography with a sensitivity of 96% and specificity of 98%.[65]

Hypovolemia [Core item]

The intravascular volume and fluid responsiveness can be estimated by observing the diameter of the inferior vena cava and its respiratory variation. In 2007, Brenann et al. demonstrated the utility of estimating the right atrial pressure based on the diameter of the inferior vena cava and the respiratory variation for predicting low and high right atrial pressure.[66] Table 14 shows the estimation of right atrial

TABLE 12 Assessment for EF.

Normal ranges and severity partition cutoff values for EF in FoCUS			
	Male, EF (%)	**Female, EF (%)**	**Visual estimation, EF (%)**
Severely reduced	<30	<30	<30
Reduced	30–51	30–53	30–50
Normal	52–72	54–74	50–70
Hypercontractile	>72	>74	>70

Abbreviations: EF, ejection fraction; FoCUS, focused cardiac ultrasound examination.

TABLE 13 Visual assessment for pericardial effusion size.

Severity partition cutoff values for pericardial effusion size in FoCUS	
Small	<10 mm
Moderate	10–20 mm
Large	>20 mm

Abbreviation: FoCUS, focused cardiac ultrasound examination.

TABLE 14 A visual assessment of the inferior vena cava.

Estimation of right atrial pressure on the basis of the assessment of inferior vena cava in FoCUS			
Estimated right atrial pressure	0–5 mmHg	5–10 mmHg	10–20 mmHg
Diameter of the inferior vena cava	<21 mm		>21 mm
Respiratory variation	>50%		<50%

Abbreviation: FoCUS, focused cardiac ultrasound examination.

pressure based on the diameter and respiratory variation, which is based on the proposal from the American Society for Echocardiography in 2015.

Various factors influence the diameter of the inferior vena cava, including the circulating blood volume, cardiac function, respiration, heart rate, and abdominal pressure. While a decrease in circulating blood volume can lead to a reduced inferior vena cava diameter,[67] it is crucial to consider the impact of other factors mentioned above. During positive pressure mechanical ventilation, the thoracic cavity experiences positive pressure, reducing venous return and resulting in a larger inferior vena cava diameter. Furthermore, the assessment of fluid responsiveness using the diameter of the inferior vena cava and its respiratory variation as dynamic indices has been explored. A meta-analysis on the assessment, reported in 2017, demonstrated an area under the curve (AUC) of 0.76 for spontaneous ventilation and 0.79 for mechanical ventilation,[68] although the accuracy remains a subject of debate.[59] In cases of decreased circulating blood volume, the left ventricle tends to become hypercontractile, unless there is a chronic decrease in left ventricular contractility. Therefore, the combined findings of the inferior vena cava and left ventricle serve as reliable indicators of hypovolemia.[54,69]

Intracardiac masses (thrombi, vegetation, tumors) and chronic changes (atrial/ventricular enlargement, wall thickening, severe valvular disease) [Core item]

FoCUS encompasses the assessment of intracardiac masses (thrombi, vegetation, and tumors) and valve abnormalities (calcification, thickening, and valve prolapse) that are visually detectable. In addition, the evaluation of chronic changes, such as atrial and ventricular enlargement and wall thickening, is essential, requiring a solid understanding of normal findings.[52–54]

Regarding valvular disease evaluation, a systematic review from 2019 indicated that FoCUS improved the sensitivity of diagnosis compared with auscultation for aortic regurgitation, mitral regurgitation, and tricuspid regurgitation. However, specificity did not show any significant differences. For the assessment of aortic stenosis, the diagnostic accuracy was not high in the absence of Doppler usage.[70] Another review in 2020 reported that FoCUS had respective sensitivity and specificity values of 63%–70% and 88%–100% for diagnosing aortic stenosis, 82%–83% and 89%–99% for aortic regurgitation, 48%–100% and 81%–99% for mitral regurgitation, and 65%–89% and 89%–98% for tricuspid regurgitation.[59]

Acute coronary syndrome (Regional wall motion abnormality, complications) [Adjunct item]

In acute coronary syndromes, the time to coronary artery revascularization must be minimized, emphasizing the importance of prompt diagnosis using ultrasonography in conjunction with the clinical course, electrocardiogram, and cardiac enzymes. Board-certified acute care physicians may be expected to possess the ability to assess wall motion and estimate the culprit coronary artery (Figure 5).[58] While there is limited high-level evidence concerning wall motion evaluations by emergency physicians, a single-center prospective observational study reported a sensitivity of 88% and specificity of 92% in patients with ST-elevation myocardial infarction.[71]

Regarding the frequency of mechanical complications, cardiac tamponade or rupture occurred in 1.4%, ventricular septal rupture in 3.9%, and acute severe mitral regurgitation in 6.9%,[72] emphasizing the significance of the early evaluation of these complications.

Acute aortic dissection (Acute aortic regurgitation, flap, etc.) [Adjunct item]

In clinical practice, the timely diagnosis and exclusion of acute aortic dissection are crucial because of its acuity and

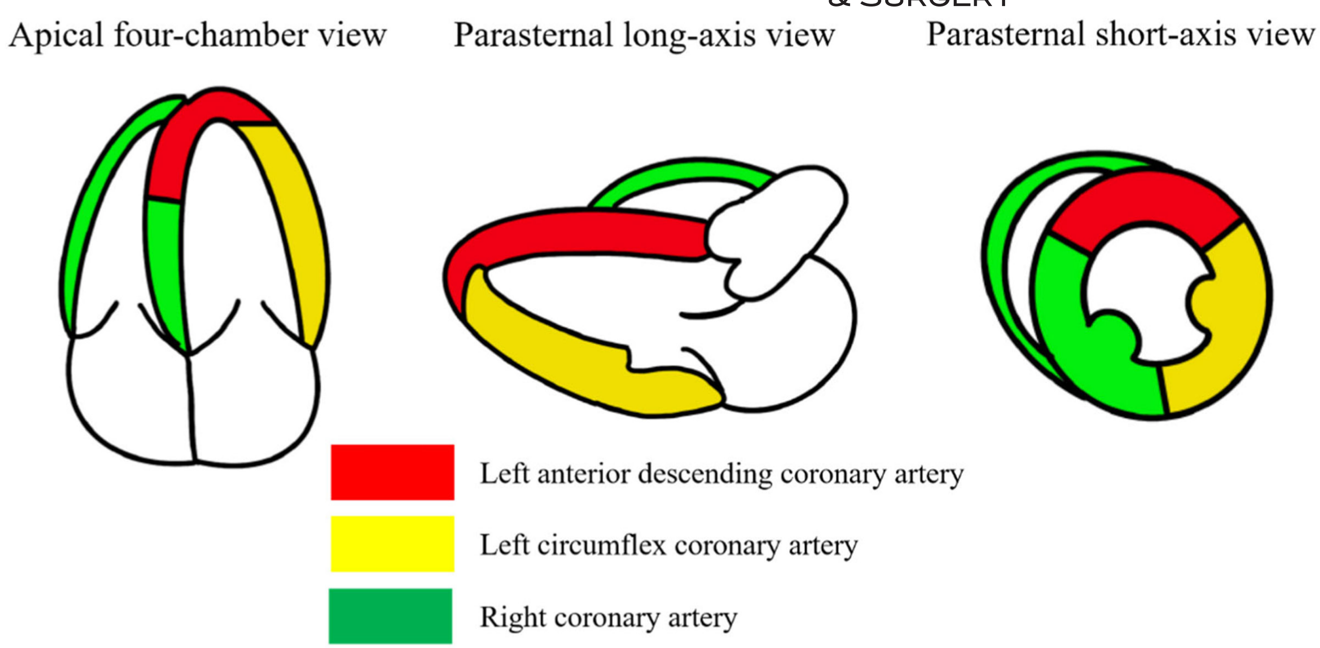

FIGURE 5 Distribution of the coronary vascular supply.

severity. Approximately one-third of acute aortic dissections extend into the abdomen, necessitating the evaluation of the abdominal aorta in addition to the thoracic aorta for the detection of aneurysms and intravascular flaps. In Stanford type A acute aortic dissection, observable findings may include pericardial effusion, acute aortic regurgitation, enlarged diameter of the ascending aorta, and carotid artery dissection. If clinically suspected, these findings should be evaluated using ultrasonography, as their presence increases the likelihood of acute aortic dissection. However, the absence of these findings does not rule out acute aortic dissection, and imaging studies such as CT are necessary in case of any doubt.[73]

The evaluation of thoracic aortic dissection by emergency physician-performed FoCUS has been reported to have high specificity but low sensitivity,[74,75] and a negative result does not rule out thoracic aortic dissection. A diagnostic algorithm utilizing a risk score and D-dimer level with FoCUS has also been proposed.[76]

Abdomen/Genital organs

Introduction

Abdominal ultrasonography enables the examination of various organs, including the liver, gallbladder, pancreas, spleen, kidney, bladder, stomach, small intestine, colon, appendix, uterus and appendages, aorta, and inferior vena cava, and is often a part of routine laboratory procedures. In the field of emergency medicine, abdominal ultrasonography is frequently performed and serves as a guide for clinical decision-making and puncture procedures.[77,78] POCUS has proven useful for conditions, such as intra-abdominal hemorrhage due to trauma or ectopic pregnancy, acute cholecystitis, abdominal aortic aneurysm (rupture), and hydronephrosis secondary to ureteric calculi or other conditions.[79] Consequently, we have designated them as “core items” in our learning goals. While evidence in other diseases and medical conditions is limited, we categorized them as “adjunct items” due to their anticipated future utilization.

Abdominal and genitourinary medicine encompass a diverse range of conditions, necessitating the learning of ultrasonography for each area and an understanding of both the diagnostic performance and limitations. It is also crucial to understand the unique challenges and techniques associated with performing abdominal ultrasonography in infants and pregnant women.

Basic scans and normal images

As mentioned above, various organs in the abdomen are the focus of POCUS, necessitating specific scan techniques. Basic scans and normal images of the abdomen are elaborated in accordance with different conditions and diseases.

Intraabdominal fluid retention (bleeding, ascites) [Core item]

Intra-abdominal fluid retention can be rapidly and accurately detected using ultrasonography, with the Morison's pouch, perisplenic area, and pelvic cavity being the primary sites for such detection. The quantity of fluid detected depends on the anatomical site and the patient position.[80]

In the primary survey of trauma care, FAST is employed to assess circulation and identify potential blood loss. It is crucial to note that FAST exhibits high specificity but low sensitivity in detecting and excluding organ injury.[81] Therefore, in cases of suspected blunt trauma, a positive finding can guide treatment decisions, but a negative finding does not rule out intra-abdominal bleeding and should be confirmed by CT or other modalities. FAST in blunt trauma in children has a particularly low sensitivity and warrants careful attention.[82] (refer to Chapter 3, FAST/EFAST).

In cases of endogenous diseases, the FAST technique is also recommended for patients presenting with abdominal symptoms or shock to identify intra-abdominal fluid retention.[78] While there is limited validation for the detection of endogenous intra-abdominal bleeding through ultrasonography, reports indicate a shorter time to the diagnosis and treatment in ectopic pregnancies and a higher rate of emergency surgery in positive cases than in others.[83,84]

Acute cholecystitis [Core item]

Acute cholecystitis is a common condition, and the gallbladder is well suited for POCUS because of its relative ease of visualization. Along with clinical symptoms, such as right upper quadrant abdominal pain, a positive finding on ultrasonography can quickly confirm acute cholecystitis, often making it the initial imaging procedure of choice. In the basic scan, the intercostal approach, in addition to the right subcostal approach, can enhance diagnostic accuracy. Ultrasound findings of acute cholecystitis include gallstones, gallbladder wall thickening, gallbladder enlargement, and pericholecystic fluid. While a previous study emphasized the excellent sensitivity and negative predictive value of gallstones alone,[85] it should be noted that identifying gallstones trapped in the neck of the gallbladder may pose challenges. The sonographic Murphy's sign, where pain intensifies upon gallbladder compression with a probe, is useful for the diagnosis and has a positive predictive value of 92% in patients with gallstones.[86,87] The diagnostic accuracy of POCUS for acute cholecystitis by emergency physicians with specific training was reported to be 87% sensitivity, 82% specificity, 44% positive predictive value, and 97% negative predictive value, comparable to ultrasound diagnoses conducted in radiology departments.[88]

Abdominal aortic aneurysm [core item] and aortic dissection [adjunct item]

The normal diameter of the adult abdominal aorta is generally 20 mm. An abdominal aortic aneurysm is diagnosed when the diameter exceeds 30 mm with spindle-like enlargement (fusiform) or when the aortic wall is locally dilated (saccular). While the recommended indication for invasive treatment of asymptomatic abdominal aortic aneurysm is a maximum short-axis diameter of ≥55 mm for men and ≥50 mm for women, invasive treatment may be considered even if the diameter is less than the indicated size. Saccular aneurysms, in particular, are deemed to have a high risk of rupture and are often recommended for surgery at an early stage, even if the size is smaller than that of fusiform aneurysms.[89] When measuring the diameter of the abdominal aorta with ultrasonography, the largest short-axis cross-section perpendicular to the long axis is visualized for fusiform aneurysms, and the diameter (round) or short axis (oval) is utilized as the aneurysm diameter. In saccular aneurysms, the diameter is measured as the long diameter from the normal side of the aorta to the tip of the saccular aneurysm. The measurements for each type are performed between the external sides (adventitia).[90]

The primary concern with abdominal aortic aneurysms is rupture, defined as leakage of blood outside the vessels, or impending rupture, when there is no obvious leakage but the pain location coincides with the aneurysm location.[89] In both cases, prompt treatment is crucial; if POCUS is appropriately utilized in the initial examination, the time to the diagnosis of (impending) rupture and treatment may be shortened. In patients with suspected abdominal aortic aneurysm (rupture), POCUS performed by emergency physicians with appropriate training exhibited excellent diagnostic performance, with a reported sensitivity of 99% and specificity of 98% in a meta-analysis.[91]

It is important to note that most of the aortic dissection cases can only be diagnosed accurately when multiple images are obtained, including images of the heart, and thoracic and abdominal aorta.[92] The presence of a flap in the aorta or a crescent shape of the wall may indicate an aortic dissection.[93] The movement of the abdominal aorta flap can be easily detected by ultrasonography and is a highly specific finding.[94] Although POCUS is useful in detecting abdominal aortic dissection and in clinical decision-making, it is considered an "adjunct item" due to its limited diagnostic ability and insufficient scientific evidence.

Urolithiasis (Hydronephrosis) and urinary retention [Core item]

Colic attacks resulting from urolithiasis are characterized by severe unilateral abdominal and back pain, which sometimes radiates to the external genitals and thighs. In addition, gastrointestinal symptoms, such as nausea, vomiting, and abdominal distention, may occur. Given the potential absence of typical symptoms, appropriate diagnostic imaging is required. Ultrasonography, a noninvasive method, is valuable in assessing upper urinary tract obstruction presenting as hydronephrosis and in detecting stones near the bladder.

The assessment of hydronephrosis involves examining the long-axis cross-section of the kidney. By visualizing the longitudinal cross-section of the kidney at the mid- to posterior-axillary line with a probe positioned along the ribs, hydronephrosis can be diagnosed if anechoic dilated renal calices and pelvis are present in the hyperechoic renal sinus. When utilizing CT as the criterion standard for diagnosing hydronephrosis in patients presenting to an emergency department with a colic attack, POCUS demonstrated a sensitivity of 73% and specificity of 73% among all physicians. However, among post-training physicians, POCUS had a sensitivity of 93% and specificity of 81%.[95] In a study on the initial evaluation of patients with suspected nephrolithiasis (urolithiasis) in the emergency department, patients were randomly assigned to three groups: initial ultrasonography by emergency physicians (POCUS), ultrasonography by radiologists, and CT. The results indicated that ultrasonography reduced radiation exposure without increasing the risk of serious adverse events.[96] Ultrasonography for urolithiasis is deemed safe, and the diagnostic accuracy of POCUS may be increased when it is performed by well-trained physicians.

When unilateral hydronephrosis is present, urinary tract obstruction due to calculi is suspected, and the presence of stones in the ureter can also be evaluated. Although stones in the ureterovesical junction are relatively easy to identify, the sensitivity and specificity of ultrasonography for detecting stones in the entire urinary tract are 78% and 31%, respectively, indicating that identifying the stones themselves is not always possible.[97] Stones >5 mm in diameter can be identified as hyperechoic structures with acoustic shadows. Bilateral hydronephrosis may suggest urinary tract obstruction in the bladder or distally. In such cases, the presence of diseases, including prostatic hypertrophy and bladder hematoma, should also be evaluated.

Intussusception in children [Adjunct item]

The use of ultrasonography in intussusception was first described in 1977.[98] Since then, ultrasonography has been an alternative to radiography as the initial evaluation method for the diagnosis of intussusception. The sensitivity and specificity of ultrasonography by radiologists have been reported to be 98%–100% and 88%–100%, respectively.[99–102]

The condition in which the proximal intestinal tract is entrapped in the distal intestinal tract is called intestinal invagination, and intussusception is defined as intestinal obstruction caused by intestinal invagination.[100] The blood vessels of the mesentery are entrapped along with the intestinal tract, resulting in circulatory disturbance, which over time leads to strangulated bowel obstruction. Since more than 90% of intussusceptions are of the ileocolonic type, the invaginated intestinal tract is often observed in the right upper quadrant. Ultrasonography is first performed to determine if there is an invaginated intestine from the ascending colon to the terminal ileum, followed by a careful search along the transverse colon and descending colon.[103] The short-axis cross-section typically seen in intussusception is called the target sign (or crescent-in-doughnut sign or multiple concentric ring sign), and the long-axis cross-section is called the pseudokidney sign. The absence of these signs is considered normal.

Since 2010, studies investigating the accuracy of the diagnosis of intussusception by POCUS performed by emergency physicians have been published,[104] and systematic reviews and meta-analyses have shown that both the sensitivity and specificity of POCUS are remarkably high.[105–108] There is reportedly no significant difference between POCUS performed by pediatric emergency physicians and ultrasonography performed by radiologists for the diagnosis of intussusception.[106] However, it has been pointed out that diagnostic accuracy can be better guaranteed when multiple emergency physicians perform ultrasonography on a single patient.[107] Because intussusception is more common in infants and toddlers between 6 months and 3 years old, a detailed history and physical examination may be difficult, and POCUS should be actively used as a tool to support diagnosis in the care of infants and toddlers.[108]

Appendix: Ultrasound-guided noninvasive reduction for intussusception

Ultrasound-guided noninvasive reduction of intussusception has been reported since the 1990s,[109] and a previous review demonstrated its efficacy and safety.[110] In a randomized trial conducted in China, the success rate of ultrasound-guided hydrostatic reduction with normal saline was significantly higher than that of X-ray-guided pneumatic reduction.[111] Ultrasound-guided reduction did not cause intestinal perforation. A subsequent large multicenter study concluded that ultrasound-guided nonoperative reduction has a high success rate and can be performed safely without radiation exposure.[112] In the present circumstances in Japan, it is emphasized that the success of the technique relies on the medical resources in the facilities and proficiency of the sonographers. Therefore, generalizing it as the standard technique for intussusception is challenging. It is recommended to communicate and establish a policy concerning the intussusception reduction method in advance with pediatricians, surgeons, and radiologists.

Bowel obstruction [Adjunct item]

Bowel obstruction in this context refers to a condition in which the intestinal contents stagnate due to mechanical blockage, and a delayed diagnosis can lead to severe complications such as intestinal necrosis and peritonitis due to intestinal perforation. Traditionally, X-ray has been the primary choice for imaging; however, its low sensitivity and specificity has been documented. Although CT is often used for confirmation, considerations must be made regarding radiation exposure and cost. In recent years, bedside ultrasonography has gained attention owing to its quick application.[113]

In the 2010s, several studies on ultrasonography for bowel obstruction were published,[114–119] with Gottlieb et al. reporting a sensitivity of 92% and specificity of 97%.[114] However, a prospective, multicenter, observational study by Becker et al. found limited accuracy in ultrasonography performed by emergency physicians, with a sensitivity of 88% and specificity of 54%.[120] The interpretation of acquired images was more accurate with a specificity of 82% when performed by physicians with a prior emergency ultrasound fellowship. This study highlights the importance of dedicated POCUS training for accurate diagnoses.

During the examination, the patient is positioned supine, and a convex probe is used, with a linear probe for thin patients and children.[117] The search for the intestinal tract extends to various regions, including the epigastric region, left side of the abdomen, peri-umbilical area, and pelvic region.[117,119] It is important to assess the presence of a dilated intestinal tract filled with fluid, and previous studies often considered significant dilation as 20–30 mm or more, measured from outer wall to outer wall. Additional parameters, such as intestinal wall thickening, to-and-fro movement of intestinal fluid, and peristalsis variations (increased, normal, decreased, or absent), can also be considered.

The presence of peritoneal fluid is not uncommon in cases of bowel obstruction and should be assessed. If there is a short time course from onset but a substantial amount of peritoneal fluid or if the fluid increases over time, strangulated bowel obstruction is more likely. Reliable evaluation of the site of mechanical obstruction and detailed blood flow assessment through ultrasonography necessitate sufficient experience and training. In diagnosing intestinal obstruction, it is crucial not to rely overly on ultrasonography but to conduct a comprehensive evaluation, considering the patient's general condition, time of onset, clinical course, and physical examination findings.

Acute appendicitis [Adjunct item]

Acute appendicitis is a common disease, and although most cases present with a typical clinical picture, certain instances pose diagnostic challenges based solely on the medical history and physical examination findings. Even when acute appendicitis is suspected, differentiation from other conditions, such as diverticulitis and enteritis is essential. In adults, CT is the preferred imaging modality for differentiation. In contrast, the American College of Radiology recommends ultrasonography as the initial imaging test for diagnosing acute appendicitis in children and pregnant women.[121]

Ultrasonography performed by radiologists and technicians can be highly accurate for diagnosing acute appendicitis. However, ultrasonography for acute appendicitis requires specialized training, and is traditionally performed by specialists. Recently, there has been an increased demand for ultrasonography in acute appendicitis, especially with the widespread use of POCUS.[122]

There are two major approaches to identifying the appendix through ultrasonography: a systematic approach that sequentially identifies the ascending colon, ileocecum, cecum, and proximal part of the appendix; and an approach that utilizes tender points as guides for scanning the enlarged appendix, with the latter frequently used in POCUS. In acute appendicitis, the swollen appendix appears as a luminal structure with a diameter exceeding 6 mm, lacks peristalsis, and resists deformation by compression with a probe. The presence of a sonographic McBurney's sign is simultaneously confirmed with localized pain upon compression of the visualized appendix. The findings of appendicolith, periappendiceal fat inflammation, and free fluid are also helpful for the diagnosis. No detection of a swollen appendix on ultrasonography does not rule out acute appendicitis. To rule out acute appendicitis with ultrasonography, a normal appendix must be visualized from the base to the blind end, a capability beyond POCUS.[123] If POCUS fails to diagnose acute appendicitis, repeated physical examinations and additional imaging studies (radiologist-performed ultrasonography, contrast-enhanced CT, or MRI) are recommended.

A meta-analysis of 17 studies revealed that ultrasonography, when conducted by emergency physicians with sufficient POCUS training, exhibited a sensitivity of 84% and a specificity of 91% for acute appendicitis.[78] An ultrasound diagnosis in adults may be challenging due to body habitus, such as obesity; therefore, patient characteristics and sonographer skills should be considered when determining POCUS indications.[124]

Children

In the 2010s, multiple studies on POCUS for acute appendicitis in children in the emergency department were reported,[125–128] demonstrating higher diagnostic accuracy than in adults.[78] A meta-analysis published in 2017 indicated a positive likelihood ratio of 9.24 and a negative likelihood ratio of 0.17, concluding that acute appendicitis can be diagnosed without CT or MRI if a swollen appendix is detected by POCUS.[129] The diagnosis of acute appendicitis in children, as in adults, is established when the appendix swells to >6 mm in diameter and remains noncompressible, along with other clinical findings.

Pregnant women

The incidence of acute appendicitis during pregnancy is 1/800 to 1/1500,[130] peaking in the second trimester (14–27 weeks).[131] Ultrasonography is the primary choice for diagnostic imaging.[132] The diagnostic accuracy varies, with a sensitivity ranging from 67% to 100% and specificity from 83% to 96%, depending on the report.[133] Nevertheless, it is deemed comparable to the diagnostic accuracy of acute appendicitis in nonpregnant patients.

A key feature of pregnant women is the changing position of the appendix with the progression of gestation. As the number of weeks increases, the appendix shifts toward the lateral, superior, and posterior sides because of the enlarging uterus.[134] Pain may be experienced in the right lower quadrant during the early stages of pregnancy, but it is important to note that the site of pain and the optimal probe location change with the progression of pregnancy. Given the enlargement of the uterus and the shift of the appendix to the upper lateral side after the fourth month of pregnancy, a meticulous scan ranging from the right lower quadrant to the lateral side of the abdomen is necessary. Acute appendicitis is diagnosed when the enlarged appendix surpasses 6 mm in diameter and remains noncompressible. Furthermore, in a comprehensive investigation of the causes of right lower quadrant pain other than acute appendicitis during pregnancy, ultrasonography should be actively conducted to differentiate conditions such as ovarian cysts, ovarian torsion (including tumor torsion), uterine myoma degeneration, myoma torsion, urolithiasis, and cholecystitis.[135]

Acute scrotum (testicular torsion, epididymitis) [Adjunct item]

Scrotal pain constitutes approximately 0.5% of emergency department visits and is primarily attributed to testicular torsion and epididymitis.[136] Scrotal pain includes emergent testicular torsion that threatens testicular viability; therefore, it is necessary to promptly determine the treatment of the patient. While ultrasonography for acute scrotum is a preferred noninvasive method without radiation exposure, it is designated as an "adjunct item" because it requires more specialized skills.

The testes and epididymis are visualized using a high-frequency linear probe. The normal testis appears as a smooth, rounded, oval structure (average size, 4 × 3 × 3 cm) with homogeneous echogenicity. Color Doppler imaging reveals blood flow throughout the testes. The epididymis, anatomically divided into the head, body, and tail, typically visualizes as a pyramid-shaped head (5–12 mm in size) on the upper testicular pole.

In cases of testicular torsion, the testis exhibits swelling due to venous congestion and appears internally heterogeneous. Confirmation of the diagnosis involves identifying a decreased or absent blood flow in the testis through color Doppler imaging.[137] The sensitivity and specificity of color Doppler are notably high at 89% and 99%, respectively,[138] and ultrasonography performed by emergency physicians demonstrated a sensitivity of 99%–100% and a specificity of nearly 100%.[139]

Epididymitis manifests as a swollen epididymal head (>17 mm), with a heterogeneous appearance. Color Doppler imaging can detect increased blood flow in the epididymis compared to the normal side, achieving a sensitivity of almost 100%.[140] However, the definitive diagnosis requires not only ultrasound findings but also a comprehensive evaluation based on the medical history (fever, dysuria), physical examination findings (tender scrotum), blood tests, and urinalysis.

Normal pregnancy [Adjunct item]

Ultrasonography should be performed on fertile women presenting with symptoms, such as abdominal pain or vaginal bleeding, accompanied by a physical examination. This study is performed to assess various aspects of pregnancy, including intrauterine pregnancy (normal pregnancy), ectopic pregnancy, fetal heart rate at all stages, gestational age, and fluid retention in the pelvic cavity. The assessment of intrauterine pregnancy, particularly in the early stages, helps identify the presence of ectopic pregnancy. Although the sensitivity and specificity of transabdominal ultrasonography in assessing ectopic pregnancy may vary,[141–143] a previous report suggested that confirmation of a normal pregnancy could virtually rule out an ectopic pregnancy.[142] However, it should be noted that this may not be universally applicable to pregnancies resulting from assisted reproductive technology, which has been on the rise in recent years, as it infrequently leads to simultaneous intrauterine and ectopic pregnancy. Confirmation of normal early pregnancy involves the identification of the gestational sac in the uterus. However, it should be noted that gestational sacs may resemble decidual cysts or fluid collections in the endometrial cavity. Previous reports mentioned that definitive confirmation is only achieved through observation of a yolk sac within the gestational sac of the uterus.[144,145] In most cases, the yolk sac becomes visible when the diameter of the gestational sac exceeds 8 mm,[146] reaching a maximum diameter of 6 mm at 10 weeks before disappearing entirely by 12 weeks.[147]

In mid-to late pregnancy, it is crucial not only to make an obstetric diagnosis but also to evaluate normal pregnancy in cases of abdominal pain, trauma, or other conditions that may impact pregnancy continuation. Particularly after 23 weeks, maternal trauma may lead to complications, such as placental abruption, uterine rupture, and preterm delivery. Therefore, beyond the initial assessment, the evaluation of a normal fetal heart rate (110–160 bpm) and placental abnormalities is essential.[148,149] Ultrasonography should be performed throughout all stages of pregnancy to determine the status, assess obstetric urgency, and promptly initiate appropriate treatment for the pregnant patient.

Deep veins

Introduction

Deep vein thrombosis (DVT) can lead to PTE and warrants special attention in emergency medicine. Epidemiological research on DVT has revealed an annual incidence of 50 cases per 100,000 people in the United States, while in Japan, the incidence is relatively low at 12 cases per 100,000 people per year, although it has been on the rise in recent years.[150]

Most cases of DVT are diagnosed in the lower limbs, with less frequent occurrences in the upper limbs.[150] DVT in the lower extremity often occurs distally (lower leg), and the majority of cases resolve spontaneously. However, 3%–9% progress to involve the proximal region (thigh),[151–153] and approximately 1.5% result in PTE.[153,154] DVT of the upper extremity is predominantly associated with catheter insertion, with the axillo-subclavian vein being the most frequently involved.[155]

POCUS is internationally recognized as the preferred imaging examination for diagnosing lower extremity DVT and is designated as a "core item" for acute care physicians, facilitating rapid bedside decision-making.[2,156,157]

Basic scans and normal images [Core item]

When performing ultrasonography of the leg veins in the supine position, the patient may be placed in a reverse Trendelenburg position at 10° to 20°, with the leg externally rotated into a "frog position" for the observation of the popliteal vein, allowing for easy visualization. Typically, a high-frequency linear probe is used to visualize the superficial region of the leg.

The anatomy of the leg veins is shown in Figure 6. The anterior tibial vein, posterior tibial vein, and peroneal vein converge to form the popliteal vein. The popliteal vein becomes the femoral vein when it enters the thigh and then unites with the deep femoral vein and great saphenous vein. The common femoral vein becomes the external iliac vein after crossing the inguinal ligament. Although previously referred to as the superficial femoral vein, the name can be misleading, as it implies a superficial vein despite being a deep vein. In recent years, the term "femoral vein" has been internationally adopted.[158,159]

Two major techniques for ultrasound scanning of lower extremity DVT include whole-leg ultrasonography, covering all major veins, and two-point ultrasonography, focusing on the common femoral vein and the popliteal vein.[160,161] Guidelines for the diagnosis, treatment, and prevention of PTE and DVT in Japan primarily target proximal DVT (central DVT) for the treatment of the lower extremities.[150] Owing to the contiguous distribution of proximal DVT with either the common femoral vein or the popliteal vein,[162] the concept of two-point ultrasonography, focusing on two points, was developed.[160,161] While whole-leg ultrasonography requires a longer scanning time and expertise, two-point ultrasonography can be conducted swiftly and is easier to perform. This has led to its widespread use in emergency medicine, aligned with the concept of POCUS. Nonetheless, approximately 6% of cases may involve DVT isolated in the femoral vein,[163] leading to the development of the three-point ultrasonography technique, encompassing the femoral vein. A meta-analysis comparing the diagnostic accuracy of two- and three-point ultrasonography in emergency departments revealed no significant difference.[164]

Recently, there has been a trend to expand the assessment area beyond a specific point, encompassing the popliteal vein up to the calf vein confluence and 1–2 cm above and below the saphenofemoral junction, forming a region or zone (depicted as squared areas in Figure 6).[158,165] This committee also recommends two-region ultrasonography. In addition, saphenofemoral junction thrombosis may be treated with anticoagulation, as in the case of proximal thrombosis in the lower extremity, so caution is necessary.[166] Furthermore, while two-region ultrasonography necessitates a repeat examination within 1 week, whole-leg ultrasonography can be employed as a single examination for decision-making and thus is generally recommended.[165]

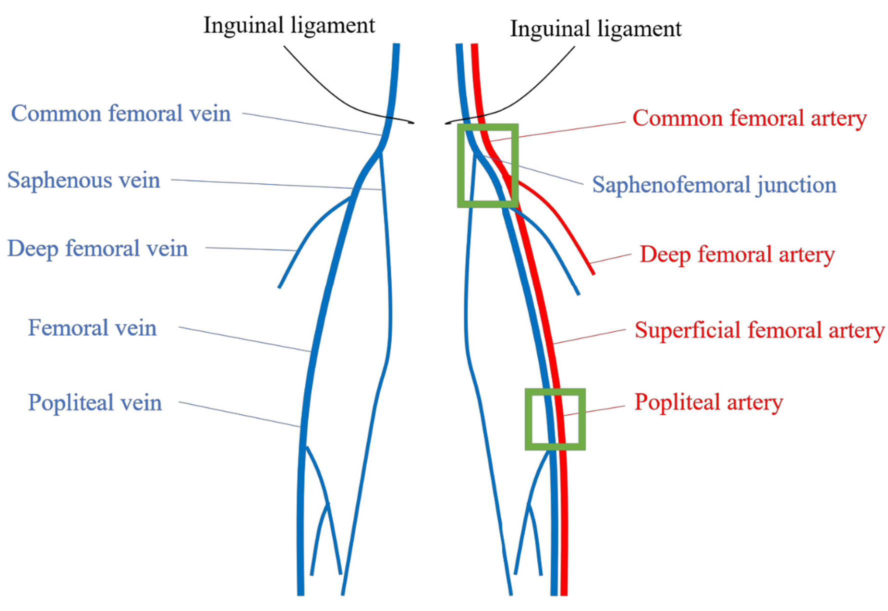

FIGURE 6 Lower extremities deep vein anatomy.

DVT of the lower extremity [Core item]

In two-region ultrasonography, compression is applied to the common femoral and popliteal veins. It is important to note that two popliteal veins may be present during the examination.[167] Typically, the absence of a thrombus can be confirmed by the complete collapse of the vein with compression. If the vein does not collapse entirely, it raises suspicion of a thrombus (Figure 7). In cases where a relatively recent thrombus is suspected, caution is advised, as strong compression may lead to embolism. Therefore, forceful compression should be avoided in cases of suspected thrombus. The milking method, which involves manual compression of the crural muscles to assess venous return between the compression and probe sites, is contraindicated when thrombosis is suspected. Lymph nodes and Baker's cysts can be easily mistaken for thrombi, necessitating careful attention during the examination.

When emergency physicians employ POCUS for a lower-extremity DVT diagnosis, the reported sensitivity and specificity are 93%–95% and 90%–96%, respectively.[168,169] In cases of suspected DVT, the Wells criteria (Table 15) are employed to estimate pre-test probability, followed by the application of D-dimer and ultrasonography of the lower extremity, as shown in Figure 8.[157,170] If technicians are unavailable for whole-leg ultrasonography, particularly during nights or holidays, two-region ultrasonography is valuable for short-term therapeutic decision-making. However, as mentioned earlier, it is essential to conduct follow-up examinations. In cases where acute PTE is suspected, bedside two-region ultrasonography may increase the likelihood of PTE by detecting DVT, thus facilitating early treatment.

Skin and soft tissue/Musculoskeletal system

Introduction

The use of ultrasonography in skin and soft tissue, as well as in musculoskeletal applications, is discussed as an "adjunct item" in this guidance. The reason for this is the lack of validated literature on ultrasonography in this field of emergency medicine. In addition, the use of ultrasonography in this field in Japan is still uncommon, especially in musculoskeletal applications, as other imaging modalities, including X-ray, tend to be given priority. Overseas, emergency physicians who perform these procedures receive a certain period of training from specialists, including radiologists, whereas in Japan, there are very few opportunities to receive systematic training in this field. Therefore, it may be challenging for acute care physicians to adapt them immediately to clinical practice, which is one of the reasons why these applications deserve to be adjunct items at present, and the expansion of educational opportunities is desired in the future. However, it should be noted that the diagnostic accuracies of skin and soft tissue ultrasonography and musculoskeletal ultrasonography are very high and constitute the core applications in the ACEP.[171]

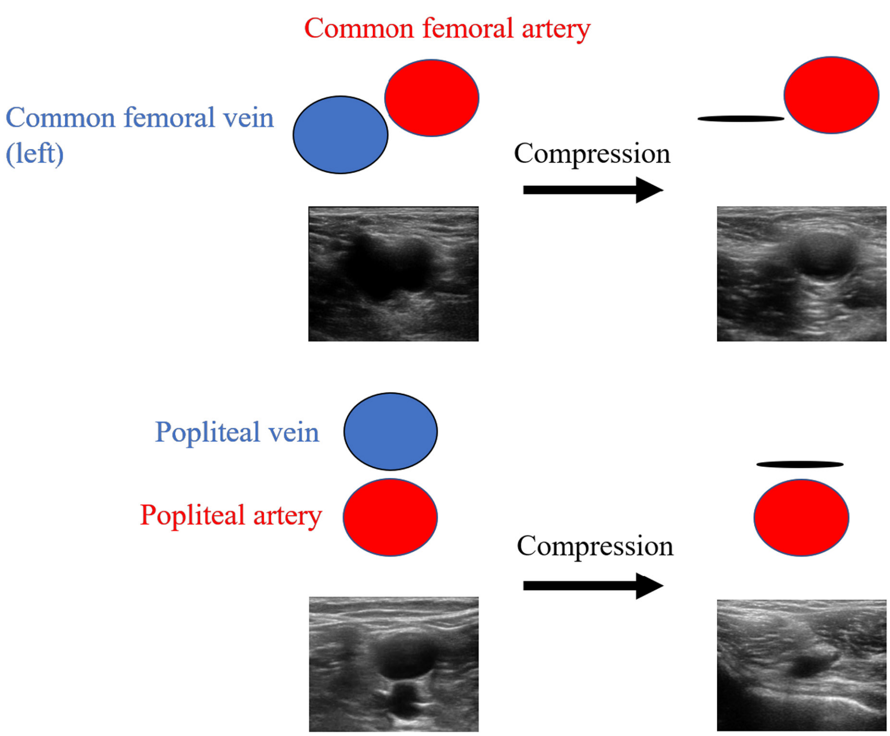

FIGURE 7 Compressions of veins.

Skin and soft tissue [Adjunct item]

The indications for emergency ultrasonography of the skin and soft tissue are the diagnosis of skin and soft tissue infection, subcutaneous abscess, and foreign bodies. Despite the difference in treatment strategies, it is difficult to distinguish these diseases based on physical findings, and ultrasonography is especially useful for differentiating abscesses from cellulitis. Two studies demonstrated that ultrasonography altered the management of patients with cellulitis or suspected cellulitis in 22%–56% of cases.[172,173] In addition, 48% of patients who were believed not to need drainage had a change in management (drainage required, or additional diagnosis or consultation) based on ultrasonography, and 73% of patients who were believed to need drainage had a change in management (drainage not required or additional diagnostic interventions).[173] The diagnostic accuracy of ultrasonography for diagnosis of abscesses is very high, with a sensitivity of 96%–97% and specificity of 83% in systematic reviews.[174,175] In contrast, clinical findings, including physical findings, had a sensitivity of 76%–86% and specificity of 60%–83% for the diagnosis of abscess.[176–179]

Necrotizing fasciitis is an uncommon severe soft tissue infection. While there are several reports on the subject, there have been no systematic reviews of necrotizing fasciitis diagnosed using ultrasonography as of 2022. Ultrasonographic findings include thickening of the subcutaneous tissue, an abnormal fluid accumulation along the deep fascia, and subcutaneous air with comet-tail artifact.[180] In particular, the diagnostic accuracy of ultrasonography for necrotizing fasciitis based on thickening of the subcutaneous tissue accompanied by a layer of fluid accumulation >4 mm in depth along the deep fascial layer is extremely high, with a sensitivity of 88%, specificity of 93%, positive predictive value of 83%, and negative predictive value of 95%.[181]

Ultrasonography can be used for the identification and removal of foreign bodies.[171] The diagnostic accuracy of ultrasonography for the diagnosis of foreign bodies is markedly higher than that of other imaging tests, and a systematic review and meta-analysis showed that the sensitivity and

TABLE 15 Wells' criteria (DVT).

Active cancer (treatment ongoing or within previous 6 months or palliative) +1
Paralysis, paresis, or recent plaster immobilization of the lower extremities +1
Recently bedridden for 3 days or more, or major surgery within 12 weeks requiring general or regional anesthesia +1
Localized tenderness along the distribution of the deep venous system +1
Entire leg swollen +1
Calf swelling at least 3 cm larger than asymptomatic side (measured 10 cm below tibial tuberosity) +1
Pitting edema, confined to symptomatic leg +1
Collateral (nonvaricose) superficial veins present +1
Previously documented deep venous thrombosis +1
Alternative diagnosis to deep vein thrombosis as likely or more likely −2
Probability of deep vein thrombosis according to the total score
Unlikely ≤1
Likely ≥2

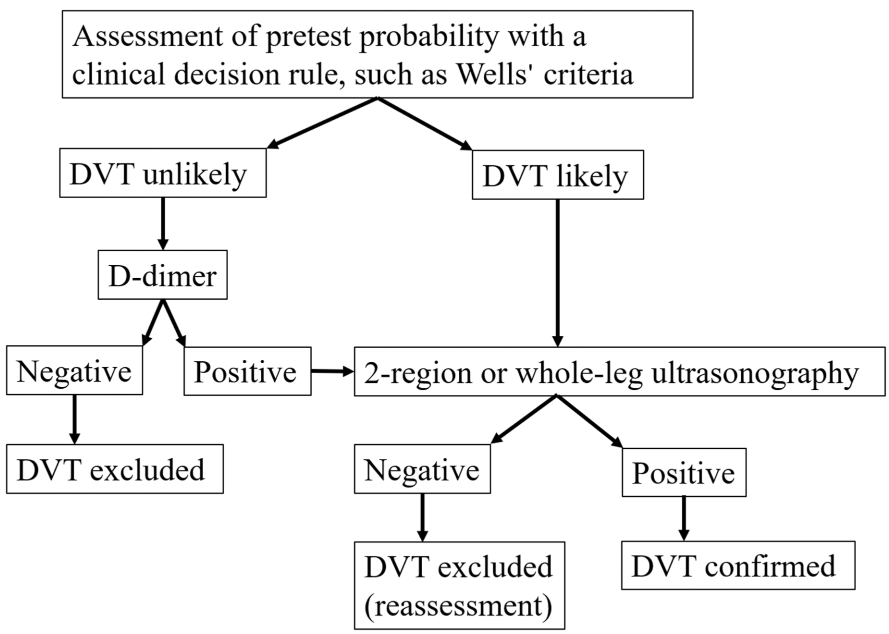

FIGURE 8 Diagnostic algorithm for deep vein thrombosis. DVT, deep vein thrombosis.

specificity were 72% and 92%, respectively.[182] In a subgroup analysis of the literature, the sensitivity and specificity of ultrasonography for radiolucent foreign bodies were 96.7% and 84.2%, respectively. In contrast, the diagnostic accuracy of X-ray for foreign bodies depends on the material of the foreign body, with sensitivities of 7.4% for wood, 76% for glass, and 99% for metal.[183]

Musculoskeletal system [Adjunct item]

The indications for musculoskeletal ultrasonography include fractures, joint effusion, and tendon and ligament injuries. Detailed anatomical knowledge is required to understand these findings, and their use may be limited. Bone fractures, especially long bone fractures, can be diagnosed relatively accurately, with a sensitivity of 65%–100% and specificity of 79%–100% reported in systematic reviews.[184,185] For the lower limbs, the Ottawa ankle and knee rules were developed based on the medical history and physical findings, and since they are aimed at avoiding missed fractures, they have high sensitivity of 98% and 99%, respectively, but low specificity of 26%–48% and 49%, respectively.[186,187] In contrast, for the upper limbs, there is considerable variation in the diagnostic accuracy of physical findings for each region (e.g. sensitivity for elbow joint range of motion ranges from 21% to 100%, specificity from 34% to 97%),[185] and there is no clinical decision rule as in the lower limbs. Fractures of the clavicle, orbit, foot, ankle, rib, femur, and humerus are suitable indications for ultrasonography, while the distal ends of the radius, ulna, tibia, and fibula can often lead to false positives owing to their anatomical morphology, requiring careful attention.[188]

Rib fractures are often associated with complications, such as pneumothorax and pulmonary contusions, and there is a risk of developing conditions, such as atelectasis and pneumonia, over the course of recovery. Therefore, the diagnosis of rib fractures is of the utmost importance. In a meta-analysis, the diagnostic accuracy of chest X-ray was 66% for sensitivity and 100% for specificity (images read by emergency physicians), whereas the diagnostic accuracy of POCUS was 97% for sensitivity and 89% for specificity.[189]

Joint swelling and tenderness are common in patients presenting to the emergency department with joint pain. Distinguishing whether the pain is within the joint or in the surrounding area is often challenging because it frequently involves joint effusion. In addition, it is often difficult to diagnose from physical findings alone whether the pain is simply due to a soft tissue abnormality or whether it is accompanied by joint effusion.[190] For example, 69% of cases in which arthrocentesis was thought to be necessary and 53% of cases in which arthrocentesis was thought not to be necessary underwent altered management with ultrasonography, and the use of ultrasonography has been reported to reduce the number of planned arthrocenteses from 72% to 37%.[191] In addition, the diagnostic accuracy of pediatric emergency physician-performed ultrasonography for the evaluation of hip effusions in pediatric patients with hip pain was 85% for sensitivity and 93% for specificity.[192] Although ultrasonography is useful for such anatomically visible structures, it is important to note that ultrasonographic findings alone do not determine whether the joint fluid is bacterial or nonbacterial in nature. Ultrasonography is also suitable for examining other joints, including those in the upper limbs (shoulder, elbow, and wrist joints) and lower limbs (knee, ankle, and hip joints).[171] However, owing to the limited evidence of its usefulness in the emergency setting, there is a need for validation studies alongside the spread of POCUS.

Injuries and ruptures in the tendons and ligaments and tenosynovitis are indications for ultrasonography.[171] Tendon ruptures, such as those in the Achilles tendon, quadriceps tendon, and patellar tendon, are particularly well suited for ultrasonography, and the diagnosis of intramuscular hematoma is also possible.[190] The diagnostic accuracy of ultrasonography for Achilles tendon rupture is 100% for sensitivity and 90% for specificity, while the sensitivity and specificity of a physical examination, specifically palpation for Achilles tendon rupture, are 71% and 89%, respectively. The Simmonds or Thompson test, a well-known diagnostic method, demonstrated 98% sensitivity and 93% specificity.[193] Ultrasonography has been reported to be useful in differentiating between complete and incomplete ruptures of the Achilles tendon, with a sensitivity of 100% and specificity of 83%.[194] In a multicenter study, the diagnostic accuracy of ultrasonography in various extremity tendon injuries was reported to be 100% for sensitivity and 95% for specificity, while the accuracy of physical findings was 100% for sensitivity and 76% for specificity.[195] The diagnostic accuracy of ultrasonography for the ankle joint (anterior talofibular ligament, calcaneofibular ligament, anterior tibiofibular ligament, trilaminar ligament, and Achilles tendon) was also reported to have a sensitivity of 96%–100% and a specificity of 95%–100%.[196]

Ultrasound-guided procedures

Introduction

Ultrasound-guided techniques for central venous cannulation have been shown to reduce major complications, including arterial punctures and pneumothorax, compared to the traditional landmark method and are now the standard method. The usefulness of ultrasound-guided techniques has also been demonstrated in peripheral venous cannulation, arterial cannulation, and fluid drainage from the body cavities (pericardial sac, thoracic cavity, and abdominal cavity). Furthermore, ultrasound-guided nerve blocks have the potential to achieve rapid, effective, and safe analgesia in patients with trauma. This section describes various types of ultrasound-guided techniques.

Central venous access (Internal jugular vein, subclavian [axillary] vein, and femoral vein cannulation) [Core item]

Central venous cannulation is an essential skill in the emergency department. The difficulty of the procedure varies according to the anatomy and condition of the patient and is associated with a variety of complications. The time required and number of attempts also vary depending on the skill of the clinician. However, the use of ultrasound guidance for central venous cannulation minimizes complications and increases the procedural success rate.[197] Two techniques are used for ultrasound-guided cannulation: dynamic guidance (real-time ultrasound guidance), in which the needle tip is tracked throughout the procedure to maintain appropriate orientation, and static guidance (using pre- and post-procedure scans), in which preprocedural scanning is performed to determine the insertion site.

Most studies on ultrasound guidance for central venous access are related to internal jugular vein cannulation.[198] Randomized trials have shown that ultrasound guidance for internal jugular vein cannulation in adults is superior to the landmark method in terms of the procedural success rate, the number of punctures, procedure time, and complications.[197,199–201] From the standpoint of patient safety, current guidelines recommend the use of ultrasound guidance for internal jugular vein cannulation.[198,202,203] Although the quality of evidence may not be as high as that of the internal jugular vein, randomized trials and meta-analyses have shown the safety and efficacy of ultrasound guidance for subclavian and femoral vein cannulation,[204–207] and the use of ultrasound guidance for these veins is also recommended (note: although the axillary vein is actually punctured in ultrasound-guided subclavian venous cannulation, the term "subclavian vein" is used to conform to commonly used terminology). In addition, multiple studies have demonstrated that ultrasound guidance for central venous cannulation is superior to the landmark method in pediatric patients.[208–210] Even under ultrasound guidance, serious complications such as pneumothorax can occur during subclavian vein cannulation if the provider is not sufficiently skilled. The information of vessel locations by static guidance can be inaccurate, with minimal changes in patient position.[211] Central vein cannulation by static guidance is not recommended because of the lower success rate and higher risk of complications than real-time ultrasound guidance.[211,212]

During ultrasound-guided vascular cannulation, the target vessel and surrounding structures should be visualized in advance. For internal jugular vein cannulation, proximity to the common carotid artery and its overlap are evaluated. In patients with a history of central venous catheterization, an evaluation for venous stenosis and thrombosis should be performed.[211] After guidewire insertion, the guidewire should be placed in the target vein before inserting the dilator. Confirmation of the guidewire position within the vein prevents unintentional arterial dilation or catheterization, minimizing the incidence of hemorrhagic complications. Furthermore, the presence of lung sliding can rule out iatrogenic pneumothorax, especially after subclavian vein catheterization.

Peripheral venous access (Peripherally inserted central catheter and peripheral venous catheter cannulation) [Core item]

The conventional insertion site of a peripherally inserted central catheter (PICC) has been limited to a superficial vein in the antecubital area, which is associated with poor comfort for the patient, difficulty in securing, and high risk of complications, including venous thrombosis.[198] However, with ultrasound guidance, it is now possible to insert a PICC into the vein in the upper arm with a high success rate even in the absence of a visible or unpalpable superficial vein.[213,214] Placement of the catheter in the upper arm provides patient comfort and ease of catheter securement. Furthermore, ultrasound-guided PICC insertion not only avoids brachial artery puncture and median nerve injury but also reduces complications such as infection, thrombosis, and phlebitis compared to conventional PICC insertion.[198,211] For these reasons, ultrasound guidance is recommended for PICC placement. PICCs are important devices in emergency medicine, as are internal jugular vein, subclavian vein, and femoral vein catheters, and ultrasound-guided PICC placement is an essential procedure.

When inserting the PICC, scan the arm to identify the appropriate vein from the basilic, brachial, or cephalic vein, determine the PICC insertion site, and check the arteries and nerves surrounding the vein. If the diameter of the vessel is small, it is associated with a high risk of venous thrombosis and should be treated with caution.[215]

Furthermore, the use of ultrasound guidance to insert peripheral intravenous catheters increases success rates and reduces the number of attempts and the time to cannulation in patients with difficult peripheral venous access compared to traditional techniques.[216–219] In emergency departments, clinicians often encounter difficulty in obtaining peripheral venous access due to several factors, such as obesity or subcutaneous edema.[220] Ultrasound-guided placement of peripheral intravenous catheters is a useful technique to increase patient satisfaction and reduce the need for placement of central venous catheters.[220]

Arterial access (Radial artery and femoral artery cannulation) [Core item]

The use of ultrasound guidance for radial artery cannulation significantly improves first-attempt success rates compared to landmark palpation techniques.[221–223] A meta-analysis in adults showed no significant differences in the overall success rate, number of attempts, or complications between them.[222] However, the landmark method has limitations in patients with subcutaneous edema and obesity. A systematic review demonstrated that the use of ultrasound guidance for femoral artery cannulation significantly increased first-attempt success rates and reduced the number of attempts and complications compared to palpation or fluoroscopy.[224] Ultrasound-guided techniques are particularly useful for femoral artery cannulation in patients with shock or weak arterial pulse,[225] such as those requiring resuscitative endovascular balloon occlusion of aorta (REBOA) and extracorporeal cardiopulmonary resuscitation (ECPR).[226,227]

The puncture site for femoral artery cannulation is the common femoral artery proximal to its bifurcation into the superficial and deep femoral arteries, and the appropriate site should be confirmed before puncture. The insertion site should be distal to the inguinal ligament because puncture proximal to the inguinal ligament can cause retroperitoneal bleeding.

Pericardiocentesis [Core item]

In cases of cardiac tamponade or symptomatic pericardial effusion, pericardiocentesis or drainage should be performed immediately. Although cardiac tamponade is not often encountered in the emergency department, it is a true cardiac emergency that can deteriorate rapidly. Thus, pericardiocentesis and drainage are essential skills in the emergency department. Ultrasound-guided pericardiocentesis can be performed with a high success rate and low complication rate.[228,229] The complication rates of landmark-based pericardiocentesis, including cardiac puncture or laceration of other organs, are substantially high; therefore, the landmark procedure should not be used except in immediately life-threatening situations.[230]

In ultrasound-guided pericardiocentesis, the optimal needle insertion site should be determined by scanning the distribution of the effusion from the subcostal (subxiphoid), parasternal, or apical window and evaluating the overlap with the lung, liver, and internal thoracic artery.[230] If the patient's condition allows, slightly elevate the head end of the bed and evaluate changes in the distribution of the pericardial effusion to determine the appropriate position for pericardiocentesis.[231] Real-time ultrasound guidance is preferable to static guidance for pericardiocentesis because complications, even if rare, can lead to lethal conditions.[230]

Thoracentesis [Core item]

Complications of thoracentesis include pneumothorax, hemothorax, and hepatic and splenic injury. The use of ultrasound for preprocedural scanning of the extent of pleural effusion, intrathoracic organs, and vessels achieves high success rates and is safe for thoracentesis. Ultrasound-guided thoracentesis has a low incidence of pneumothorax[232] and significantly reduces the incidence of pneumothorax compared to the landmark-based technique.[233,234] Static ultrasound guidance for thoracentesis is safe when there is a large amount of pleural effusion with sufficient space for puncture;[235] however, real-time needle visualization is useful for avoiding accidental injuries,[236] especially when the pleural effusion is small or encapsulated.[45]

First, the diaphragm, liver, spleen, and pleura are scanned for a thoracic evaluation. A normal lung examination shows a curtain sign at the lung bases, in which the lungs expand and descend during inspiration, covering the liver and spleen. When pleural effusion is present, the curtain sign disappears, and the area of pleural effusion is seen as anechoic or hypoechoic (echo-free space). A tissue-like sign, in which the collapsed lung appears as a solid organ, and a spine sign, in which the thoracic vertebral bodies are visualized, are also observed in the presence of pleural effusion.

The preferred site for insertion of the needle for thoracentesis is called the triangle of safety, which is bordered by the lateral edge of pectoralis major, the lateral edge of latissimus dorsi, and the line of the fifth intercostal space.[45] The insertion site should have at least 1-cm-deep pleural effusion, no interference with the lung at maximal inspiration, and minimal risk of puncturing other organs including the heart, liver, and spleen.[45] If the pleural effusion is small, patients can be asked to hold their breath.[237] Ultrasound can be used to evaluate lung sliding before and after the procedure to exclude pneumothorax.[235]

Paracentesis [Core item]

The major complications of paracentesis include ascitic fluid leakage, hemorrhage, intestinal perforation, and iatrogenic infections. Hemorrhagic complications can cause serious condition. The use of ultrasound guidance for paracentesis significantly increases success rates and reduces complications, including abdominal hemorrhage, compared with the landmark method.[234,238] Preprocedural ultrasound scanning of major blood vessels in the abdominal wall and intra-abdominal organs allows for the selection of a safe puncture site for paracentesis. Real-time ultrasound guidance should be used for paracentesis when fluid collection is small or the risk of injury to adjacent organs, including the intestines, liver, and spleen, is high.[239,240]

Peritoneal fluid can be detected by scanning the right upper quadrant (the right subdiaphragmatic space, Morrison's pouch, and inferior pole of the right kidney), left upper quadrant (the left subdiaphragmatic space, splenorenal space, and inferior pole of the left kidney), and lower abdomen (the Douglas pouch and rectovesical pouch).[240] The needle insertion site should be selected to avoid adjacent organs such as the intestines and vessels, like the inferior epigastric artery and veins. The inferior epigastric artery and veins are located in the inferior half of the rectus abdominis muscle. The area along the muscular aponeurosis lateral to the rectus abdominis muscles is safe as the needle insertion site for paracentesis.[240]

Peripheral nerve block (Femoral nerve, distal sciatic nerve [popliteal fossa], brachial plexus, and radial/median/ulnar nerves) [Adjunct item]

Ultrasound-guided peripheral nerve blocks can be used to provide rapid and effective bedside analgesia in patients with extremity trauma who present to the emergency department. Rapid and effective analgesic management with peripheral nerve blocks can improve patient satisfaction and reduce the need for procedural sedation or opioid medication.[241,242] However, in consideration of the current prevalence of peripheral nerve blocks in the emergency department and in the training system for acute care physicians, the learning goal for peripheral nerve blocks is set as an "adjunct item". This section focuses on the different types of nerve blocks that acute care physicians can incorporate into clinical practice.

The femoral nerve block is suitable for analgesia in patients with hip, femur, and patellar fractures.[243] Hip fractures are common trauma in older adults and often cause delirium. Inadequate analgesia is a risk factor of delirium. The occurrence of delirium after hip fractures has been shown to increase the incidence of functional decline and a poor prognosis.[244] However, ultrasound-guided nerve block for hip fractures can provide effective analgesia and reduce opioid administration, which poses the risk of adverse events, including respiratory depression and delirium.[241] Thus, ultrasound-guided nerve block can be a safe and effective approach to acute pain management in the emergency department.

Distal sciatic nerve block at the popliteal fossa can provide analgesia for trauma to the lower leg, ankle, and foot. In the operating room, ultrasound guidance for distal sciatic nerve block has been shown to increase success rates compared to nerve stimulation guidance, indicating its safety and efficacy.[245] In the emergency department, ultrasound-guided distal sciatic nerve block allows for rapid and effective analgesia for lower leg and calcaneus fractures, which is a significant advantage over other analgesic approaches.[246,247]

Brachial plexus blocks include the interscalene, supraclavicular, and axillary approaches. The efficacy of brachial plexus blocks has been reported in analgesia for trauma, such as upper extremity trauma, in the emergency department, as well as in anesthesia for shoulder and upper extremity surgery.[248,249] The interscalene approach provides analgesia from the shoulder to the proximal upper arm. Ultrasound-guided interscalene nerve block has been shown to be superior to procedural sedation for analgesia in patients requiring reduction of shoulder dislocation.[242] The supraclavicular approach provides analgesia from the upper arm to the hand. Ultrasound guidance for supraclavicular nerve blocks has been shown to be effective for elbow and forearm trauma.[250] The axillary approach provides effective analgesia from the elbow to the hand. Ultrasound guidance for radial, median, and ulnar nerve blocks also allows for rapid analgesic management of forearm trauma in the emergency department.[251,252]

CHAPTER 3: INTEGRATED APPLICATIONS

FAST/EFAST [Core item]

The introduction of Japan Advanced Trauma Evaluation and Care (JATEC) in 2002 has advanced the standardization of initial trauma management in Japan.[253] FAST is integrated as an important component of JATEC to detect pericardial effusion, hemothorax, and intraperitoneal hemorrhage. The utility of ultrasonography in cases of blunt abdominal trauma was initially reported by Kimura et al. in 1992.[254] In 1996, it garnered recognition among American surgeons as a "focused abdominal sonogram for trauma,"[255] and was subsequently designated as a "focused assessment with sonography for trauma" in the international consensus conference.[256] In the 2000s, as the efficacy of the ultrasound diagnosis for traumatic pneumothorax became apparent, EFAST incorporating a pneumothorax assessment was introduced.[253,257] EFAST can rapidly assess the presence of pneumothorax in the supine position as part of FAST flow and is effective in detecting clinically significant pneumothorax. Currently, it is recommended that EFAST be performed rapidly during the primary assessment of the JATEC.

A meta-analysis conducted by Netherton et al. demonstrated the diagnostic accuracy of EFAST, with a sensitivity of 69% and specificity of 99% for pneumothorax, a sensitivity of 91% and specificity of 94% for pericardial effusion, and a sensitivity of 74% and specificity of 98% for intraperitoneal hemorrhage.[258] Although multiple studies have demonstrated similar results, it is important to note that the specificity of FAST is high, and its sensitivity is limited. In hemodynamically stable pediatric patients, it has been demonstrated that the sensitivity of the initial FAST is lower than that in adults.[82,259,260] It is crucial not to rule out the possibility of intraperitoneal hemorrhage simply based on a negative result in the initial FAST but to consider repeating FAST multiple times despite the negative result when hemorrhage is clinically suspected.[261]

The utility of FAST in prehospital emergency care has been reported internationally,[262] and it has been suggested that FAST image acquisition may be better when performed in a stationary ambulance than in an in-motion ambulance.[263] The introduction of FAST has been reported to be associated with a shorter time to operative care, less-frequent CT, shorter hospital stays, fewer complications, and lower costs, making it a procedure that should be actively implemented.[264]

Shock and dyspnea [Core item]

The causes of shock are diverse and not limited to a single region or organ but require an integrated evaluation. In 2010, rapid ultrasound in shock (RUSH) was introduced as POCUS based on four classifications of shock.[265] RUSH combines ultrasound findings in organ-specific applications for rapid evaluation and is now widely recognized. After the publication of RUSH, various clinical studies on integrated ultrasonography as POCUS for shock and dyspnea have been conducted.[266] The classification and diagnosis of shock by integrated ultrasonography have been shown to be highly consistent with the final diagnosis.[267–271] However, diagnostic accuracy may be reduced in cases of overlapping shock conditions.[270,271] In addition, it has not been shown to improve the care of patients with shock.[272] In dyspnea, by contrast, integrated ultrasonography can detect serious illnesses that may be missed by a conventional initial assessment and improve diagnostic performance.[273–275] Large prospective studies have shown that integrated ultrasonography can shorten the time to the diagnosis of dyspnea without compromising diagnostic accuracy, especially in patients with cardiogenic pulmonary edema.[276]

Based on the accumulated evidence on organ-specific and integrated ultrasonography, a framework based on the airway, breathing, and circulation approach (ABC approach), which can be used for the assessment of both shock and dyspnea, is proposed (Figure 9).[267] The reasons for this proposal are as follows: (1) acute care physicians often manage shock and dyspnea, regardless of endogenous disease or trauma; (2) diseases suitable for the assessment with POCUS such as (tension) pneumothorax, hemothorax, cardiac tamponade, acute heart failure, and acute PTE, can be the causes of shock, dyspnea, or both; (3) the POCUS framework for dyspnea is covered by the framework for shock. (4) ultrasound-guided techniques are useful in the management of shock and dyspnea; (5) the ABC approach is established for resuscitation and management of critically ill patients, and it is practical to use ultrasonography according to the ABC approach.[266] The ABC approach-based framework is applied based on clinical reasoning. If the initial assessment indicates a probable disease or a differential diagnosis, the necessary applications can be selected from this framework. If the initial assessment is not helpful in narrowing down the differential diagnoses, the framework can be used as a protocol along the ABC in order.

Cardiac arrest [Core item]

Introduction

Acute care physicians frequently encounter cardiac arrest, a condition that requires immediate response. Basic life support (BLS) and advanced cardiac life support (ACLS) emphasize continuous high-quality chest compressions and early defibrillation for indicated cardiac rhythms.[277,278] Clinically, however, pulseless electrical activity (PEA) and

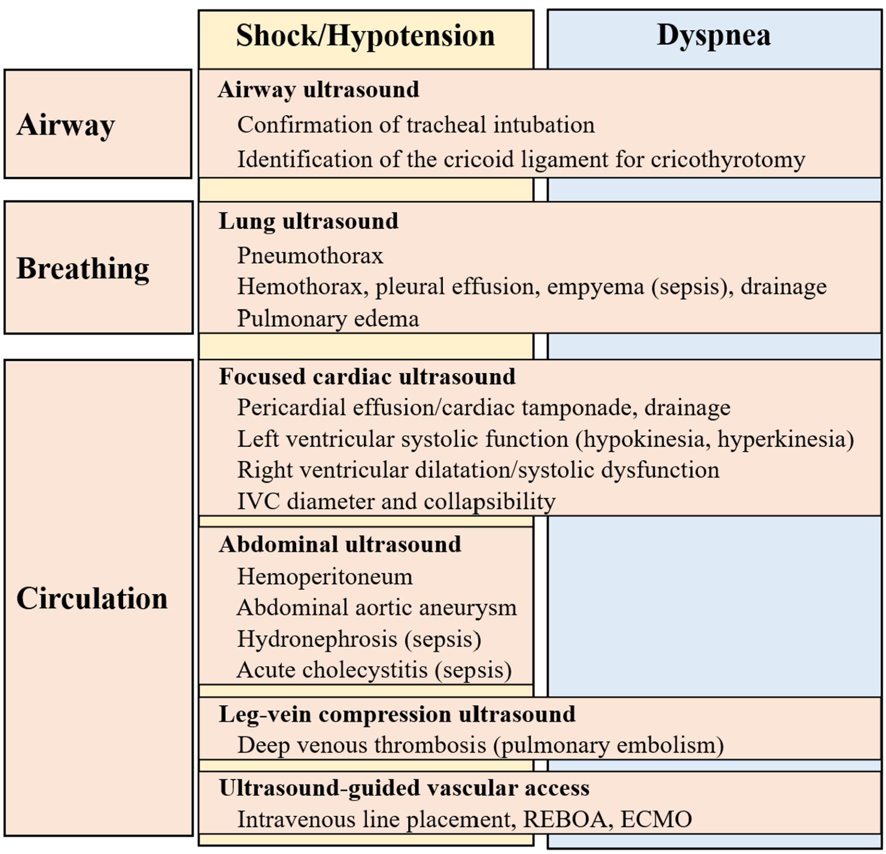

FIGURE 9 POCUS framework based on the airway, breathing, and circulation (ABC) approach. ECMO, extracorporeal membrane oxygenation; IVC, inferior vena cava; REBOA, resuscitative endovascular balloon occlusion of aorta.

asystole, which are not indicated for defibrillation, are more frequently encountered.[279] In both cases, early identification of the etiology is required. Tension pneumothorax, hypoxia, hypokalemia, cardiac tamponade, PTE, and so forth require an appropriate diagnosis and prompt treatment, without which the possibility of successful resuscitation decreases. These treatments are sometimes invasive and may be harmful to other conditions; therefore, an accurate evaluation is essential.

Conditions that should be evaluated using ultrasonography during cardiac arrest

The diseases and conditions that need to be evaluated, along with the protocols for ultrasonography in patients with cardiac arrest, are described below.

Identification of myocardial contractility

The presence or absence of spontaneous circulation by carotid artery palpation is not always reliable, and up to 45% of healthcare professionals are reported to be unable to detect it accurately.[280–282] As a result, the possibility of prolonged interruption of chest compressions or inappropriate termination of resuscitation cannot be ignored. Several studies have shown that carotid pulsation can be evaluated more accurately by POCUS than by palpation; however, most of them were small studies, and additional research is still needed.[283,284] Furthermore, as a method other than palpation of the carotid artery, the placement of an arterial line has high accuracy, but it may be difficult and time-consuming when the patient is in cardiac arrest. Ultrasonography can easily evaluate the contractile activity of the heart during cardiac arrest and thus may be more accurate and rapid than pulse palpation. Regular contractions, which can also be observed in cardiac arrest in the clinical setting, have been shown to be associated with a higher rate of return of spontaneous circulation.[285] However, the Japan Resuscitation Council (JRC) resuscitation guidelines 2020 and the American Heart Association (AHA) guidelines 2020 weakly recommend not performing POCUS for prognostication during cardiopulmonary resuscitation (CPR).[277,278] This is mainly due to the lack of high-quality research; therefore, we need to be careful about using ultrasonography alone to determine the return of spontaneous circulation. Conversely, the AHA guidelines 2020 weakly recommend that ultrasonography be considered as an additional diagnostic tool to identify potentially reversible causes, as described below.

Differential diagnoses for cardiac arrest

A diagnosis based on cardiac rhythm is crucial for ventricular fibrillation and pulseless ventricular tachycardia, making POCUS somewhat less useful. However, in PEA and asystole, identification of the underlying disease and therapeutic intervention are important factors that determine the success or failure of resuscitation. The utility of POCUS in these scenarios is discussed below, although most studies were conducted on patients without cardiac arrest, and whether or not POCUS is effective during cardiac arrest is unclear.

Ultrasonography is beneficial in diagnosing cardiac tamponade caused by pericardial fluid retention.[286] Generally, ultrasonography is highly reliable for diagnosing pericardial fluid retention, with both sensitivity and specificity exceeding 95%.[65] Although scanning from the parasternal view is often used, scanning from the subxiphoid view, which does not interfere with chest compressions, is sufficient for detection. If pericardial fluid retention with diastolic right ventricular collapse is observed on ultrasonography, cardiac tamponade should be suspected. However, whether or not the above judgment is also appropriate in patients with PEA as in those with spontaneous circulation is unclear. When a patient with asystole presents with pericardial fluid retention, it is challenging to determine whether or not the retention causes cardiac tamponade followed by asystole. Therefore, the diagnosis must be made in combination with other findings. An advantage of this approach is that ultrasound-guided pericardiocentesis can be quickly performed if cardiac tamponade is suspected. Ultrasound-guided pericardiocentesis decreases the risk of complications.[287]

Tension pneumothorax is a known cause of cardiac arrest, and a thoracic evaluation should be performed in the emergency department. Tension pneumothorax is suspected when there is loss of unilateral respiratory movement, in addition to tracheal deviation and subcutaneous emphysema.[288] Jugular venous distension is a known finding in tension pneumothorax, but its diagnostic value in cardiac arrest is unclear. In patients with cardiac arrest suspected of having tension pneumothorax, ultrasonography can be a valuable diagnostic aid in the absence of lung sliding during artificial ventilation with collapsed right ventricle and atrium. Ultrasonography can play a valuable role during resuscitation, as it is difficult to accurately assess the absence of breath sounds or jugular venous distension.

Most patients with cardiac arrest due to PTE are diagnosed with PEA or asystole. In such cases, the use of thrombolytic agents can be lifesaving; therefore, a prompt diagnosis is essential.[289] Dilation of the right ventricle and flattening of the interventricular septum reflect the pressure load on the right heart; flattening of the septum in the parasternal short-axis view is known as the D-shape. However, right ventricular dilation generally occurs shortly after cardiac arrest, making it difficult to determine whether right ventricular dilation in patients with cardiac arrest is due to cardiac arrest itself or PTE.[78,290,291]

Protocol for cardiac arrest

Maximizing the use of ultrasonography to identify these diseases requires the development of specific protocols designed to minimize the interruption time of chest compression. Several protocols, such as the Cardiac Arrest UltraSound Exam (CAUSE),[292] Focused Echocardiographic Evaluation in Resuscitation (FEER),[293] and Cardiac Arrest Sonographic Assessment (CASA),[294] have been proposed.

The CAUSE does not specify the timing but recommends visualizing a four-chamber view of the heart in patients with no indication for defibrillation, identifying cardiac tamponade and PTE based on pericardial effusion and the size of the left and right ventricles.

The FEER is performed within 10 s when interrupting chest compressions, such as during a rhythm check. A probe is applied below the xiphoid process (epigastric area) to determine the presence of cardiac tamponade, PTE, or cardiac contractions.

In the CASA, the timing of ultrasonography and the elements to be evaluated are sequentially determined. Ultrasound examinations are conducted during pulse checks three times in total as follows: (1) cardiac tamponade is evaluated at the first examination, (2) PTE at the second examination, and (3) cardiac activity at the third examination. The following are also recommended: the recorder should announce each pause time out loud; a sector probe should be used, and all images should be recorded for review; the subxiphoid view is often preferable, as this view can be performed during the ongoing CPR; ultrasonography should be conducted by a healthcare provider other than the person performing chest compressions; and the evaluation of pericardial fluid retention, abdominal fluid retention, and tension pneumothorax can be performed during CPR as a possible cause of cardiac arrest.

Most protocols focus on the identification of cardiac tamponade, PTE, or tension pneumothorax. Because there is no clear advantage or disadvantage with any protocol, it is preferable to select one and use it systematically in each department, where it is important to share information that can and cannot be evaluated with each protocol among team members. In addition to palpation of the pulse, the evaluation of return of spontaneous circulation using ultrasonography with sufficient cardiac contraction is considered useful; therefore, ultrasonography can be an important evaluation method.[295] However, it has been suggested that ultrasonography may prolong the interruption of chest compressions, and it is important to implement ultrasonography without reducing the quality of standard CPR.[296]

Appendix: Transesophageal echocardiography during cardiac arrest

The usefulness of transthoracic echocardiography during resuscitation has been reported previously. However, a major disadvantage of transthoracic echocardiography is the difficulty in obtaining images of an adequate quality because of the patient's body habitus and procedures, such as chest compressions. Recently, transesophageal echocardiography during cardiac arrest has gained increasing attention. In addition to possessing similar diagnostic and prognostic capabilities to transthoracic echocardiography, transesophageal echocardiography offers unique advantages, including optimizing the quality of chest compressions, reducing the interruption time of chest compressions, continuously observing cardiac contractile activity, and guiding cannulation when providing percutaneous cardiopulmonary support.[297,298]

Prehospital emergency medicine

Physician-staffed ambulance/ Physician-staffed helicopter

The performance of compact, lightweight, and pocket-sized ultrasound devices has been improving, and ultrasonography has become widely utilized in prehospital emergency care. Patients transported by physician-staffed ambulances or helicopters often require prompt medical intervention, and a rapid assessment by ultrasonography is expected to enhance the quality of medical care. It is desirable for acute care physicians providing prehospital care to be proficient in practicing ultrasonography using the framework based on the ABC approach promptly and appropriately, according to the situation at the scene.[299] FAST and EFAST for trauma, POCUS for shock and dyspnea, and so forth should be performed in line with in-hospital care.

Although there are few high-quality studies on prehospital ultrasonography, multiple systematic reviews have been reported. In trauma care, the usefulness of prehospital ultrasonography performed by physicians has been suggested.[300,301] In addition to trauma, ultrasonography for dyspnea may be useful in selecting a treatment strategy.[302] Although ultrasonography for out-of-hospital cardiac arrest may be beneficial, it may prolong the interruption time of chest compressions and should be carefully performed.[302] Ultrasonography with a pocket-sized device makes it challenging to determine the cause in some cases. Therefore, it must be performed with a full understanding of the time restrictions of prehospital care to avoid delaying definitive treatment due to sticking to making a diagnosis.

Telemedicine

Telemedicine, which utilizes image and video transport systems to conduct diagnostic evaluations, is becoming more widespread and has the potential to enhance the quality of care. Although there are limited reports on the effectiveness of telemedicine using ultrasonography in emergency care settings, it has been suggested that the diagnostic accuracy of telemedicine is nearly equivalent to that of conventional medical care.[303] Even in situations where there are few physicians skilled in POCUS in emergency medicine, telemedicine with ultrasonography can facilitate prompt and appropriate decision-making. In telemedicine, it is desirable to be able to perform ultrasonography quickly using a framework based on the ABC approach, depending on the situation. Telemedicine is important from the viewpoint of improving the quality of medical care, but responsibility sharing in case problems arise should be discussed in advance.

Disaster medicine

In the guidelines of the ACEP, disaster medicine, tactical medicine, and military medicine are also mentioned as areas of application for POCUS.[2] When a disaster strikes, the need arises not only for the rapid screening and diagnosis of injured and sick patients but also for the continuation of regular medical care for the general public. Medical services utilizing ultrasonography have become essential in situations where there is an imbalance between the supply and demand of medical care.[304] Since 1990, ultrasonography has been used at disaster sites to determine appropriate definitive treatment and to control the unnecessary waste of medical resources for mass casualties resulting from earthquakes, landslides, and cyclones.[305–307] Based on these findings, a portable ultrasound device has been listed as standard medical equipment for disaster medical assistance teams (DMATs) in Japan.[308] It has also been demonstrated to play an important role in the detection of DVT in evacuation centers.[309]

The fundamental principle in the acute phase of a disaster is to provide maximum possible medical care to the largest number of patients who can survive and to identify those who require definitive treatment through appropriate triage.[310] Particularly important techniques for prioritizing patients for surgery include (1) the detection of intra-thoracic and intra-abdominal bleeding and (2) the diagnosis of long bone fractures of the extremities. These skills are essential for allowing acute care physicians to provide emergency care in the acute phase of a disaster.[311,312] In addition, when providing support in evacuation facilities from the subacute to the chronic phase, the identification of DVT, which poses a high risk of causing PTE, is required.[313]

The medical equipment used naturally differs depending on the disaster phase. In the hyperacute phase, compact equipment is preferred, including arm mounts for tablets, smartphone-type handhelds, pole mounts (large tablet-type hanging on an infusion pole or specialized stand), laptops, and cart-based equipment (console mounted on a cart). Therefore, it is crucial to understand the advantages and disadvantages of each device.[314]

Based on previous reports of medical responses to disasters and mass casualty incidents, a framework for disaster medical care is proposed, utilizing organ-specific and integrated POCUS (Figure 10). It emphasizes the following points: (1) selecting the most appropriate equipment based on the disaster phase and location of activity; (2) understanding the characteristics and limitations of equipment in the acute phase of a disaster;[315] (3) familiarizing with EFAST to diagnose thoracoabdominal trauma;[314] (4) practicing a comprehensive sonographic examination in the evaluation of chest, abdomen, vena cava, and extremities in acute triage (CAVEAT), if possible, to include evaluating the presence or absence of long bone fractures and intravascular volume by assessing the inferior vena cava;[312,316] and (5) practicing ultrasonography to rapidly evaluate high-risk DVT for the subacute phase and beyond, especially two-region ultrasonography.[164,317]

Thus, acute care physicians engaged in disaster medicine should ideally be proficient in using EFAST, CAVEAT, and two-region ultrasonography of the lower extremities. It is also desirable to provide evidence that ultrasonography can be useful in the acute phase of disaster medicine, as reported in other countries.

Coronavirus disease 2019 (COVID-19)

Introduction

Since it was first reported in China, COVID-19 has become prevalent worldwide, leading to higher morbidity and mortality than influenza virus infection. Respiratory symptoms are the most common, ranging from mild to life-threatening acute respiratory failure.[318]

The gold standard for diagnosing COVID-19 pneumonia is CT,[319] which may initially show ground-glass opacity beneath the pleura, followed by consolidation around 2 weeks later.[320] CT is valuable for evaluating disease progression, indicating improvement with the disappearance of abnormal findings and worsening with the presence of residual parenchymal bands.[320] However, in addition to radiation exposure, CT has other drawbacks as well, including risks associated with patient transfer and an increased workload for hospital personnel.[321] By contrast, POCUS can be performed at the bedside without the need for patient transfer and can be repeated at any time.[321]

In November 2020, an international expert consensus was published, suggesting the utility of lung ultrasonography for pneumonia, a primary condition of COVID-19.[23] Besides pneumonia, COVID-19 may also cause cardiomyopathy and DVT, so an evaluation by POCUS is considered beneficial.[23] In this section, we present information that acute care physicians at the forefront of COVID-19 treatment should be aware of.

Lung ultrasonography for a COVID-19 pneumonia diagnosis

Lung ultrasonography has been reported to be more effective than chest X-rays in diagnosing COVID-19 pneumonia, and it can even diagnose the disease in asymptomatic patients.[322] In COVID-19 pneumonia, diffuse or focal multiple B-lines, confluent B-lines that fuse together and become generally white, and band-shaped

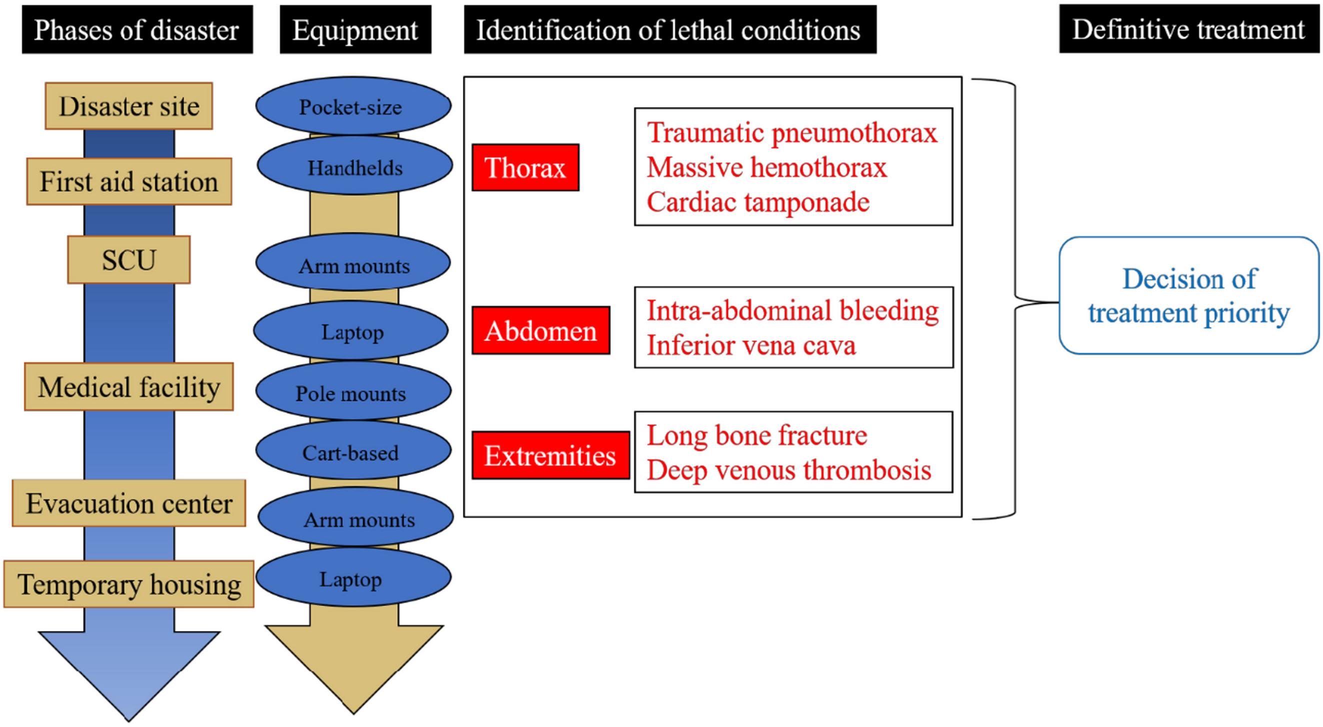

FIGURE 10 POCUS framework in disaster medicine. SCU, staging care unit.

vertical B-lines extending from the pleural line (light beam) can be observed. As the pleural line thickens to more than 2 mm and the air volume in the lungs decreases, subpleural consolidation to large consolidation can be seen.[323] These findings are particularly prominent in the lower lobes of the lungs and are more apparent in severe cases than in mild ones.[324] In contrast, if A-lines are seen throughout the lungs, B-lines are not observed, and lung sliding can be confirmed, the possibility of COVID-19 pneumonia is considered low.[325] However, it is recommended that lung ultrasonography alone should not be used to diagnose COVID-19 pneumonia, and integrated POCUS should be employed to enhance the diagnostic performance.[326] In patients with dyspnea, if lung ultrasonography reveals a positive finding but antibody or polymerase chain reaction tests are negative, the possibility of a false negative result should be considered.[327]

FoCUS for the evaluation of cardiovascular complications

Acute cardiac injury is reported to occur in up to 17% of hospitalized COVID-19 patients, leading to increased mortality.[328] Besides cellular damage from inflammation, hypoxic injury due to an oxygen supply demand imbalance is considered a potential mechanism for cardiac injury.[329] High-sensitivity troponin measurement can detect myocardial injury, but as it is elevated in both myocardial infarction and myocarditis, FoCUS should be utilized to differentiate them by assessing wall motion abnormalities, their extent, myocardial brightness, and the presence of cardiac tamponade.[53,330]

Furthermore, in cases of congestive heart failure, multiple B-lines may appear, making it challenging to distinguish the condition from pneumonia. In such instances, FoCUS can be used to evaluate the left and right ventricular function. If a decreased function is observed, heart failure may be present. If pneumonia progresses to ARDS, right-sided heart failure may occur in association with mechanical ventilation. It is crucial to use FoCUS to assess the right ventricular function during respiratory management.[53,331]

Ultrasonography for DVT

COVID-19 induces an abnormal coagulation function, leading to elevated D-dimer, C-reactive protein (CRP), and antiphospholipid antibody levels. The incidence of DVT is reported to be high even with standard prophylactic strategies.[332,333] While ultrasonography is useful for diagnosing DVT, routine screening is not suggested in critically ill COVID-19 patients.[334] For patients with severe COVID-19 with a central venous catheter, regular screening is recommended because of the high risk of venous thrombosis. It has been reported that twice-weekly evaluations detected DVT and reduced mortality from PTE.[335] In cases of unexplained hypoxemia or circulatory failure, ultrasonography for DVT and FoCUS are recommended to investigate suspected PTE.[334]

Lung ultrasonography in the management of COVID-19 pneumonia

In COVID-19 pneumonia, two phenotypes have been suggested.[48] The first is type L with low elastance, characterized by hypoxia due to ventilation-perfusion mismatch. The lungs are well aerated, and a high positive end-expiratory pressure (PEEP) is not required. This is observed in the early stages of COVID-19. As the disease progresses, lung aeration, especially in the dorsal aspect, decreases, and the patient develops the type H phenotype with high elastance, requiring high PEEP for recruitment. This resembles conventional ARDS, and lung ultrasonography can assess this progression with a similar capability to CT.[336]

Although not predictive of improved oxygenation, the effect of recruitment by prone positioning can reportedly be evaluated by lung ultrasonography, which can be useful in COVID-19.[337,338] Furthermore, lung ultrasonography has been shown to assess the progression and improvement of lung injury through semi-quantitative scoring.[339] This approach can be applied to COVID-19,[340] reducing the need for chest X-ray and CT. In addition, complications associated with mechanical ventilation (such as pneumothorax, ventilator-associated pneumonia, and diaphragmatic dysfunction) and the potential for ventilator weaning can also be evaluated using lung ultrasonography.[341,342]

POCUS for infection prevention

Laptops, tablets, and pocket-sized ultrasound devices offer excellent functionality and portability, are easy to clean, and facilitate infection control measures. In some instances, an ultrasound diagnosis is conducted remotely as an infection control measure, and even in such cases, recording and storing ultrasound images is deemed necessary.[343] To minimize the risk of infection among healthcare providers, the use of X-ray and CT should be decreased by incorporating POCUS. POCUS should be conducted efficiently within a short time frame, focusing on specific items. Disinfection of ultrasound devices should follow the methods recommended by the manufacturer.[23]

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