CHEST Consensus Statement

American College of Chest Physicians/ La Société de Réanimation de Langue Française Statement on Competence in Critical Care Ultrasonography*

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Objective: **To define competence in critical care ultrasonography (CCUS).**
Design: **The statement is sponsored by the Critical Care NetWork of the American College of Chest Physicians (ACCP) in partnership with La Société de Réanimation de Langue Française (SRLF). The ACCP and the SRLF selected a panel of experts to review the field of CCUS and to develop a consensus statement on competence in CCUS.**
Results: **CCUS may be divided into general CCUS (thoracic, abdominal, and vascular), and echocardiography (basic and advanced). For each component part, the panel defined the specific skills that the intensivist should have to be competent in that aspect of CCUS.**
Conclusion: **In defining a reasonable minimum standard for CCUS, the statement serves as a guide for the intensivist to follow in achieving proficiency in the field.**

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Key words: critical care; echocardiography; imaging; ultrasonography

Abbreviations: ACCP = American College of Chest Physicians; CCE = critical care echocardiography; CCUS = critical care ultrasonography; GCCUS = general critical care ultrasonography; IVC = inferior vena cava; LV = left ventricle, ventricular; RV = right ventricle, ventricular; SRLF = La Société de Réanimation de Langue Française; TEE = transesophageal echocardiography; TTE = transthoracic echocardiography; 2D = two-dimensional

Executive Summary

Ultrasonography has widespread utility in the diagnosis and treatment of critical illness, and is a valuable and accessible tool for intensivists and pulmonary physicians. With proper training, intensivists and pulmonary physicians can achieve a high level of competence in all aspects of ultrasonography relevant to their specialty. The clinician needs to understand what constitutes competence in the field. A defined standard allows the formulation of training goals and serves to guide the clinician in developing proficiency in the field. The goal of this Consensus Statement is to define competence in critical care ultrasonography and critical care echocardiography.

1. **We suggest that critical care ultrasonography requires competence in modules in the following areas: pleural; vascular; thoracic; and cardiac (basic and advanced echocardiography).**
2. **We suggest that each module has specific and definable components.**
3. **We suggest that mastery of each of these components defines competence.**
4. **We suggest that the specific skills listed in this document can serve as a guide for training in achieving competence and certification in the field of critical care ultrasonography.**

The La Société de Réanimation de Langue Française (SRLF) and the American College of Chest Physicians (ACCP) have a combined international membership of > 18,000. Both organizations have a strong interest in critical care ultrasonography (CCUS) and have collaborated to define the competencies in this field. Although this document is directed primarily toward intensivists, ultrasonography of the pleura and lung are also relevant to pulmonary medicine.

The purpose of this document is not to summarize the knowledge base of ultrasonography as it applies to critical care and pulmonary medicine, nor to evaluate the evidence supporting its use. Rather, the purpose is to describe the components of competence so that clinicians may have specific goals of training while they develop their skills. Competence is distinguished from *certification*, which is defined as the process by which competence is recognized by an external agency.

The working group for this statement was identified by the leadership of SRLF and ACCP, and consists of expert critical care and pulmonary specialists who use and teach ultrasonography in their daily practice. This document is based on the consensus opinion of these experts and is not an evidence-based guideline. The competence that we define is that which the intensivist should reasonably achieve for routine ICU operations and represents a minimum standard for a clinician who practices ultrasonography. It should not discourage the development of additional skills.

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CCUS may be divided into general critical care ultrasonography (GCCUS) [thoracic, abdominal, and vascular], and echocardiography (basic and advanced). The only references cited are related to advanced critical care echocardiography (CCE) because a complete bibliography is outside the scope of this article.

Materials and Methods

This consensus statement is sponsored by the ACCP Critical Care NetWork Steering Committee, which identified ACCP representatives for this project; SRLF members were assigned separately. Working groups representing both organizations were responsible for different components of manuscript preparation. The contents of this statement should not be used for performance measurement or establishing competency purposes because they are not evidence-based as outlined by the ACCP Health and Science Policy Committee.

In a meeting of the entire panel, each working group presented their findings, the contents of the statement were developed following formal vote; all statements reflect unanimous opinion. A writing group circulated drafts of this document to all panel members for comment and final approval, followed by review and approval of the ACCP Critical Care NetWork Steering Committee and the executive committee of the ACCP Board of Regents.

Delphi Questionnaire

Validation of clinical competencies in CCUS was accomplished using the Delphi method of the Rand Corporation[1] and two panels of experts in the field. The Delphi approach was chosen because it represents an established method of obtaining anonymous expert opinion, determining levels of agreement, and evaluating the degree of consensus on a given topic.[2,3] Responses were returned to an ACCP research methodologist for statistical analysis and determination of the level of group consensus.

The questionnaire consisted of 27 items assessing proposed competencies across six modules in the field of CCUS. These included pleural, lung, abdominal, vascular-guidance, vascular-diagnosis, and basic and advanced echocardiography. The questionnaire employed a 5-point Likert scale to assess the level of agreement to statements contained in the questionnaire as follows: 1, "strongly disagree"; 2, "somewhat disagree"; 3, "neither agree nor disagree"; 4, "somewhat agree"; and 5, "strongly agree."

Expert Panel Selection and Instructions

To assure that the proposed competencies are relevant to the real-world needs of the intensivist, the specific competencies were validated by two groups of intensivists with different levels of experience in CCUS. The questionnaire was given to the participants and faculty of an ACCP ultrasound course and took 20 min to complete. The faculty also scored one additional item related to pleural CCUS and five items that related to advanced CCE that were not given to the course participants. Answers were collected anonymously using a standard computerized response system. There was no advance notice that the questionnaire would be given, nor was the rationale known.

Statistical Analysis

To evaluate whether these competencies were relevant to practitioners in CCUS outside the working group, we evaluated the levels of agreement among clinicians with different levels of experience. Consensus on a topic can be determined if a percentage of the votes falls within a prescribed range.[4–7] In this statement, agreement was assessed on two levels based on answers to the following questions: (1) Does each group of expert respondents agree with the proposed competency under consideration? and (2) Does each group of expert respondents agree with the opinion of the other expert group on a proposed competency? The results of the data analyses are expressed as the percentage of respondents (total agreement) scoring an item as either 4 or 5 on the Likert scale. Agreement with a proposed competency under consideration was defined as a mean total agreement of the expert groups of ≥ 70%. If this condition was met, consensus was established and the proposed competency was defined as appropriate.

The major statistics used in Delphi studies have been described elsewhere.[8–12] We chose to express the levels of agreement in terms of percentage agreement (consensus), range, mean, and median[13] because these terms allow for the identification and potential influences of outlier responses.

Results

Analysis of Delphi Surveys

One group of respondents consisted of 126 participants of a 3-day course on CCUS. A second group of experts consisted of 18 faculty who taught the CCUS course. Appendix 1 summarizes the demographics of course participants.

There were 22 faculty members, of whom 18 had a 100% response rate; the 4 faculty members who did not have a 100% response rate were excluded because they had prior knowledge of the consensus statement content. The response rate of the course participant group varied, with rates of response to each question ranging from 78 to 94% with a mean response rate of 89%. Following testing, two participants reported that they were confused by the Likert scale rankings of agreement. However, their responses did not change the overall results.

Appendix 2 summarizes agreement levels for each group for each competency module. The percentage agreement for course participants group ranged from 61 to 98%. The percentage agreement for the faculty group ranged from 61 to 100%. Acceptable levels of consensus were obtained for 26 of 27 statements (> 70%) based on the mean level of agreement of the two expert groups. Therefore, no additional rounds of questionnaires were administered to establish consensus.

As expected, a greater level of consensus was achieved with the faculty group than with the course participant group (26 of 27 statements), possibly reflecting their greater expertise and experience with CCUS. The level of agreement for the course participant group alone exceeded 70% for 17 of 20 statements, supporting the contention that the competencies proposed by the working group are relevant to the real-world needs of the intensivist.

The highest levels of consensus were achieved for the modules in vascular diagnosis and guidance. Consensus was not established for one statement of the advanced echocardiography module that addressed the importance of the measurement of transvalvular velocity gradient (61% agreement). Greater agreement on a statement of the vascular-diagnosis module addressing the importance of basic screening echocardiography in CCUS was found with the course participant group (96%) than the faculty group (89%). Median values for all responses were higher than the means, indicating that outlier responses may have skewed the mean level of consensus toward disagreement.

GCCUS

GCCUS is performed and interpreted by the intensivist at the bedside to establish diagnoses and to guide procedures. The elements of ultrasonography that are required to achieve competence in GCCUS are as follows:

1. Pleural ultrasonography;
2. Lung ultrasonography;
3. Abdominal ultrasonography;
4. Vascular ultrasonography: guidance of vascular access; and
5. Vascular ultrasonography: diagnosis of venous thrombosis

Overview

In performing GCCUS, the clinician assumes responsibility for all aspects of image acquisition. Therefore, competence in GCCUS requires knowledge of basic ultrasound physics and machine controls, performance of a systematic scanning sequence, knowledge of normal and abnormal anatomy, the influence of patient positioning on imaging quality, and mastery of transducer manipulation. In addition to technical skills, cognitive skills required for image interpretation and application of the information derived from ultrasonography to the clinical situation are required.

A machine with good quality two-dimensional (2D) imaging must be continuously available in the ICU. This is essential for clinical operations, training, and maintenance of competence. Whenever possible, examinations should be recorded and documented because image review and continuous quality improvement is an integral component of competence.

Basic Principles

Knowledge and skills required for competence in GCCUS include the following:

1. Knowledge of basic ultrasound physics. Ultrasonography images are generated by the interaction of ultrasound signals with tissue. An understanding of the fundamental principles of

ultrasound physics is required to obtain high-quality images and to understand and recognize artifacts of ultrasound imaging.

2. Knowledge of machine controls and transducer manipulation. The clinician must be able to acquire the ultrasound images personally at the bedside.
3. Knowledge of normal and abnormal ultrasound anatomy and the pathophysiologic consequence of the imaged abnormality.
4. Knowledge of image interpretation, clinical applications, and specific limitations of ultrasonography.
5. Knowledge of when the examination is beyond the technical or interpretative capability of the clinician performing the study. Frequently, GCCUS is performed as a limited or goal-directed examination. The intensivist seeks to answer the clinical question with a definitive positive or negative result from the ultrasound examination, and he or she must have the knowledge to identify an indeterminate result.

Pleural Ultrasonography

Table 1 summarizes the requirements for competence in ultrasonography of pleura. An important application is to guide thoracentesis and pleural device insertion in the critically ill. This skill requires competence in the identification of a site, angle, and depth for safe needle penetration. To avoid inadvertent injury, a key component of competence is the ability to identify the anatomic structures that are listed. To evaluate for postprocedure pneumothorax, the assessment of sliding lung (see the "Lung Ultrasonography" section) is a necessary component of competence, along with semiquantitative assessment of the remaining fluid and identification of intrapleural device placement.

Table 1—*Technical (Image Acquisition) and Cognitive (Image Interpretation) Elements Required for Competence in Pleural Ultrasonography*

Identification of a relatively hypoechoic or echo-free space surrounded by typical anatomic boundaries: diaphragm, chest wall, ribs, visceral pleura, normal/consolidated/atelectatic lung
Identification of liver and ascites, spleen, kidney, heart, pericardium and pericardial effusion, spinal column, aorta, inferior vena cava
Identification of characteristic dynamic findings of pleural fluid, such as diaphragmatic motion, floating lung, dynamic fluid motion, respirophasic shape change
Characterization of fluid: anechoic; echogenicity (using liver/spleen as reference); homogeneous or heterogeneous; presence of strands/debris/septations
Identification of miscellaneous findings, such as pleural-based masses or thickening
Performance of semiquantitative assessment of fluid volume
Recognition of specific limitations of ultrasonography to identify pleural fluid, such as inadequate image quality due to technical limitations, subcutaneous emphysema, hemothorax, echo-dense purulent fluid, mimics of effusion such as mesothelioma or pleural fibrosis

Table 2—*Technical (Image Acquisition) and Cognitive (Image Interpretation) Elements Required for Competence in Lung Ultrasonography*

Knowledge of the basic semiology of lung ultrasound: A-lines, B-lines, sliding lung, lung point
Identification and characterization of consolidated lung: identification of tissue density lung, with or without air bronchograms
Identification and characterization of air artifacts suggestive of the normal aeration pattern: A-lines with sliding lung
Identification and characterization of air artifacts suggestive of alveolar interstitial pattern: number and location of B lines
Knowledge of the limitations of not visualizing lung sliding/B lines
Identification and characterization of air artifacts to rule out pneumothorax: presence of sliding lung, presence of B-lines
Identification and characterization of findings that rule in pneumothorax: presence of lung point (both by 2D imaging and M-mode)

Lung Ultrasonography

Table 2 summarizes the requirements for competence in lung ultrasonography.

Abdominal Ultrasonography

Requirements for competence in critical care abdominal ultrasonography are summarized in Table 3. An important application of abdominal ultrasonography is to guide paracentesis in the critically ill. This skill requires competence in the identification of a site, angle, and depth for safe needle penetration. To avoid organ injury, a key component of competence is the ability to identify the anatomic structures listed.

Vascular Ultrasonography: Guidance of Vascular Access

Table 4 summarizes the requirements for competence in vascular ultrasonography for guidance of vascular access. Specific competence in guided vascular access requires integration of ultrasonography skills into real-time guidance of the needle into the target vessel. This requires knowledge of proper machine placement, transducer preparation with sterile cover, transducer manipulation, and ability to identify wire placement in the target vessel and the needle tip throughout the insertion maneuver. Assessment for lung sliding is a necessary component in ruling out pneumothorax (see the "Lung Ultrasonography" section).

Vascular Ultrasonography for Diagnosis of Venous Thrombosis

Requirements for competence in vascular ultrasonography for diagnosis of venous thrombosis are

Table 3—*Technical (Image Acquisition) and Cognitive (Image Interpretation) Elements Required for Competence in Abdominal Ultrasonography*

Assessment for intraperitoneal fluid
Identification of a relatively echo-free space surrounded by typical anatomic boundaries: abdominal wall, diaphragm, liver, gallbladder, spleen, kidney, bladder, bowel, uterus, spinal column, aorta, IVC
Identification of abdominal wall, diaphragm, liver, gallbladder, spleen, kidney, bladder, bowel, uterus, spinal column, aorta, IVC
Identification of characteristic dynamic findings of intraperitoneal fluid, such as diaphragmatic motion, floating bowel, bowel peristalsis, dynamic fluid motion, and respirophasic shape change, compressibility
Characterization of fluid: anechoic; echogenicity (using liver/spleen as reference); homogeneous or heterogeneous; presence of strands/debris/septations
Qualitative assessment of intraperitoneal fluid volume
Recognition of specific limitations of ultrasonography to identify intraperitoneal fluid such as inadequate image quality due to technical limitations, hemoperitoneum, echo-dense purulent fluid
Assessment of the urinary tract
Bladder: identification of bladder, identification of urinary catheter, identification of abnormal bladder contents
Differentiation of distended bladder from ascites
Qualitative assessment of intravesicular volume, identification of overdistention
Kidneys: identification of both kidneys, identification of presence or absence of hydronephrosis, measurement of kidney in longitudinal axis
Assessment of the aorta
Identification of abdominal aorta
Identification of abdominal aortic aneurysm

summarized in Table 5. Competence requires knowledge of how to perform a compression maneuver (*ie*, the degree and vector of force application, and the number of sites of examination along the course of a vein).

Table 4—*Technical (Image Acquisition) and Cognitive (Image Interpretation) Elements Required for Competence in Vascular Ultrasonography for Guidance of Vascular Access*

Identification of relevant veins and arteries: internal jugular/carotid, subclavian vein/artery, axillary vein/artery, brachial vein/artery, radial artery, femoral vein/artery vein, peripheral veins such as basilic, cephalic, external jugular
Differentiation of vein from artery based on anatomic position, compressibility, respirophasic changes
Identification of normal anatomic variability such as vascular hypoplasia, variability of carotid artery position relative to internal jugular
Identification of vascular thrombosis by direct visualization or by compression study (see "Vascular Ultrasonography for Diagnosis of Venous Thrombosis" section in text)
Identification of adjacent nonvenous structures such as sternocleidomastoid muscle, mass, lymph node
Knowledge of the effects of patient positioning on anatomic topography: head/lower extremity rotation effects on overlap of the artery by the vein, effects of Trendelenburg position on vascular distention

Table 5—*Technical (Image Acquisition) and Cognitive (Image Interpretation) Elements Required for Competence in Vascular Ultrasonography for Diagnosis of Venous Thrombosis*

Identification of relevant veins and their associated artery: internal jugular, subclavian, axillary, brachial, basilic, common femoral, proximal saphenous, superficial femoral, popliteal with differentiation from adjacent artery
Identification of venous thrombosis: visualization of endoluminal thrombus, performance of compression study with identification of noncompressible vein consistent with thrombosis
Knowledge not to perform compression maneuver if there is a visible thrombus
Identification of adjacent structures such as lymph node, mass, hematoma, ruptured Baker cyst

CCE

CCE is performed and interpreted by the intensivist at the bedside to establish diagnoses and to guide therapy of patients with cardiopulmonary compromise. This part of the document defines the elements of echocardiography that are required to achieve competence in CCE.

Levels of Competence

Competence in CCE can be separated into basic and advanced levels. Basic CCE is performed as a goal-directed examination using transthoracic echocardiography (TTE) or transesophageal echocardiography (TEE) 2D imaging to identify specific findings and to answer straightforward clinical questions. Intensivists may readily achieve competence in basic CCE. Competence in advanced CCE allows the intensivist to perform a comprehensive evaluation of cardiac anatomy and function including hemodynamic assessment using TTE or TEE 2D and Doppler echocardiography. Competence in advanced CCE requires a high level of skill in all aspects of image acquisition and interpretation. Compared to basic CCE, advanced level competence requires far more extensive training and experience.

In performing CCE, the clinician assumes responsibility for all aspects of image acquisition and interpretation. For this reason, competence in both basic and advanced CCE requires the knowledge and skills of ultrasonography described previously. Unlike GCCUS, where the application of scan results to bedside management is relatively straightforward, the information derived from CCE requires a high level of cognitive training, particularly for advanced CCE applications. These may be categorized as those required for image interpretation and those required for integration of the results into an effective management strategy.

A key element of both basic and advanced level CCE is that a machine with high-quality 2D imaging and full Doppler capability be available on a 24 h-basis in the ICU. A multiplane transesophageal probe is highly recommended, particularly for patients receiving mechanical ventilation who may have poor TTE image quality or for diagnoses requiring TEE for diagnostic accuracy.

Basic CCE

Basic CCE aims to answer a limited number of clinical questions commonly encountered by the intensivist. The evaluation is qualitative, target-oriented, and can be repeated after specific therapeutic interventions. Importantly, it favors specificity over sensitivity; definite findings will lead to changes in patient management, whereas uncertain findings require consultation.

Competence in Basic CCE

Competence in image acquisition of the following standard views is required: parasternal long and short axis views, apical four-chamber view, subcostal four-chamber view, and inferior vena cava (IVC) view. Table 6 summarizes the image interpretation skills required for competence in basic CCE. Competence in cognitive skills required for application of image interpretation results requires knowledge of the common clinical indications for the study. These include evaluation and management of hemodynamic instability, shock, cardiac arrest, unsuccessful response to acute therapy, and respiratory failure. Competence in basic CCE requires that the intensivist have the cognitive training to integrate echocardiography into management strategy. This requires recognition of the echocardiographic patterns listed in Table 7. Requirements for competence in image interpretation include qualitative assessment of left ventricular (LV) cavity size (small, normal, or severely dilated), LV systolic function (normal, hyperdynamic, mild-to-moderate dysfunction, or severe dysfunction), and distinguishing homogeneous from heterogeneous patterns of LV contraction. Qualitative assessment of global right ventricular (RV) cavity size and function using the parasternal short-axis and apical four-chamber views (normal vs dilated, when RV size exceeds LV size); identification of pericardial fluid (with distinction from pericardial fat, pleural effusion, and ascites); and 2D findings consistent with tamponade physiology (right atrial/RV diastolic collapse, and dilated, noncollapsible IVC in spontaneously breathing patients) are requirements for competence. Measurement of IVC diameter (between the right atrial junction and the superior hepatic vein) and qualitative assessment of its respiratory variations (present or absent) in the subcostal view, including knowledge of problems with adequate interpretation of IVC dynamics (dis-

Table 6—*Competence in Basic Critical Care Echocardiography: Required Cognitive Skills in Image Interpretation*

Echocardiographic patterns
Global LV size and systolic function
Homogeneous/heterogeneous LV contraction pattern
Global RV size and systolic function
Assessment for pericardial fluid/tamponade
IVC size and respiratory variation
Basic color Doppler assessment for severe valvular regurgitation

Table 7—*Competence in Basic CCE: Required Cognitive Skills in Recognition of Clinical Syndromes*

Clinical Syndromes	Echocardiographic Findings
Severe hypovolemia	Small, hyperdynamic ventricles
	Small IVC with wide respiratory variations
LV failure	Global LV systolic dysfunction
	Heterogeneous contractility pattern suggestive of myocardial ischemia
	LV cavity dilatation suggestive of chronic cardiac disease
RV failure	Acute cor pulmonale: RV dilatation and paradoxical septal motion*
	Isolated RV dilatation suggestive of RV infarct
	Associated findings: dilated, noncollapsible IVC
Tamponade	Pericardial effusion (regardless of size)†
	Right atrial/RV diastolic collapse
	Associated findings: dilated, noncollapsible IVC
Acute massive left-sided valvular regurgitation	Normal LV cavity size (acute valvulopathy)
	Normal/hyperdynamic LV systolic function (LV volume overload)
	Massive color Doppler regurgitant flow‡
Circulatory arrest	
During resuscitation	Tamponade or acute cor pulmonale (from massive pulmonary embolism)
	LV systolic function (cardiac standstill vs severely depressed vs hyperdynamic)
	Global LV systolic dysfunction
After successful resuscitation	Heterogeneous contractility pattern suggestive of myocardial ischemia

*Accurate identification of paradoxical septal motion may be challenging; acute cor pulmonale is mainly associated with ARDS or massive pulmonary embolism in critically ill patients.
†The rate of fluid accumulation within the pericardium rather than its volume determines the risk of tamponade; although echocardiographic findings are considered, the diagnosis of cardiac tamponade should be made on clinical grounds.
‡The absence of apparent valvular regurgitation during color Doppler examination does not definitely rule out the diagnosis.

Table 8—*Competence in Advanced CCE: Specific Indications for Advanced CCE**

Suspected Pathology	Echocardiographic Findings
Infectious endocarditis*	Vegetation (size, location), abscess, valvular destruction, quantification of valvular regurgitation
Acute aortic dissection*	Intimal flap (location, extension), signs of extravasation, pericardial effusion, aortic regurgitation
Blunt cardiovascular trauma*	Aortic rupture, mediastinal hematoma, myocardial contusion, and hemopericardium
Cardiovascular source of systemic emboli*	LV apical thrombus, mass in the left atrium/appendage, patent foramen ovale, aortic thrombus, and atherosclerotic lesions
Right-to-left shunt	IV air bubble contrast injection to examine for right-to-left shunt
Pulmonary embolism	Thrombus within pulmonary artery, thrombus in transit through the right heart
Complications of myocardial infarction	RV infarction, LV free wall rupture, papillary muscle rupture

*TEE has higher diagnostic accuracy than TTE for these indications.

tinction from the abdominal aorta and effects of mechanical ventilation and of elevated intraabdominal pressure), are part of competence. Competence in basic CCE includes qualitative assessment of valve function using color Doppler to assess for severe valvular regurgitation. Competence in basic CCE does not include use of color or spectral Doppler for comprehensive assessment of valvular or hemodynamic function, definitive identification of isolated mild to moderate LV dysfunction, identification of specific segmental wall dysfunction, RV dysfunction in the absence of RV dilatation, or identification of abnormal or paradoxical interventricular septal motion pattern. The intensivist must also have knowledge as to when to identify an indeterminate result that may require consultation with a more advanced echocardiographer.

Advanced CCE

Advanced CCE allows comprehensive hemodynamic evaluation and monitoring that is used to directly guide patient management at the bedside. Competence requires mastery of image acquisition for all TTE and TEE views that are standard to performance of a

Table 9—*Competence in Advanced CCE: Cognitive Background Required for Comprehensive Hemodynamic Evaluation*

Cognitive Background for Advanced-Level CCE
Heart-lung interactions
Influence of positive-pressure ventilation on systemic venous return and RV ejection
Influence of ventilator settings on echocardiographic examination
Influence of respiratory system compliance, intrinsic positive end-expiratory pressure, and plateau pressure on echocardiographic examination
Physiology and pathophysiology of the left ventricle
LV diastolic properties: active relaxation and passive compliance (high elastance)
LV systolic function: variability according to time course of disease, drug administration, and loading conditions
LV systolic dysfunction: variability of relationship to cardiogenic pulmonary edema or cardiogenic shock
LV systolic dysfunction: distinction between chronic and acute LV systolic dysfunction secondary to cardiac disease
Physiology and pathophysiology of the RV
RV properties: low elastance, high sensitivity to increased afterload
RV systolic dysfunction in shock: association with (marked) RV dilatation
Influence of ventilator settings on RV function and impact of RV systolic dysfunction on ventilator settings
Frequency and significance of acute cor pulmonale in massive pulmonary embolism or in ARDS
Pathophysiology of sepsis
Hyperkinetic state in sepsis: origin, treatment, and prognostic implications
LV dysfunction in sepsis: frequency and origin
Persistent hypovolemia in the presence of LV failure: origin
Pathophysiology of cardiac tamponade
RV/right atrial interdependence
RV/LV interdependence
Effect of respiration on intracardiac hemodynamics

Table 10—*Competence in Advanced CCE: Key Questions Addressed with Advanced CCE*

Key Questions Addressed with Advanced CCE
Is the heart preload sensitive?
What is the efficacy and tolerance of a fluid challenge or fluid removal?
What is LV systolic function?
What is LV ejection performance?
What is LV size?
Are there segmental wall motion abnormalities?
What is RV systolic function? Is acute cor pulmonale present?
Is the RV cavity dilated?
Is paradoxical septal motion present?
Is RV systolic function impaired by ventilator settings?
What are pulmonary arterial pressures?
Is clinically relevant valvulopathy or a prosthetic valve dysfunction present?
What is LV diastolic function? Are LV filling pressures elevated?
Is the presence of an acute cor pulmonale related to a massive pulmonary embolism, to elevated intrathoracic pressures (from ventilator), or severe underlying lung disease?
Is a thrombus in transit within the right atrium or ventricle?
Is a thrombus entrapped into the proximal pulmonary artery/foramen ovale?
Is circulatory failure related to pericardial tamponade?
Is a clinically relevant pericardial effusion present?
Is a localized mediastinal hematoma or a loculated pericardial effusion present (surgical/trauma settings)?
Are intracardiac or intrapulmonary shunts present?

Table 11—*Competence in Advanced CCE: Echocardiographic Parameters of Fluid Responsiveness Used for Advanced-Level CCE**

Dynamic Indexes	Technical Considerations and Interpretation
IVC distensibility index[14,15]	TTE (subcostal view); measured on ventilatory support without spontaneous respiratory effort; not validated in patients with elevated intraabdominal pressure
SVC collapsibility index[16]	TEE (SVC long axis view), measured on ventilatory support without spontaneous respiratory effort
Respiratory variations of maximal Doppler velocity of aortic blood flow[17]	TTE (apical five-chamber view) and TEE (deep transgastric view); measured on ventilatory support without spontaneous respiratory effort; sinus rhythm
Cardiac output change following passive leg raising[18–21]	TTE (apical five-chamber view); patients with or without spontaneous breathing

*SVC = superior vena cava.

complete echocardiography study including full Doppler examination. Competence in image acquisition for advanced CCE is similar to that required for cardiologists trained in echocardiography. In addition, the intensivist must have specific competence in measurements of hemodynamic function such as dynamic indexes of preload sensitivity and detailed measurement of flows, pressures, and right ventricular function that are not part of standard echocardiography performed by cardiologists. Competence in image acquisition with TEE is strongly recommended as part of CEE, if this resource is available.

Requirements for competence in the cognitive elements of advanced CEE extend beyond simple image interpretation and knowledge of indications for the study; these are centered broadly on the assessment of acute cardiopulmonary failure. Table 8 lists some specific indications. To combine the information derived from the scan into a comprehensive management plan, competence requires that the intensivist be trained in critical care medicine, with special reference to the pathophysiology of hemodynamic and respiratory failure. This requires cognitive training in specific aspects of hemodynamic function that are listed in Table 9. Competence requires knowledge of how to integrate the results of advanced CCE into a management strategy that addresses the questions listed in Table 10. The limited reference list serves as an introduction to some important applications of advanced CCE.

Although competence in advanced CCE is similar to that of cardiologist echocardiographers, some situations require cardiology consultation. These include prosthetic valve function, complex congenital heart disease, cardiac source of systemic embolism, and stress echocardiography. However, the intensivist develops competence in the measurement of hemodynamic function and integration of advanced CCE into bedside management strategy that is beyond the scope of most cardiologists. Because advanced CCE focuses on the critically ill patient with severe cardiopulmonary failure, specific competence in the following key elements of image acquisition and cognitive function is required.

1. Evaluation of fluid responsiveness. Measurement of dynamic indexes used to predict fluid responsiveness[14–21] are required components of competence in CCE (Table 11).
2. Evaluation of LV ejection performance and size. Measurement of stroke volume, LV ejection fraction, LV fractional area change,[22] iden-

Table 12—*Competence in Advanced CCE: Parameters of RV Function and Size**

Parameters	Technical Considerations and Interpretation
RV size	Measurement of RVEDA and LVEDA using TTE (apical four-chamber view) or TEE (transesophageal four-chamber view) RVEDA/LVEDA: < 0.6, no RV dilatation RVEDA/LVEDA: 0.6–1, moderate RV dilatation RVEDA/LVEDA: > 1, severe RV dilatation
Paradoxical septal motion	TTE (parasternal short-axis view) or TEE (transgastric short-axis view): abnormal curvature and systolic recruitment toward RV ejection
RV outflow	Pulse wave Doppler velocities of RV outflow recorded by TTE or TEE: abnormal pattern (low flow velocity, systolic notch)
Pulmonary artery pressure	Continuous wave Doppler velocities of tricuspid and pulmonary insufficiency Systolic, diastolic, and mean pulmonary artery pressure using Bernoulli simplified equation
Abnormal RV outflow Doppler patterns	Biphasic profile in severe pulmonary hypertension; acceleration time < 100 ms in pulmonary hypertension

*RVEDA = RV end-diastolic area; LVEDA = LV end-diastolic area.

Table 13—*Competence in Advanced CCE: Parameters of LV Filling Pressure*

Parameters	Technical Considerations and Interpretation
E/A ratio, DTE[25]	Pulsed wave Doppler recorded at the tip of the mitral valve
	A restrictive pattern (E/A ratio ≥ 2, DTE < 120 ms) is highly suggestive of a PAOP > 18 mm Hg
Systolic fraction of the pulmonary vein flow[26–28]	Pulsed wave Doppler recorded in upper left pulmonary vein
	A low systolic fraction (≤ 40%) suggests a PAOP > 18 mm Hg
E/E′[29]	Pulsed wave Doppler recorded at the tip of the mitral valve (E)
	Tissue Doppler recorded at the mitral annulus (E′)
	PAOP and E/E′ are closely related

*A = maximal Doppler velocity of late diastolic mitral wave (during atrial contraction); DTE = deceleration time of mitral Doppler E wave; E = maximal Doppler velocity of early diastolic mitral wave; E′ = maximal tissue Doppler velocity of early diastolic displacement of the mitral annulus; PAOP = pulmonary artery occlusion pressure.

tification of LV regional wall motion abnormalities, and accurate qualitative assessment of global LV systolic function[23] are required components of competence in advanced CCE.

3. Evaluation of RV systolic size and function. Measurement of RV size and function is a required component of competence in advanced CCE[24] (Table 12).
4. Evaluation of LV filling pressure and LV diastolic function. Measurement of Doppler indexes[25–29] to evaluate LV filling pressures and LV diastolic function are required components of competence in advanced CCE (Table 13).
5. Evaluation of native and prosthetic valve function. Recognition and quantitation of significant native valvular regurgitation and stenosis using color and spectral Doppler is a required component of competence in advanced CCE. Comprehensive evaluation of prosthetic valve function is not a requirement for competence in advanced CCE; expert consultation may be needed in this situation.
6. Evaluation of the pericardial space. In the presence of pericardial effusion, recognition of signs of cardiac tamponade including diastolic collapse of the right atrium and of the right ventricle and exaggerated respiratory variations of tricuspid and mitral Doppler inflow velocities (in spontaneously breathing patients) are required components of competence in advanced CCE.

Conclusions

The purpose of this document is to define explicitly the competencies of CCUS. This statement has two important uses:

1. It may be used as a practical guide for physicians who seek training and for those who provide training in the field. With this standard statement of competence, the goals of training are now clearly defined.
2. It may be used as a foundation for developing training methods and standards, as well as providing a framework for developing a formal system of certification in the field of CCUS.

Appendix 1

Demographic Analysis of Course Participants and Faculty*

Demographic	Participant Group (n = 126), %
Position	
Resident	5
Fellow	20
Attending	73
PA/NP	1
Other	1
Age	
20–30 yr	3
30–40 yr	45
40–50 yr	20
50–60 yr	24
≥ 60 yr	8
Residence	
South	26
West coast	7
Midwest	38
East coast	18
International	10
Practice	
Front-line PCCM	79
Consultative PCCM	13
Hospitalist	4
Other specialty	4
Interest	
Pleural	7
Abdominal	0
General	48
Procedural guidance	45
Experience	
None	45
1–5 USs/wk	38
6–10 USs/wk	12
10–20 USs/wk	2
≥ 20 USs/wk	3

*PA = physician assistant; NP = nurse practitioner; PCCM = pulmonary and critical care medicine; US = ultrasound.

Appendix 2

Agreement by Expert Group and Competency Module*

Modules/Statements	Agreement, % G1	Agreement, % G2	Mean Level of Agreement, %	Range G1	Range G2	Mean (Median) G1	Mean (Median) G2
Lung							
S1	75	100	88	1–5	4–5	4.0 (4)	4.9 (5)
S2	83	100	92	1–5	4–5	4.2 (5)	4.9 (5)
S3	61	95	78	1–5	3–5	3.6 (4)	4.6 (4)
S4	69	100	84	1–5	4–5	3.8 (4)	4.9 (5)
S5	69	95	82	1–5	3–5	3.8 (4)	4.8 (5)
Pleural							
S6	93	94	94	1–5	2–5	4.6 (5)	4.7 (5)
S7	96	100	98	1–5	5–5	4.5 (5)	5.0 (5)
S8	94	100	97	1–5	5–5	4.7 (5)	5.0 (5)
S9		94	94		2–5		4.6 (5)
Vascular guidance							
S10	91	100	96	1–5	4–5	4.5 (5)	4.4 (5)
S11	94	94	94	1–5	3–5	4.8 (5)	4.3 (5)
S12	94	94	94	1–5	3–5	4.7 (5)	4.3 (5)
S13	93	94	94	1–5	3–5	4.7 (5)	4.3 (5)
Abdominal							
S14	77	95	86	1–5	3–5	4.0 (4)	4.2 (5)
S15	84	94	90	1–5	4–5	4.3 (5)	4.7 (5)
S16	94	100	97	1–5	5–5	4.5 (5)	5.0 (5)
S17	84	89	86	1–5	2–5	4.3 (4)	4.4 (5)
Basic echocardiography							
S18	96	89	92	1–5	3–5	4.8 (5)	4.7 (5)
S19	98	100	99	1–5	4–5	4.8 (5)	4.2 (5)
S20	98	100	99	2–5	4–5	4.8 (5)	4.9 (5)
S21	97	100	98	1–5	4–5	4.7 (5)	4.8 (5)
S22	91	100	96	2–5	4–5	4.4 (4)	4.2 (5)
Advanced echocardiography							
S23		100	100		4–5		4.6 (5)
S24		78	78		2–5		3.9 (4)
S25		84	84		3–5		4.1 (4)
S26		61	61		2–5		3.9 (4)
S27		78	78		2–5		4.2

*G1 = course participant group; G2 = faculty group 2; S = statement.

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