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Expert Round Table on Echocardiography in ICU

International consensus statement on training standards for advanced critical care echocardiography

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All authors certify that they endorse all parts of the published manuscript. The expert round table participants and the authors as a group are listed in the Appendix.

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Background

This expert panel statement is written in order to provide guidance to faculty and learners who are involved with training in advanced critical care echocardiography (CCE). For faculty, it defines explicitly how to design a training program; while for the learner it provides a guide to training that they should follow and expect from their faculty. This document is not meant to stand-alone, but is the continuation of two previous expert statements [1, 2]. Many of the participants who are part of the present working group were involved with preparation of these two prior publications. The reader should regard the three documents as part of a continued international effort to organize training in all aspects of critical care ultrasonography (CCUS), of which advanced CCE is one part.

In 2007, the Société de Réanimation de Langue Française and the American College of Chest Physicians convened an expert panel to develop a consensus statement designed to define competence in CCUS. The resulting statement established a standard definition of CCUS, including general CCUS (GCCUS), which includes elements of thoracic, vascular, abdominal ultrasonography, and basic and advanced CCE; and what the intensivist needed to achieve in order to be competent in the field [1]. That document, by design, set out the objectives of training, but provided no instruction on how to achieve competence. Its purpose was to establish the goals of training, and to subsequently develop recommendations as to how to proceed with training.

In 2009, the European Society of Intensive Care Medicine (ESICM) convened an expert panel to develop a consensus statement designed to establish standards for training in CCUS [2]. Eleven critical care societies from five continents sent representatives to the meeting and the resulting document, The International Expert Statement on Training Standards for Critical Care Ultrasonography, was subsequently endorsed by their critical care societies [2]. The training statement [2] used the competence statement [1] as its foundation document, and stated specifically that training in GCCUS and basic CCE should be a required part of critical care training. However, both working groups recognized that advanced CCE is

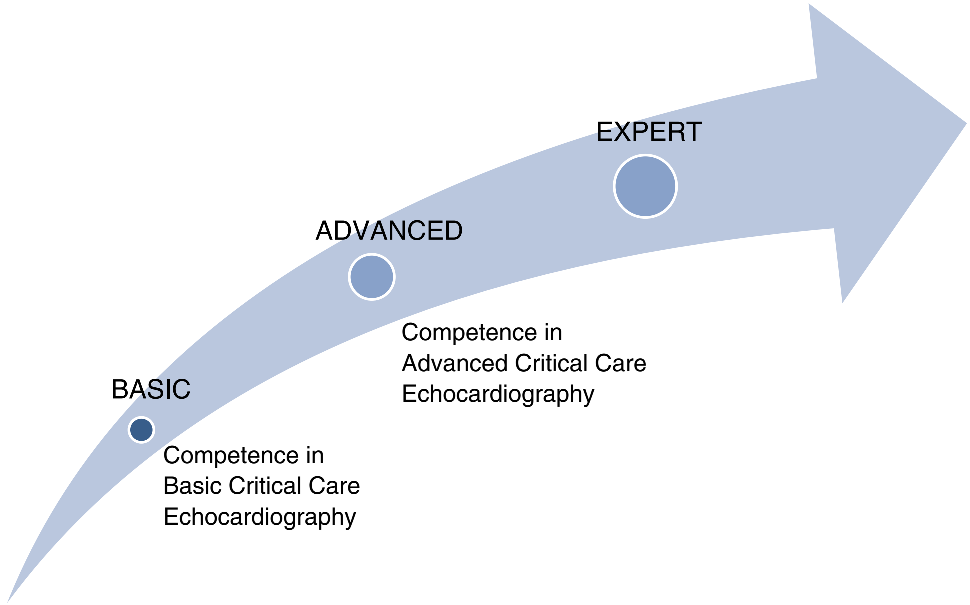

Fig. 1 Advanced critical care echocardiography refers to a spectrum of echocardiographic techniques and skills (image acquisition, image interpretation, and clinical integration) that extend the competencies required for basic critical care echocardiography. Advanced critical care echocardiography relies on qualitative and quantitative assessment of cardiac structure and function with particular emphasis on hemodynamic monitoring and titration of care in the critically ill. Competence in critical care echocardiography occurs along a continuum. Competence to basic level may be achieved with a short period of training. Competence to advanced level requires a much longer period of training. Competence to expert level requires training and experience well beyond that needed for advanced level competence

different from basic CCE and needed a separate standard training document.

There are several reasons that advanced CCE, and therefore its training sequence, should be considered separately from GCCUS and basic CCE.

1. Advanced CCE is more complex and requires significantly more training time commitment than GCCUS and basic CCE do (Fig. 1). Accordingly, it cannot be integrated into general critical care training, but rather requires a dedicated training sequence.
2. Advanced CCE uses measurement techniques that have traditionally been performed by cardiologists, though their focus and use is often different from that of the cardiologist. The training sequence must be rigorous and include competence-based testing in order to assure professional credibility at the interface between the intensivist and the cardiologist. The training statement recommended that a formal certification process be developed to assure that the intensivist is technically and interpretively competent, which is not the case for either GCCUS or basic CCE.
3. While competence in GCCUS is regarded as a standard skill for the intensivist, advanced CCE is an optional skill that requires special training and additional competence.

Although the initial training statement provided some guidance for those interested in training in advanced CCE [2], the present expert statement presents a more detailed review of the subject. Panel members believe that the document is timely, as critical care programs offering organized training in the subject are not yet widespread. We hope to encourage international development of the field, by establishing a standard approach to training. This will help both faculty and learners to organize training, bring international academic credibility to the concept of advanced CCE training, and foster dissemination of a useful clinical tool.

Methods

The process, chaired by Prof. Vieillard-Baron and Dr. Mayo, started in May 2013 under the auspices of ESICM. Societies of critical care medicine involved in the development of training programs in CCUS were asked to designate experts as representatives (see Appendix). All participants in this expert panel are actively engaged in programs dedicated to training intensivists in advanced CCE and are recognized as experts in the field and/or who have special expertise in education design. Four aspects of training in advanced CCE were considered as especially relevant to the discussion. These were assigned to panel members, who wrote initial parts of the draft statement. Two panel members (AVB, PHM) were assigned to combine the parts and to edit a working draft document. This document was then submitted for review to all panel members on 15 September 2013 and edited through email exchange before the entire group met on 4 October 2013 in Paris. At the Paris meeting, the amended preliminary draft underwent systematic review by the entire group with subsequent discussion and debate leading to a consensus on all points. A final draft was edited by the two co-chairs and accepted without restriction by all members of the expert roundtable panel after separate review.

General considerations

Advanced CCE may be defined as any aspect of echocardiography that has utility to the intensivist. While it shares with cardiology the same imaging device, transducer, the image interpretation methods, and much of the same knowledge base and standard views, it differs in many ways from cardiology-based echocardiography. First, it is performed by the intensivist at the bedside of the patient during the active process of diagnosis and management of cardiovascular instability, so the clinician decides what component of the examination is relevant within the clinical context. Thus, the examination may be as complete as the cardiology-type examination; or it may be as limited as needed to aid in diagnosis and management (e.g., measurement of the stroke volume, right ventricular dysfunction, or assessment of left atrial pressure). Accordingly, its use is guided by the clinical diagnostic and therapeutic question. Secondly, while the cardiologist and the intensivist both use the examination to identify a diagnosis, the intensivist also integrates the findings into an immediate clinical management plan in ways that are different from the consultative cardiology echocardiographer.

Beyond determining diagnosis and initial management strategy, the intensivist uses advanced CCE as a hemodynamic monitoring tool by performing sequential examinations on patients on mechanical ventilation to assess the efficacy and tolerance of therapeutic changes. The intensivist must have similar skill at diagnosis of cardiac dysfunction as the cardiologist, but must have the training to use echocardiography as a sequential assessment tool. The cognitive base outlined in this document for advanced CCE emphasizes the importance of training in both the diagnostic and the hemodynamic monitoring aspects of the technique. Unlike the cardiologist, the intensivist with training in advanced CCE also has, by definition, competence in GCCUS; given that competence in GCCUS should be a standard part of critical care training. Skill at GCCUS is complementary to advanced CCE.

Not all intensivists need training in advanced CCE. Basic CCE is a very useful tool for the intensivist to guide in the diagnosis and management of the patient with hemodynamic insufficiency. All critical care doctors should be competent in basic CCE, but intensive care unit management will benefit if some proportion of these doctors are also trained in advanced CCE.

In approaching training in advanced CCE, faculty and learners will address the following four questions:

(A) Competence in image acquisition and interpretation. What are the required echocardiographic views?
(B) Competence in the cognitive base. What constitutes the cognitive base in cardiovascular physiology and echocardiographic interpretation?
(C) Training requires specific requirements and methods of training. What are these?
(D) Training is designed to result in competence. How is competency determined and certified?

The purpose of this statement is to answer these questions and to thereby present faculty and learners with a useful framework for training.

Part A: what are the required echocardiographic views for training in advanced CCE?

Competence in advanced CCE requires that the clinician be adequately trained in both image acquisition and image interpretation. It follows that this document must set out a defined minimal set of echocardiographic views deemed necessary to accomplish those goals. Clearly, more views and their interpretation can be added to the CCE examination as clinical conditions demand. A major goal of advanced CCE training is mastery of image acquisition and image interpretation of these views. This section will define the image set for transthoracic (TTE) and transesophageal echocardiography (TEE) that is a required element of training and competence in advanced CCE. Both TTE and TEE are mandatory parts of advanced CCE training.

1. Competence in image acquisition and interpretation of the two-dimensional (2D) TTE views with associated Doppler measurements listed in Table 1.
2. Competence in image acquisition and interpretation of the two-dimensional (2D) TEE views with associated Doppler measurements listed in Table 2.

The main differences, advantages, and disadvantages of TTE and TEE are summarized in Table 3. While TTE is widely available, some intensive care units do not have yet TEE capability. In this case, training in TEE image acquisition may be provided in cooperation with cardiac anesthesiology and cardiologists.

Table 1 Two-dimensional transthoracic echocardiography views and associated Doppler measurements required for competence in image acquisition and interpretation

View	Mandatory assessments	Optional
PLAX	RV subjective LV measurement—formal 2D/M-mode LA/LVOT/aortic root measurement—2D/M-mode AV/MV—CD Tilted PLAX views RV inflow (RV/RA/TV)—2D/PW/CW RV outflow (PA/PV—2D/PW/CW) TV—CD/CW, d*P*/d*t* Superiorly: PA, CD/CW Descending aorta: size/appearance Pericardial effusion/features of tamponade Pleural effusion characteristics	
SAX	RV wall thickness Aortic level AV—CD TV—CD, CW PV—CW, PW, CD RVOT (distal)—2D MV level[a] Papillary muscle level[a] Apical level[a]	AV planimetry RV wall motion
A4C/A5C	LV Chamber volumes—LV/LA Contractility—EF, SWMA TDI mitral annulus—septal/lateral E′/A′/S′ Mitral inflow E/A LVOT: 2D, CD, PW, CW Recognize SAM Measurement of SV RV Size—RV/RA (RV:LV ratio) RV/RA dimensions RV contractility subjective TAPSE Fractional area change TDI tricuspid annulus S′ Valves MV—2D, CD, PW, CW TV—2D, CD, CW AV—CD, PW(LVOT), CW	MR d*P*/d*t* Estimate LAP MPI MS-PISA, vena contracta Pulmonary vein PW
A2C/A3C	LV Chamber size—LV/LA volume Contractility—EF, SWMA TDI mitral annulus Mitral inflow E/A MV—2D, CD, PW, CW AV—CD, PW (LVOT), CW	
SC	All chambers—size, ventricular contraction (subjective) IAS—CD Pericardial effusion IVC—M-mode/2D collapsibility/distensibility Hepatic vein flow—CD, PW	SC-SAX views, if PLAX suboptimal RV wall thickness
Suprasternal view		Aortic dilatation/dissection Severe aortic regurgitation Retrograde flow in ascending and descending aorta Coarctation of aorta—PW, CW

PLAX parasternal long axis, *RV* right ventricle, *LV* left ventricle, *2D* two dimensional, *M-mode* time motion study, *LA* left atrium, *LVOT* left ventricular outflow tract, *AV* aortic valve, *MV* mitral valve, *CD* color Doppler, *RA* right atrium, *TV* tricuspid valve, *PW* pulsed wave Doppler, *CW* continuous wave Doppler, *PA* pulmonary artery, *PV* pulmonary vein, *dP/dt* change in pressure/change in time, *SAX* parasternal short axis, *RVOT* right ventricular outflow tract, *SWMA* segmental wall motion abnormality, *A4C/A5C* apical 4/5 chamber views, *MR* mitral regurgitation, *EF* ejection fraction, *LAP* left atrial pressure, *TDI S′/E′/A′* tissue Doppler imaging of systolic, early, and late diastolic annular velocities, respectively, *MPI* myocardial performance index, *MS* mitral stenosis, *PISA* proximal isovelocity surface area, *E/A* early (E) and late (A) ventricular filling velocities, *SAM* systolic anterior motion, *SV* stroke volume, *TAPSE* tricuspid annular plane systolic excursion, *A2C/A3C* apical 2/3 chamber views, *SC* subcostal, *IAS* interatrial septum, *IVC* inferior vena cava

[a] LV measurements, SWMA, paradoxical septal motion, fractional area change

Table 2 Two-dimensional transesophageal echocardiographic views with associated Doppler measurements required for competence in image acquisition and interpretation

TEE views	Assessed anatomical structures	Qualitative measurements or functional information	Quantitative measurements	Diagnoses
Mid-esophageal views (25–30 cm from incisors)				
Great vessels views[a]				
0°	Ascending aorta Main PA Right PA SVC	PA Doppler profile, respiratory variations[d], embolus Entrapped embolus, flow interruption[e] SVC size and respiratory variation	PA VTI, acceleration time	Aortic dilatation/diseases Low RVSV, PHT Massive PE Systemic venous congestion RV preload responsiveness
90°	Right PA SVC[c]	Embolus, flow interruption[e] Central venous catheter position and related thrombus	SVC collapsibility index	Massive PE Systemic venous congestion RV preload responsiveness
Atrial views[b]				
0–30°	RA and LA Upper left PV LA appendage	RA and LA size and contour PV Doppler profile, respiratory variations[d] Thrombus, spontaneous contrast of LA appendage	Vmax S, D, S/D; DT D wave, SF[d] Vmax LA appendage[d]	Atrial compression or dilatation LV filling pressures, massive MR Source of systemic embolus
90° bicaval view[b]	SVC, IVC, RA, interatrial septum	Morphology and mobility of interatrial septum, foramen ovale, shunting[f]	Maximal interatrial septal excursion during cardiac cycle[g]	Atrial septal aneurysm/defect, patent foramen ovale Position of ECLS/ECMO cannulae
Distal esophageal views (30–35 cm from incisors)				
Long-axis ventricular views[b]				
0° four-chamber view	RA, RV, LA, LV	Cardiac cavity size, thrombus Ventricular wall thickness and thickening Visual assessment of LVEF Mitral/tricuspid valve morphology and function	LVEF RVEDA/LVEDA Vmax E, A, E/A, DT E wave[d] Vmax E′, A′ lateral/septal mitral annulus[h]	Global LV/RV systolic function RWMA LV/RV dilatation/hypertrophy LV diastolic dysfunction LV filling pressures MR/MS LVOT obstruction, SAM
0° five-chamber view	Aortic root	Aortic valve morphology and function		AR/AS
90° two-chamber view	LA, LV, LA appendage	Cardiac cavity size, thrombus Ventricular wall thickness and thickening Visual assessment of LVEF Mitral valve morphology and function Thrombus, spontaneous contrast of LA appendage	LVEF (biplane) Vmax E′, A′ anterior/inferior mitral annulus[h]	Global LV systolic function RWMA LV dilatation/hypertrophy MR/MS LV diastolic dysfunction
Ventricular outflow tract views				
40° RVOT view	RA, RV, RVOT Tricuspid valve Pulmonary valve Aortic valve	RV and infundibulum systolic function Tricuspid, pulmonary, aortic valve morphology and function	Vmax TR (assessment of systolic PA pressure) Aortic valve orifice area	RV dysfunction TR PR, PS AR, AS
120° LVOT view	LVOT, aortic root, mitral valve, LA	Ventricular septal hypertrophy Mitral/aortic valve morphology and function	Diameter of LVOT (LVSV measurement)	MR, AR, AS Aortic root disease
Transgastric views[a] (40–45 cm from incisors)				
0° short-axis view	LV, RV	LV cavity size, wall thickness and thickening RV cavity size, ventricular septal motion	FAC LV eccentricity index	Global LV systolic function RWMA LV hypertrophy RV dilatation, paradoxical septal motion

Table 2 continued

TEE views	Assessed anatomical structures	Qualitative measurements or functional information	Quantitative measurements	Diagnoses
120° long-axis view	LVOT, aortic root	Aortic valve morphology and function	Vmax and VTI of LVOT flow, respiratory variations[d,i]	LVSV measurement[d] LV preload responsiveness[d] Aortic valve pressure gradient[i]
0° deep ventricular outflow tract views	LVOT, LV	Aortic valve morphology and function	Vmax and VTI of LVOT flow, respiratory variations[d,i]	LVSV measurement[d] LV preload responsiveness[d] Aortic valve pressure gradient[i]
	RVOT	Pulmonary valve morphology and function PA Doppler profile, respiratory variations[d]	PA VTI, acceleration time[d]	Low RVSV PHT
Thoracic aortic views[a] (25–45 cm from incisors)				
0° short-axis view of descending aorta 90° long-axis view of descending aorta	Descending aorta Posterior mediastinum Left pleural space and lung	Aortic size, contour, and morphology Spontaneous contrast, aortic flow pattern[e] Presence of fluid/blood in the mediastinal/pleural space		Aortic diseases Non-laminar or low blood flow Hemomediastinum, left pleural effusion Left lung consolidation Position of IABP
0° long-axis view of aortic arch 90° short-axis view of aortic arch	Aortic arch Take-off of left subclavian artery	Aortic size, contour, and morphology Spontaneous contrast, aortic flow pattern[e]		Aortic diseases Non-laminar or low blood flow

TEE views are described from the most proximal to the most distal position of the probe within the upper digestive tract; if not stated otherwise, transverse views usually refer to a 0° rotation of the TEE probe, whereas longitudinal views usually refer to a 90° rotation of the TEE probe; angles of intermediate views are provided as illustrative examples, but may vary in certain patients according to anatomy

PA pulmonary artery, *SVC* superior vena cava, *VTI* velocity–time integral, *RV* right ventricle, *SV* stroke volume, *PHT* pulmonary hypertension, *PE* pulmonary embolism, *RA* right atrium, *LA* left atrium, *PV* pulmonary vein, *Vmax* maximal velocity, *S* systolic pulmonary vein Doppler wave, *D* diastolic pulmonary vein Doppler wave, *DT* deceleration time, *SF* systolic fraction calculated as VTI S/VTI S+VTI D and expressed as a percentage, *MR* mitral regurgitation, *IVC* inferior vena cava, *ECLS* extracorporeal life support, *ECMO* extracorporeal membrane oxygenation, *EF* ejection fraction, *EDA* end-diastolic area, *E* early diastolic mitral Doppler wave, *A* end-diastolic mitral Doppler wave, *E′* early diastolic mitral tissue Doppler wave, *A′* end-diastolic mitral tissue Doppler wave, *RWMA* regional wall motion abnormality, *MS* mitral stenosis, *LVOT* LV outflow tract, *SAM* systolic anterior motion, *RVOT* RV outflow tract, *TR* tricuspid regurgitation, *PR* pulmonary regurgitation, *PS* pulmonary stenosis, *AR* aortic regurgitation, *AS* aortic stenosis, *FAC* fractional area change, *IABP* intra-aortic balloon pump

[a] A careful anteflexion of the TEE probe is frequently necessary to improve its contact with the esophageal mucosa, hence image quality

[b] A retroflexion of the TEE probe is frequently necessary to obtain an untruncated view of the scanned anatomical structures

[c] Or ascending aorta, according to the rotation of the TEE probe handle

[d] Pulsed wave Doppler

[e] Color Doppler mapping

[f] Using contrast study and color Doppler mapping

[g] M-mode

[h] Pulse wave tissue Doppler imaging

[i] Continuous wave Doppler

Table 3 Advantages and disadvantages of transthoracic (TTE) and transesophageal echocardiography (TEE)

Advantages of TTE	Advantages of TEE
1. Easy to clean probe	1. Shorter training period to become competent than TTE
2. Non-invasive (no side effects)	2. Not as operator-dependent as TTE 3. Good spatial resolution
3. Superior to TEE for assessment of superficial anatomic structures (e.g., apical thrombus, pericardial space, inferior vena cava)	4. Superior to TTE for assessment of deep anatomic structures (great vessels, base of heart, mediastinum, and atrial appendages) 5. Superior to TTE for visualization of superior vena cava to determine preload sensitivity
4. Superior to TEE for optimal alignment of Doppler beam for measurement of transvalvular blood flows (mitral, aortic, pulmonic, and tricuspid valves), and abnormal jets (e g., valvulopathy, left ventricular outflow tract obstruction, measurement of pulmonary artery pressure)	6. Superior to TTE for diagnosis of endocarditis, aortic dissection, localized pericardial hematoma 7. Superior to TTE for identification of intracardiac shunts, great vessel disease 8. Superior to TTE for assessment of hemodynamic instability post cardiac surgery 9. Superior to TTE for assessment of valvular dysfunction (eccentric mitral jet, prosthetic valve) 10. Can obtain views where TTE views are of low quality (e.g., obesity, post cardiac, etc.)
Disadvantages of TTE	**Disadvantages of TEE**
1. Views limited by patient factors (e.g., obesity, post cardiac surgery, presence of blocking devices and dressings, high PEEP, and hyperinflation) 2. Longer training period than TEE 3. More operator-dependent than TEE 4. Limited spatial resolution 5. Inadequate view of superior vena cava 6. Limited diagnostic value in some diseases (endocarditis, aortic dissection, localized pericardial hematoma, post cardiac surgery)	1. Difficult to perform repeated studies 2. Requires a strict protocol to clean the probe (typical turnaround time at least 30 min) 3. Minimally invasive but with esophageal perforation rate 1/3,000, common but minor superficial pharyngeal lesions, and possibility of procedure-related loss of airway and medication side effect

Part B: what is the cognitive base required for training in advanced critical care echocardiography?

Competency in the cognitive base is one of the three essential elements of advanced CCE along with mastery of image acquisition and subsequent image interpretation. The unique cognitive base permits the intensivist to apply the results of the imaging study to the clinical situation for purposes of immediate diagnosis and management. The goal is for the intensivist to integrate echocardiography into the care of the patient with cardiopulmonary failure. It follows that training in the cognitive base of advanced CCE should emphasize clinical applications that are specific to the management of the critically ill and unstable patients.

1. Specialty training in critical care medicine is a requirement for training in advanced CCE. Implicit to specialty training in critical care medicine is comprehensive knowledge of cardiopulmonary physiology as related to the critically ill patient. With this background, the intensivist may productively combine their general knowledge of critical care with a specific knowledge of advanced CCE. The interface between knowledge of essential aspects of pathophysiological function and advanced CCE is a key component of the cognitive base.
2. Intensivists are uniquely qualified to use advanced CCE owing to the nature of their clinical work, which regularly includes ongoing bedside diagnosis and management of hemodynamic and respiratory failure. Knowledge of a wide variety of pathophysiological processes peculiar to critical care medicine where echocardiography may be productively integrated into the care plan is important. The training sequence for advanced CCE must provide competence in the cognitive base relevant to a wide variety of clinical applications of echocardiography (Table 4) and to key clinical questions relevant to advanced CCE (Table 5).

Part C: what are the specific methods and requirements of training in advanced CCE?

The design of an effective training program requires identification and deployment of effective methods of training that may differ according to faculty preference, local resource availability, and learner preference. The

Table 4 Clinical applications of advanced critical care echocardiography

Clinical settings	Goal of advanced CCE
1. Circulatory failure (sustained hypotension, shock)	Identify main mechanism(s)
2. Cardiac arrest	
a. During resuscitation	Identify a reversible cause
b. After successful resuscitation	Identify a potential cause of cardiac arrest and the mechanism of subsequent circulatory failure
3. Acute respiratory failure	
a. Severe hypoxemia with bilateral radiological infiltrates	Distinguish between cardiogenic pulmonary edema and ARDS, identify the origin of pulmonary edema
b. ARDS	Identify acute cor pulmonale Identify consequences of ventilator settings
c. Decompensated chronic respiratory failure	Identify a cardiac cause of decompensation, chronic cor pulmonale, pulmonary hypertension
d. Weaning failure from the ventilator	Identify a cardiac cause
e. Unexplained sustained hypoxemia	Identify an anatomical shunt
4. Specific clinical settings	
a. Suspected systemic embolism	Identify a cardiovascular source
b. Suspected acute infective endocarditis	Identify Duke's criteria and assess anatomical/functional consequences
c. Acute aortic syndrome	Identify blood extravasation and associated aortic disease
d. Severe chest trauma	Identify blood extravasation and associated cardiovascular injury
e. Circulatory assistance	Confirm adequate anatomical localization of devices Identify potential associated local complications Guide weaning
f. Brain dead donor	Identify main mechanism(s) of hemodynamic instability Identify cardiovascular disease Evaluate suitability for organ donation

ARDS acute respiratory distress syndrome

challenge in creating an effective local training program is compounded by a paucity of literature on the subject. In addition to a review of methods of training, the training program must include some specific requirements of milestones that need to be achieved by the learner.

1. Training in advanced CCE must be supervised by expert faculty. The faculty must be skilled in and recognized by the critical care community as an expert in advanced CCE, preferably with formal certification by a national level authority. As certification at national level is not yet widely available, the alternative is recognition by critical care societies established at a national or international level. Recognition by private or local groups is not sufficient. The expert faculty assumes responsibility for the development of a local training program that provides training in image acquisition, image interpretation, and the cognitive base. The responsible faculty must be a critical care specialist who may choose to partner with colleagues in cardiology and cardiac anesthesiology in developing the training sequence. An example of requirements for expert faculty designation is presented in Table 6.
2. A minimum of 100 full TTE studies is required as part of training in advanced CCE. Although there is no definitive literature on the subject, this minimum number is supported by the experience of all the experts involved in this document. It represents a reasonable balance between the need to achieve competence and the time required for training. By comparison, the American Society of Echocardiography has recommended 150 TTE studies for level 2 competence [3]. The studies must be personally performed by the learner. Initially, studies may be performed on normal subjects, but the majority of studies must be performed on patients. A full image set (as outlined in part A) must be obtained for each study and interpreted by the learner. A proportion of the TTE studies must be performed under the direct supervision of faculty, particularly at the beginning of training. Subsequent studies may be performed without direct supervision. Each full TTE study requires recording of the relevant images and a formal interpretation of the image set with review by expert faculty. Elements that are required for the study report are summarized in Table 7. If the learner is judged not to be competent following 100 studies, the expert faculty may require further training in image acquisition.
3. A minimum of 35 full TEE studies is required as part of training in advanced CCE. This minimum number is based on a well-conducted trial [4]. A significant proportion of these studies should be performed in critically ill patients. The studies must be personally performed by the learner under the direct supervision of the expert faculty and must include the process of patient selection, the introduction and manipulation of

Table 5 Relevant clinical questions addressed with advanced CCE in patients with cardiopulmonary compromise

	Clinical questions
1.	Is tamponade physiology present? Is a compressive pericardial effusion present? Is a compressive mediastinal hematoma or loculated pericardial effusion present?
2.	What is the stroke volume (SV) and cardiac output (CO); is SV/CO decreased or not?
3.	Is the heart preload sensitive? What is the efficacy and tolerance of fluid challenge?
4.	Is LV systolic dysfunction present? Are there regional wall motion abnormalities? Is this LV dysfunction acute (and potentially reversible)? Is there an associated chronic cardiomyopathy or valvulopathy?
5.	Is RV systolic dysfunction present? Is acute cor pulmonale present? Is acute cor pulmonale related to a (proximal) pulmonary embolism? Is RV systolic function impaired by ventilator settings? What is the level of pulmonary hypertension?
6.	Is LV diastolic dysfunction present (regardless of LV systolic function)? Are LV filling pressures elevated? Is there an associated chronic cardiomyopathy? Is RV dysfunction secondary to LV dysfunction?
7.	Is a relevant valvular disease or prosthetic valve dysfunction present? Is the valvulopathy or the prosthetic valve dysfunction severe? Is the regurgitation acute or chronic? What is the level of pulmonary hypertension? What is the likelihood that the lesion is causing the clinical presentation?
8.	Is there a relevant obstruction to LV ejection? What is the maximal pressure gradient? Is this obstruction dynamic or fixed? Is there an associated systolic anterior motion and eccentric mitral regurgitation?
9.	Is an intracardiac or intrapulmonary anatomical shunt present (contrast study)? Is a patent foramen ovale present? What is the degree of interatrial shunting? Is an intrapulmonary shunt present? On which side (pulmonary veins)?
10.	Specific settings: a. Extended/complicated AMI: Are LV regional wall motion abnormalities extended? Is RV involved? Is an LV pseudoaneurysm, a mural (apical) thrombus, or a pericardial effusion present? Is a ventricular septal defect (with active shunting) present? Is a ruptured papillary muscle (with massive mitral regurgitation) present? b. Suspected systemic embolism Is there a cardiac or aortic source of embolism? c. Suspected acute infective endocarditis Are vegetations (anatomical structure of implanted devices), annular abscess, valvular lesions, or intracardiac/great vesselsanatomical shunts present? d. Acute aortic syndrome Are signs of blood extravasation present (hemopericardium, hemothorax)? Is the ascending aorta abnormal (dissection, wall hematoma, ulcer)? e. Severe chest trauma Blunt: Is myocardial contusion, hemopericardium, acute valvular insufficiency (including tricuspid), septal defect present? Is aortic injury (isthmus), hemomediastinum, left hemothorax present? Penetrating Is hemopericardium and/or any intracardiac injury present? f. Circulatory assistance Is the intra-aortic balloon pump adequately located? Are extracorporal life support cannulae adequately located and functional? Is there any related complication (e.g., intracavitarythrombus, local hematoma)? Can the patient be weaned from the circulatory assistance? g. Brain dead donor Is hemodynamic instability related to preload-dependence, ventricular dysfunction, or vasoplegia? Is an underlying cardiomyopathy, valvulopathy, or aortic disease present?

LV left ventricle, *RV* right ventricle, *AMI* acute myocardial infarction

the probe, and the preparation of the final report. A full image set (as outlined in part A) must be obtained for each study and interpreted by the learner. Each full TEE study requires recording of the relevant images and a formal interpretation of the image set with review by the faculty. Elements that are required for

Table 6 Requirements for expert faculty designation to provide training in advanced critical care echocardiography in France

Criteria	Description
Professional medical profile	Intensivist, anesthesiologist, or other specialist working in an intensive care unit who uses advanced critical care echocardiography on a regular basis to guide diagnosis and management of the critically ill patient
Background in critical care echocardiography	Board certification in echocardiography or person clearly identified[a] as an expert in critical care echocardiography, either locally, regionally, or nationally Publications in the field are not required, but can be taken into account for confirming expertise
Equipment	Dedicated ultrasound system with a transthoracic echocardiographic probe accessible around-the-clock in the intensive care unit Access to a multiplane transesophageal probe

[a] See text for definition of bodies recognizing the expertise of the local trainer

Table 7 Elements that are required in the written transthoracic and transesophageal echocardiography study report

1) Patient identification
2) Date of examination
3) Name of operator(s)
4) Machine and examination type
5) Patient-related conditions
   a. Ventilator settings: tidal volume, FiO_2, plateau pressure, and PEEP level
   b. Medications (vasoactive agents, drug name, and dosage)
   c. Heart rate, cardiac rhythm, blood pressure
   d. Passive or spontaneous breathing effort
6) Reason for the study (e.g., hemodynamic evaluation and monitoring, examination for endocarditis, rule out aortic pathology)
7) Results
   a. Anatomy and function of cardiac structures derived from the structured sequential echocardiography examination (e.g., atria and inter-atrial septum, superior vena cava, left ventricle, right ventricle, valves, pericardium, aorta, pleura, pulmonary artery)
   b. Relevant quantitative and qualitative measurements (e.g., stroke volume, chamber dimensions, filling pressures, transvalvular and chamber pressures, M-mode-derived values)
8) Conclusions
   a. Summary of the relevant findings
   b. Answer to the reason for the study
   c. Changes in study results referenced to previous studies
   d. Recommendations regarding treatment based upon study results and clinical condition of the patient

The report should be designed to be placed in the patient record

the study report are summarized in Table 7. If the learner is judged not to be competent following 35 studies, the expert faculty may require further training in image acquisition. A validated scoring system for assessment of competence in hemodynamic monitoring using TEE is proposed in Table 8. Examinations performed with miniaturized TEE probes are not counted in the requirement for 35 full TEE studies. These probes have limited imaging capabilities compared to standard TEE probes, so they cannot be considered as counting for training in advanced CCE.

4. Both TTE and TEE simulators may be used in order to facilitate skill acquisition, particularly at the beginning of training. Studies performed on simulators are not taken into account in the 100 TTE and 35 TEE required for qualification.
5. The expert faculty is responsible for the design and implementation of the local training program. Methods of training for the cognitive base include case-based teaching, internet-based methods, formal conferences, study of articles and textbooks, and attendance at organized courses. If training faculty chooses to design a course in advanced CCE that is required of all learners, the suggested duration of the course time is approximately 40 h. As there is considerable overlap in the knowledge base required for cardiology and advanced CCE, modern textbooks on echocardiography for cardiologists are an excellent resource for the intensivist learner for some part of the cognitive base. Many of these textbooks have useful image files that can be retrieved from an online repository in coordination with the text content. The learner should have full mastery of standard cardiology textbook content with the exception of chapters related to complex congenital heart disease and stress echocardiography. However, standard cardiology textbooks do not cover many topics that are part of advanced CCE. For this part of the cognitive base, the learner must access articles and the few textbooks on the subject that are currently available. A comprehensive list of key articles that are relevant to training in advanced CCE is given in an online supplement.

Table 8 Proposed scoring system to test competency in TEE hemodynamic evaluation in mechanically ventilated patients. From [5]

Qualitative data collection				Score
Introduction of the probe	No	Problematic	Yes	/2
ME four-chamber view	Not recorded	Not optimal	Optimal	/2
ME aortic valve long-axis view	Not recorded	Not optimal	Optimal	/2
TG mid papillary short-axis view	Not recorded	Not optimal	Optimal	/2
TG long-axis view (LVOT)	Not recorded	Not optimal	Optimal	/2
Great vessels view 0° (SVC)	Not recorded	Not optimal	Optimal	/2
Great vessels view 90° (SVC)	Not recorded	Not optimal	Optimal	/2
			Total	/14
Semiquantitative data collection				
Mitral regurgitation	None	Moderate	Marked to massive	/2
Aortic regurgitation	None	Moderate	Marked to massive	/2
Dilatation of right ventricle	None	Moderate	Marked	/2
Pericardial effusion	None	Noncompressive	Compressive	/2
Variation in diameter of superior vena cava	None	Minimal	Large	/2
			Total	/10
Quantitative data collection				
	Intensivist		Expert	
E/A ratio				/2
LV FAC (%)				/2
Aortic VTI (cm)				/2
Pulmonary VTI (cm)				/2
			Total	/8
Conclusions				
LV contractility	Normal	Moderately decreased	Greatly decreased	/2
Hypovolemia	No		Yes	/2
RV failure	No		Yes	/2
Treatment proposed	Wrong or incomplete		Right	/2
			Total	/8
Final score/42*				

For views acquisition, grade was zero if the view is not obtained, 1 if obtained but suboptimal, and 2 if optimal. For semiquantitative evaluation part, score was maximal in case of agreement between trainee and expert, zero in case of major disagreement (e.g., no RV dilatation for trainee versus dilatation for expert whatever its importance), 1 in case of slight disagreement (e.g., moderate RV dilatation for the trainee versus marked for the expert). For quantitative data collection, score was graded as 2 if difference between trainee and expert is <10 %, 1 if between 10 and 20 %, and zero if >20 %. In all cases, score was zero if the measurement is not done at end-expiration. *Two "extra points" were scored if the examination is done in <10 min since the introduction of the probe. For more details, see Charron et al. [5]

ME mid esophageal, *TG* transgastric, *SVC* superior vena cava, *LVOT* left ventricular outflow track, *FAC* fractional area contraction, *LV* left ventricle, *RV* right ventricle, *VTI* velocity–time integral

6. Training in image interpretation requires that the learner reviews a large number of studies. Some proportion of image interpretation training must occur under the direct supervision of an expert reader. Although there are many ways of accomplishing this, initially partnership with the cardiology service where the learner spends time in a cardiology reading room reviewing a large number of studies may prove useful. It is not reasonable to expect that each learner will encounter all important abnormal findings either in the reading room or during their image acquisition training. Therefore, a comprehensive panel of abnormal images with their clinical scenarios must be reviewed with supervisory faculty. Abnormal images and their clinical scenarios may be presented in interactive lecture format or through internet-based methods and should include both TTE and TEE cases. There is no specific requirement for number of images that need to be reviewed, beyond that the number should exceed many hundreds.

Part D: training is designed to result in competence. How is it determined that training has resulted in competence?

Competence is the combination of knowledge, skills, and behavior required to perform a specific function in an adequate and well-qualified manner. As this document is focused on developing explicit recommendations regarding training in advanced CCE, defining competency is important.

There are two general approaches to determine whether a learner has achieved competence in advanced CCE. One method is that the learner acquires skill at image acquisition, image interpretation, and cognitive knowledge of the field under the supervision of knowledgeable faculty within the context of residency or fellowship training or as an attending physician if there is local faculty support in their hospital. This approach may include a requirement that there be a certain number of image sets performed and interpreted, and may include some formal course work. After some amount of training, the learner is designated by their trainers as being competent to perform advanced CCE. The advantage of this method is its informality and simplicity of administration. As a credit to its efficacy, a generation of advanced critical care echocardiographers has been trained in this way. The disadvantages of this method are that there is no formal assessment of skill that encompasses the key components of competence: image acquisition, image interpretation, and cognitive base, there is an intrinsic conflict of interest when the trainer is responsible for final assessment of competence, and it may be difficult to assure the competence of the trainer.

The alternative approach to determine whether a learner has achieved competence is to require competency-based testing at the end of the training period. With this method, the training program follows the specific requirements that have been presented in this document regarding image acquisition, image interpretation, and cognitive base. The expert panel members recognize that methods of training in advanced CCE will differ to some extent between countries. However, at the end of training, the learner should undergo formal evaluation of their skill with a summative test of skill. If they have fulfilled the training requirements and performed adequately on the comprehensive test, they are recognized as being competent. We recommend that formal assessment of competence should be a required component of training in advanced CCE.

Requirements for competency based testing

1. At the completion of training, the learner must successfully complete and pass an examination that includes assessment of image acquisition, image interpretation, and cognitive base for advanced CCE in order to be deemed competent. No candidate may take the examination until they fulfilled all parts of training as described in this statement. This includes a formal statement by the expert faculty that the candidate has successfully completed training.
2. Determination of skill at image acquisition is the responsibility of local expert faculty. Design of the structured training program includes the responsibility to develop summative competence-based testing of skill at image acquisition. This may include testing of image acquisition using a simulator, especially for TEE. Testing of image interpretation and cognitive elements should be standardized at the national level or international level by national bodies or critical care societies, and use secure computer-based testing methods that are typical of board-style examinations. The results of the examination may be incorporated into a formal national level certification process, as recommended in the Vienna statement [2].
3. Completion of training and competency-based testing designates the intensivist as being competent in advanced CCE as a clinical skill. This designation is binary, and implies no hierarchy of competence.

Conclusion

This international expert statement on training standards for advanced CCE serves to provide guidance to faculty and learners who are engaged in advanced CCE training. The document establishes specific requirements to guide expert faculty who are tasked with the development of structured training programs that provide mastery of image acquisition, image interpretation, and the cognitive base. In the future, it should be adapted by national authorities or critical care medicine societies to establish their own certification process according to specific national requirements.

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Appendix: colleges and societies involved in the statement with their representatives

- European Society of Intensive Care Medicine (ESICM): Drs. Philippe Vignon, Frances Colreavy, Jean-Luc Canivet, Daniel De Backer, Bernard Cholley. Dr. Maggiorini represented the educational and training committee of the ESICM.
- American College of Chest Physicians (ACCP): Drs. Paul Mayo, Seth Koenig.
- American Thoracic Society (ATS): Drs. Michael Pinsky, Antoine Vieillard-Baron.
- French Society of Intensive Care Medicine (SRLF): Dr. Michel Slama.
- Hong Kong College of Anaesthesiologists (Board of Intensive Care): Dr. Gordon Choi
- Hong Kong Society of Critical Care Medicine: Dr. Gordon Choi.
- Asia Pacific Association of Critical Care Medicine (APACCM): Drs. Anthony McLean, Gordon Choi.

- Canadian Critical Care Society: Drs. Yanick Beaulieu, Rob Arntfield.
- College of Intensive Care Medicine of Australian and New Zealand: Drs. Anthony McLean, Gordon Choi.

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