Guidelines for the Appropriate Use of Bedside General and Cardiac Ultrasonography in the Evaluation of Critically Ill Patients—Part II: Cardiac Ultrasonography

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Dr. Blaivas disclosed a relationship with healthcare product makers (GE and Analogic consultant), healthcare service providers (Sonosim consultant), and participation in other healthcare professional organizations (AIUM and ACEP member). Dr. Kirkpatrick disclosed a relationship with healthcare products makers, a relationship with healthcare service providers, and having received grant funding (he consulted for the Innovative Trauma Care, Acelity, and LifeCell Corporations. He consulted for the Canadian Space Agency and serves in a Reserve Force Capacity in the Canadian Forces Medical Services. The Acelity Corporation sponsored an RCT on Open Abdomen Management that he was the PI on). He disclosed other healthcare professional organization activities (he is on the Executive and Scientific Advisory Committees of the World International Network Focused on Critical Ultrasound and is the President of the Abdominal Compartment Society). Dr. Slonim disclosed a relationship with healthcare services providers (healthcare consultant on healthcare reform for pharma) and participation in other healthcare professional organizations (AAPL Board of Directors). Dr. Price disclosed other healthcare professional organization activities (European Society of Cardiology [committee member for Press, Education, CPC, MQC professional standards, chair of Acute Cardiac Care Association] and the Resuscitation Council UK [chair of FEEL committee, member of ALS subcommittee]). Dr. McLaughlin disclosed a relationship with a maker of healthcare products (Stockholder Pfizer). Dr. Elbarbary disclosed other healthcare professional organization activities (Winfocus organization [member of Board of Directors and chairman of Guideline committee]). The remaining authors have disclosed that they do not have any potential conflicts of interest.

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Objective: To establish evidence-based guidelines for the use of bedside cardiac ultrasound, echocardiography, in the ICU and equivalent care sites.

Methods: Grading of Recommendations, Assessment, Development and Evaluation system was used to rank the "levels" of quality of evidence into high (A), moderate (B), or low (C) and to determine the "strength" of recommendations as either strong (strength class 1) or conditional/weak (strength class 2), thus generating six "grades" of recommendations (1A–1B–1C–2A–2B–2C). Grading of Recommendations, Assessment, Development and Evaluation was used for all questions with clinically relevant outcomes. RAND Appropriateness Method, incorporating the modified Delphi technique, was used in formulating recommendations related to terminology or definitions or in those based purely on expert consensus. The process was conducted by teleconference and electronic-based discussion, following clear rules for establishing consensus and agreement/disagreement. Individual panel members provided full disclosure and were judged to be free of any commercial bias.

Results: Forty-five statements were considered. Among these statements, six did not achieve agreement based on RAND appropriateness method rules (majority of at least 70%). Fifteen statements were approved as conditional recommendations (strength class 2). The rest (24 statements) were approved as strong recommendations (strength class 1). Each recommendation was also linked to its level of quality of evidence and the required level of echo expertise of the intensivist. Key recommendations, listed by category, included the use of cardiac ultrasonography to assess preload responsiveness in mechanically ventilated (1B) patients, left ventricular (LV) systolic (1C) and diastolic (2C) function, acute cor pulmonale (ACP) (1C), pulmonary hypertension (1B), symptomatic pulmonary embolism (PE) (1C), right ventricular (RV) infarct (1C), the efficacy of fluid resuscitation (1C) and inotropic therapy (2C), presence of RV dysfunction (2C) in septic shock, the reason for cardiac arrest to assist in cardiopulmonary resuscitation (1B–2C depending on rhythm), status in acute coronary syndromes (ACS) (1C), the presence of pericardial effusion (1C), cardiac tamponade (1B), valvular dysfunction (1C), endocarditis in native (2C) or mechanical valves (1B), great vessel disease and injury (2C), penetrating chest trauma (1C) and for use of contrast (1B–2C depending on indication). Finally, several recommendations were made regarding the use of bedside cardiac ultrasound in pediatric patients ranging from 1B for preload responsiveness to no recommendation for RV dysfunction.

Conclusions: There was strong agreement among a large cohort of international experts regarding several class 1 recommendations for the use of bedside cardiac ultrasound, echocardiography, in the ICU. Evidence-based recommendations regarding the appropriate use of this technology are a step toward improving patient outcomes in relevant patients and guiding appropriate integration of ultrasound into critical care practice. (*Crit Care Med* 2016; 44:1206–1227)

Key Words: echocardiography; evidence-based medicine; Grading of Recommendation, Assessment, Development and Evaluation criteria; guidelines; RAND Appropriateness Method; sonography; ultrasound

Although a number of technologies including pulse contour analysis (1), transpulmonary thermodilution (2), and bioreactance (3) have shown promise in evaluation of critically ill patients, bedside cardiac ultrasound (BCU) is an established technique to evaluate cardiac function. BCU evaluation in the ICU is undertaken by a healthcare provider who serves as both the operator performing the study and the interpreter of the images captured in the context of their clinical significance. The purpose of the ultrasound evaluation is to obtain diagnostic information relevant to the immediate care of the critically ill patient in real time. BCU may also be used to reevaluate a patient after a significant change in condition or therapeutic intervention.

Those who perform BCU can have varying levels of expertise and training, which is why the present recommendations are both broad and tiered. The two-tiered levels of expertise (basic and expert) generally parallel American College of Cardiology/American Heart Association conventions but with different prerequisites as appropriate for the scope and skills necessary for the BCU. We have omitted the intermediate level of expertise when compared with American Heart Association (AHA)/American College of Cardiology (echocardiography, 1–3) (4). A basic level can be achieved by noncardiologists after a 12-hour training program (blending didactics, interactive clinical cases, and tutored hands-on sessions) that has been shown to provide students with the BCU skills capable of improving patient care (5–9). This basic skill set will allow the provider to recognize the presence of pericardial effusion, severe right and LV failure, regional wall motion abnormalities (signifying coronary artery disease [CAD]), gross anatomical valvular abnormalities, and assess the size and collapsibility of the inferior vena cava (IVC).

In addition to these basic skills, the expert level physician is expected to competently utilize transthoracic and transesophageal echocardiography (TEE) techniques. Similarly, American College of Chest Physicians/La Société de Réanimation de Langue Française Statement on Competence in Critical Care Ultrasonography divides echocardiography skills into two competency levels: basic and advanced (10). BCU is performed as a goal-directed examination using transthoracic echocardiography (TTE) or TEE 2D imaging to identify specific findings and to answer focused clinical questions. ICU providers may readily achieve competence in basic BCU. Competence in advanced BCU 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 BCU requires a high level of skill in all aspects of image acquisition and interpretation. When compared with basic BCU, advanced-level competence requires far more extensive training and experience. We, however, believe that TEE is beyond the basic skill level of an average North American intensivist and recommend that TEE is performed by only those with advanced-level training. Exceptions to this may be anesthesiology-trained intensivists (particularly cardiac anesthesia-based intensivists) and European intensivists with advanced echocardiography training. TEE requires dedicated training and competency that can be achieved through specific training programs (11). In progression from basic to advanced skill level, practitioners will obtain intermediate levels of expertise that are not easily definable. For that reason, the workgroup decided not to define an intermediate level of expertise.

This document also provides recommendations regarding the use of cardiac sonography in adult and pediatric patients. For the latter, these recommendations refer to usage in neonates, infants, and older children, unless otherwise specified.

The committee that authored these guidelines was tasked by the Society of Critical Care Medicine to use evidence-based medicine to create a document to assist providers in determining the optimal use of BCU in ICU patients. The committee representation is multiprofessional and multidisciplinary and most, but not all, members personally perform BCU in a clinical setting.

It is anticipated that BCU will continue to expand and evolve as more practitioners become competent with this technology and utilize it as a tool to care for their patients. Many professional societies including the Society of Critical Care Medicine offer programs for physicians who desire training in BCU. These programs are in a state of flux to accommodate both evolving technology and the changing needs of practicing intensivists. Emergence of new technologies such as minimally invasive TEE and automatic assessment of cardiac output may enable those with lower levels of expertise to utilize more sophisticated parameters. The workgroup was composed entirely of physicians proficient in the use of ultrasound, thus, its view point may not be shared by novice or nonusers of the technology. We believe, however, that the unprecedented expansion of bedside ultrasonography as a bedside tool will increase the number of clinicians utilizing this technology who might benefit from these guidelines. These guidelines are not intended to endorse a specific type of BCU—complete or focused—nor the use of specific ultrasound systems—portable versus full sized. Instead, these guidelines attempt to provide the rationale for intensivists with different levels of expertise and training to perform bedside examination or to seek expert consultation and guidance.

METHODS

Disclosures

There were no members of the committee from industry nor was there industry input into the development of the guidelines or industry presence at any meetings. No member of the guideline committee received honoraria for participation. Full disclosure of all committee members' potential conflicts of interest at the time of deliberation and publication was provided.

Approach

There were two plenary sessions of the writing committee group leaders to establish the content. Then, the guidelines process followed combined Grading of Recommendations, Assessment, Development and Evaluation (GRADE) and RAND appropriateness methodology (RAM). RAM included the modified Delphi method, multiple teleconferences, and several subsequent meetings (including electronically) of subgroups.

Scientific Questions

Clinical questions related to the use of BCU for cardiac diagnoses were established by the writing group for subsequent discussion, grading of evidence by a methodologist, and then voting on the overall appropriateness of the recommendation.

Systematic Evidence Search

A thorough systematic evidence search was done for each question. This included English and translated literature. Literature related to the use of ultrasound in the ICU setting was the primary focus. If high-quality evidence was present (i.e., randomized controlled trials with large number of patients and no significant downgrading factors), then lower level evidence (i.e., case series) was not included. If no appropriate literature with ICU patients was available, that involving patients in all other appropriate areas such as the emergency department was considered, if patients were considered equivalent. After the comprehensive literature search, the methodologist performed a secondary search, and additional relevant articles were included as appropriate. Literature support for individual questions was reviewed by a minimum of two members of the committee in addition to the methodologist.

Expert Panel Formulation

Members were selected to represent the different constituencies of the Society of Critical Care Medicine—i.e., surgical, medical, pediatric, and anesthesia intensivists. A methodologist and intensivist (M.E.) supported the group.

Development of Consensus and Clinical Recommendations

Multiple electronic and teleconferencing discussions and meetings occurred among subgroup members to generate the draft recommendations (statements) presented. GRADE methodology was used to develop these evidence-based recommendations (12). The process involves two phases: determining the level of quality of evidence (phase I) and developing the recommendation (phase II). Relevant articles with clinical outcomes were classified into three levels of quality (A–B–C) based on the criteria of the GRADE methodology (**Tables 1** and **2**). RAM was used within the GRADE steps that required panel judgment and decisions/consensus. RAM was also used in formulating the recommendations based purely on experts' consensus. Recommendation strength was assigned to one of two classes: strong (strength class 1) or weak/conditional (strength class 2) based on the GRADE criteria. The implication of a strong versus conditional recommendation is described in **Table 3**.

The transformation of evidence into a recommendation depends on the panel evaluation of several factors referred to as "evidence-to-recommendation or evidence-to decision factors" as listed in section C of Table 2 as the "5 transformers." Among these factors are the quality of evidence level, outcome/problem importance, balance of benefit to burden and benefit to harm, and degree of certainty about feasibility, accessibility, equity, and the expected similarity in values/preferences across an average patient population. The voting on the five transformers and on the total appropriateness of the statement (draft recommendation) was done using nine-points Likert's scale, where one denotes extremely inappropriate and nine extremely appropriate. The scale has three zones: 1–3 inappropriate zone, 4–6 uncertain zone, and 7–9 appropriate zone. The

TABLE 1. Levels of Quality of Evidence: Grading of Recommendations, Assessment, Development and Evaluation Methodology

Level[a]	Points[b]	Quality	Interpretation
A	≥ 4	High	Further research is very unlikely to change our confidence in the estimate of effect or accuracy
B	= 3	Moderate	Further research is likely to have an important impact on our confidence in the estimate of effect or accuracy and may change the estimate
C	≤ 2	Low[a]	Further research is very likely to have an important impact on our confidence in the estimate of effect or accuracy and is likely to change the estimate....................or any estimate of effect or accuracy is very uncertain (very low)

[a]Level C = can be divided into low (points = 2) and very low (points = ≤ 1).

[b]Points are calculated based on the nine–Grading of Recommendations, Assessment, Development and Evaluation quality factors (Table 3).

TABLE 2. The 15-Grading of Recommendations, Assessment, Development and Evaluation Factors

Section A: factor 1 outcome factor	Critical	Important	Less important	Not important
Section B: factors 2–10 The nine-GRADE quality factors	Study design as quality starting factor[a]	Quality of evidence	The five downgraders Quality is lowered if	The three upgraders Quality is raised if
	Randomized controlled trial = 4	A = High = Four points B = Moderate = Three points	Risk of bias[b] −1 Serious −2 Very serious Inconsistency −1 Serious −2 Very serious	Large effect +1 Large +2 Very large Dose response +1 Evidence of a gradient
	Observational studies = 2	C = Low[c] = Two points D = Very low[c] = One point	Indirectness −1 Serious −2 Very serious Imprecision −1 Serious −2 Very serious Imprecision −1 Serious −2 Very serious Publication bias −1 Likely −2 Very likely	Antagonistic bias +1 All plausible confounding would reduce the effect, or +1 Would suggest a spurious effect when results show no effect
	Total points			
Section C: factors 11–15 The five-GRADE transformers[d]	Problem priority/importance Overall quality of evidence Benefit/harm balance Benefit/burden balance Certainty/concerns about preference-equity-acceptability-feasibility	Critical High Favorable Favorable Certain	Important Moderate Uncertain Uncertain Uncertain	Less important Low Unfavorable Unfavorable Concerned

GRADE = Grading of Recommendations, Assessment, Development and Evaluation.

[a]Based on the design, the evidence will qualify for four points (if randomized controlled trial) or two points (if observational) and then points will move down by one or two points (by downgraders) or up (by upgraders) if applicable as indicated in the table.

[b]Risk of bias in diagnostic accuracy studies using QUADAS-2 (216) criteria while in diagnostic strategies effectiveness the risk of bias to be assessed using Cochrane criteria.

[c]Low and very low levels of quality of evidence can be combined in one level (if total points ≤ 2).

[d]The voting on the five transformers (from evidence-to-recommendation) and the voting on appropriateness of the draft recommendations to be done using nine-point Likert's scale. More details in *Methods* section and Appendix.

TABLE 3. Implications of the Strong and Weak Recommendations in the Grading of Recommendations, Assessment, Development and Evaluation Method

User	Strong Recommendations	Weak (Conditional) Recommendations
Clinicians	Most patients should be offered to receive the recommendation as the most appropriate option	Recognize that different options should be offered as all will be appropriate options for different patients
Policy makers	The recommendation can be adopted as a policy in most situations	Should not be considered as a standard of care
Patient	Most patients in similar condition would accept the recommendation and only a few would not	Expected variability among different patients with your condition to choose or reject the recommendations

voting results are then interpreted based on preset rules that defined the panel consensus/agreement and its degree (**Fig. 1**). RAM helps to generate the strength of recommendations in a well-structured statistically analyzable methodology for panel voting/decisions. The GRADE methodology (with or without RAM) ultimately creates six "grades" of recommendations (1A–1B–1C–2A–2B–2C). The explanation and implication of each of the six grades is well described in a table format freely accessible on the internet (http://www.uptodate.com/home/grading-guide).

A strong recommendation is worded as "we recommend," whereas a conditional/weak recommendation as "we suggest" (**Table 4**). The list of the most relevant literature references is provided for each recommendation and is limited to no more than 10 articles. Differences in opinion were resolved using a set of rules previously described in development of the Surviving Sepsis guidelines (13). Recommendations rendered required more than 70% of the committee to be in support. Strong recommendations required at least an 80% majority following the previously validated RAND algorithm as shown in Figure 1 (14).

Guidelines are based on the notion that any bedside ultrasound information is complimentary to the physical examination and intensivist clinical judgment and therefore organized around most common suspected ICU diagnoses. Repeat examinations are predicated on significance of the change in patient condition or to follow the outcome of a therapeutic intervention.

RESULTS

Fourteen domains containing 45 statements (draft recommendations) were considered. Among these statements, six did not achieve agreement based on RAM rules (majority of at least 70%). Fifteen statements were approved as conditional recommendations (strength class 2). The rest (24 statements) were approved as strong recommendations (strength class 1). Each recommendation was also linked to its level of quality of evidence and to the required level of echocardiography expertise of the intensivist. These results are summarized in **Table 5**. **Table 6** shows a detailed statistical analysis of two recommendations as an example of applying the agreement/disagreement rules and degree of consensus based on the median score and the dispersion of voting around the median. **Table 7** is an example of the summary of findings (SoF) tables. The remainder of the SoF tables can be found in the **digital supplement** (Supplemental Digital Content 1, http://links.lww.com/CCM/B909). The detailed explanation of the domains and subdomains, the recommendations, their GRADE, required expertise, and rationales are fully listed below.

Preload Responsiveness

In Mechanically Ventilated Patients About to Undergo Fluid Resuscitation (Recommended for All Levels of Training).

- We recommend critical care practitioners consider measuring IVC collapsibility in patients on positive pressure ventilation by BCU to assess fluid responsiveness prior to undergoing large volume fluid resuscitation. Any patient who has more than 15% change in vena caval diameter should be considered preload responsive. Patients with a smaller change in IVC diameter may not respond favorably to fluid resuscitation. **Grade 1B**
- *Rationale*: Recent data have suggested that central venous pressure (CVP) does not correlate with fluid responsiveness (27, 28). In addition, overly aggressive crystalloid-based resuscitation may result in untoward outcomes (29). Echocardiographic functional or dynamic assessments of fluid responsiveness can be performed on the venous or arterial side. Venous measures include superior and IVC collapsibility. Various studies have examined the relationship between changes in IVC diameter during respiration and fluid responsiveness. A cutoff value of 15% change in IVC diameter between inspiration and expiration in mechanically ventilated patients was found to accurately separate responders and nonresponders (27, 30–32). However, several limitations of this method should be noted. Among these limitations, the standardization and measurement technique specifically the distance distal to hepatic veins (1–2 cm) and the movement of point of measurement during lung inflation can be overlooked when using M-mode. Using cine-loop and manually measuring a fixed anatomical point may overcome this common mistake. RV function and RV to LV coupling are presumed to be normal. Patients should be ventilated in a flow-limited (volume-control) mode with 8 mL/kg ideal body weight tidal volume and

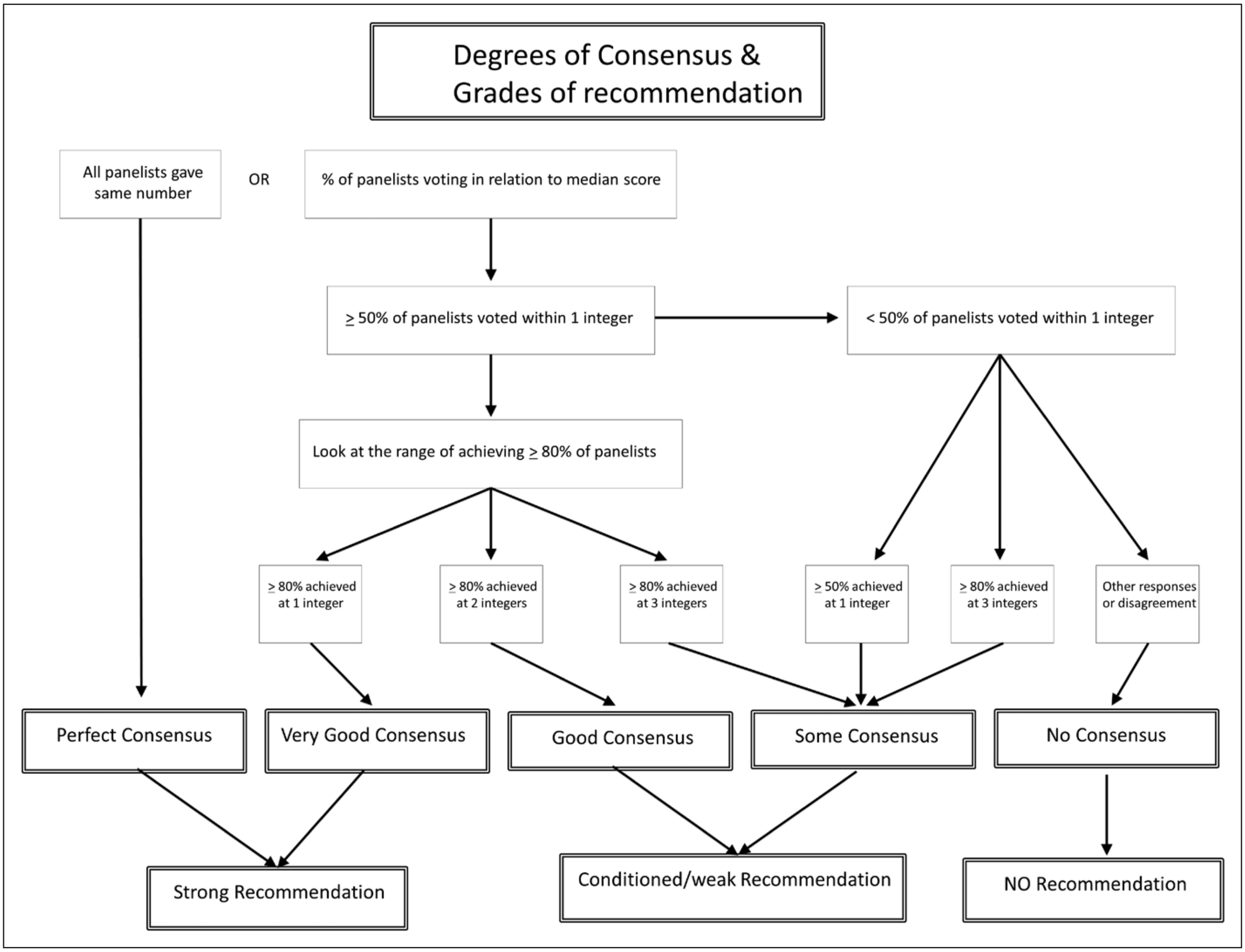

Figure 1. RAND algorithm.

not display ventilator dyssynchrony. Simultaneous assessment of LV end-diastolic diameter and RV function while the patient is in sinus rhythm and echocardiographic and clinical reassessment after the intervention is strongly encouraged (33).

There are less data on functional arterial side measurements using echocardiography to predict fluid responsiveness in ventilated patients although the assessment of stroke volume variation by velocity time integral (VTI) methodology, described below, is not complicated. However, operator error particularly in selecting VTI sample site can significantly alter calculations.

In Spontaneously Breathing Patients About to Undergo Fluid Resuscitation.

In Patients With Intra-Abdominal Hypertension About to Undergo Fluid Resuscitation.

- We make no recommendation regarding the method of assessment of fluid responsiveness either by IVC diameter and collapsibility or other methods to assist with shock resuscitation of the spontaneously breathing patient.
- We make no recommendation regarding the method of assessment of fluid responsiveness in those with abdominal compartment syndrome.
- *Rationale*: Making no recommendation does not mean that functional assessment of fluid responsiveness in spontaneously breathing patients is without merit, rather the group could not come to consensus regarding the appropriate methodology. Furthermore, as large recent clinical trials emphasize, resuscitation targeted to established endpoints, whether echocardiographic, should not be a substitute for sound clinical judgment (34, 35). Taking the time to determine fluid responsiveness by echocardiographic measures in a patient with obvious clinical signs and symptoms of hypovolemia may be detrimental. However, determining volume status and responsiveness is a daunting clinical task in most critically ill and the dangers of overresuscitation, including increased mortality, are real. To be sure, the panel recognized the substantial data underscoring the inability of static measures of volume status to predict fluid responsiveness (36–45).

TABLE 4. Wording Based on Degree of Consensus and Grading of Recommendations, Assessment, Development and Evaluation of Recommendations

Degree of Consensus	Grading of Recommendations, Assessment, Development and Evaluation of Recommendation	Wording
Perfect consensus	Strong	Recommend: must/to be/will
Very good consensus	Strong	Recommend: should be/can
Good consensus	Conditioned/weak	Suggest: may be/may
Some consensus	Conditioned/weak	Suggest: might be
No consensus	No	No recommendation was made regarding

It is difficult to assess volume status in the spontaneously breathing patient; however, the passive leg raise has been validated in many studies. This technique quickly mobilizes approximately 300 mL of blood from the lower extremities to the thorax increasing preload without changing the patient's intravascular volume. An increase in stroke volume (as assessed by the VTI multiplied by the aortic cross-sectional area) of more than 12% during passive leg raise was found to be highly predictive of fluid responsiveness (36–45). Finally, passive leg raising was unable to predict fluid responsiveness in patients with intra-abdominal hypertension and IVC collapsibility was also of limited use (46).

In Patients Unable to Obtain Adequate Images With TTE (Recommended for Expert Levels of Training).

- We recommend that TEE presents a reliable, low-risk, and timely solution to help the practitioner evaluate a patient's preload responsiveness when TTE cannot be performed. **Grade 1C**
- *Rationale:* Various authors have examined the usefulness of TEE in predicting fluid responsiveness. Respiratory changes in diameter of the IVC, SVC, and LV stroke area measured by TEE can help predict fluid responsiveness (33, 47, 48). The limitation of TEE is that it requires additional training, presents additional risks, and is more time consuming than TTE. Finally, TEE transducers can add considerable expense to a point-of-care ultrasound budget.

Assessment of the LV Function

Assessment of LV Systolic Function (Recommended for All Levels).

- We recommend that assessment of LV systolic function should be attempted in all patients with either preexistent or ICU-acquired cardiac disease to better understand limitations of fluid resuscitation and choice of inotropic and vasoactive medications. **Grade 1C**
- *Rationale:* Up to one-third of all critically ill patients have reduced LV systolic function during their ICU stay (49). In the past, systolic function and particularly assessment of LV ejection fraction (LVEF) was overstated at the expense of diastolic function and fluid responsiveness. However, LVEF assessment is still an important part of the point-of-care cardiac evaluation. Assessment of LV systolic function and its changes over time are helpful in therapeutic decision making for the critically ill patient.

The most important and commonly used method of assessing LV global and focal wall motion is by a qualitative assessment in multiple views. This method is extremely effective, rapid, and consistent with quantitative echocardiographic assessment and nuclear scanning studies. It can be used by a bedside operator with basic training. Alternatively, the American Society of Echocardiography recommends the volumetric-modified Simpson's method (50). This method calculates end-systolic volume, end-diastolic volume, stroke volume, and EF in two planes (apical four- and two-chamber views) and averages them. This method is well suited for experienced (advanced level) operators and nonemergent situations (50, 51).

Assessment of LV Diastolic Function (Suggested for an Expert Level).

- We suggest that assessment of LV diastolic function may be considered in all patients with either preexistent or ICU-acquired cardiac disease to better understand limitations of fluid resuscitation and choice of inotropic and vasoactive medications. **Grade 2C**
- *Rationale*: Some reports indicate that no less than 23% of critically ill have pure LV diastolic dysfunction during their stay in the ICU. In addition to that, more than 40% of all ICU patients may have both systolic and diastolic dysfunction present (49). In critical care practice, the assessment of left heart filling pressures has clinical utility, as an elevated left atrial (LA) pressure is associated with cardiogenic or hydrostatic pulmonary edema. As these measurements require skill with Doppler, the intensivist with skill at advanced critical care ultrasound can identify and grade diastolic function using standard techniques in cardiac echocardiography (52, 53).

RV Dysfunction

ACP (Recommended for All Levels of Training).

- We recommend that BCU be used to evaluate for signs of acute RV failure due to pressure or volume overload. **Grade 1C**

TABLE 5. Summary of Recommendations

Topic	Overall Grade	Level of Training	Strength of Recommendation	Degree of Consensus	Level of Evidence
Preload responsiveness, ventilated	1B	Basic	Strong	Very good	B
Preload responsiveness, not ventilated	NA	NA	NA	NA	
Preload responsiveness with intra-abdominal hypertension	NA	NA	NA	NA	
Supplemental TEE	1C	Advanced	Strong	Very good	C
Left ventricular systolic function	1C	Basic	Strong	Very good	C
Left ventricular diastolic dysfunction	2C	Advanced	Conditional	Good	C
Acute cor pulmonale	1C	Basic	Strong	Very good	C
Pulmonary hypertension	1B	Advanced	Strong	Very good	B
Use of tricuspic annular plane systolic excursion	NA	NA	NA	NA	
Symptomatic pulmonary embolism	1C	Basic	Strong	Very good	C
Right ventricular infarct	1C	Basic	Strong	Very good	C
Sepsis resuscitation	1C	Basic	Strong	Very good	C
Left ventricular dysfunction, sepsis	2C	Basic	Conditional	Good	C
Right ventricular dysfunction, spesis	2C	Basic	Conditional	Good	C
Asystole	2C	Basic	Conditional	Good	C
Pulseless electrical activity	2C	Basic	Conditional	Good	C
Ventricular tachycardia/fibrillation	1B	Basic	Strong	Very good	B
Use of TEE in cardiac arrest	2C	Basic	Conditional	Good	C
Acute coronary syndrome	1C	Advanced	Strong	Very good	C
Cardiac tamponade	1B	Basic	Strong	Very good	B
Pericardial effusion	1C	Basic	Strong	Very good	C
Shock, undifferentiated	1B	Basic	Strong	Very good	B
Native valvular dysfunction	1C	Basic	Strong	Very good	C
Mechanical valvular dysfunction	1C	Basic	Strong	Very good	C
Endocarditis	2C	Advanced	Conditional	Good	C
Prosthetic valve endocarditis	1B	Basic	Strong	Very good	B
Great vessel pathology	2C	Advanced	Conditional	Good	C
Blunt chest trauma, when no CT	2C	Advanced	Conditional	Good	C
Blunt chest trauma	2C	Advanced	Conditional	Good	C
Blunt chest trauma for pericardium	1B	Basic	Strong	Very good	B
Penetrating chest trauma	1C	Basic	Strong	Very good	C
TEE	1B	Advanced	Strong	Very good	B
Right ventricular contrast	2C	Advanced	Conditional	Good	C
Left ventricular contrast	1C	Advanced	Strong	Very good	C
Hepatopulmonary syndrome diagnosis	1C	Advanced	Strong	Very good	C
Pediatric reversible causes of cardiac arrest	1B	Basic	Strong	Very good	B
Pediatric irreversible causes of cardiac arrest	1C	Basic	Strong	Very good	C
Pediatric preload responsiveness	1B	Basic	Strong	Very good	B

(*Continued*)

TABLE 5. (*Continued*). Summary of Recommendations

Topic	Overall Grade	Level of Training	Strength of Recommendation	Degree of Consensus	Level of Evidence
Pediatric cardiogenic shock	2C	Basic	Conditional	Good	C
Pediatric septic shock	NA	NA	NA	NA	
Pediatric patent ductus arteriosus	2C	Advanced	Conditional	Good	C
Congenital heart disease	2C	Advanced	Conditional	Good	C
Pediatric valvular dysfunction	2C	Advanced	Conditional	Good	C
Pediatric right ventricular dysfunction	NA	NA	NA	NA	
Use in extracorporeal membrane oxygenation	NA	NA	NA	NA	

TEE = transesophageal echocardiography.
NA is not applicable for those statements without recommendations due to lack of agreement.

TABLE 6. Example of Statistical Results of Voting for Two Recommendations

Main theme	S3	S19
No. of votes	11	11
Median of votes	4	8
Median value of votes for appropriateness, median [Q1/Q3]	4 [2.5/5.5]	8 [7.5/9]
Middle 50% interquartile range (Q3–Q1)	3	1.5
No. of votes outside the region of median, *n* (%)	5 (45.45)	2 (18.18)
No. of votes one point around the median	5	9
No. of votes two points around the median[a]	8	10
Number of votes three points around the median	10	11
Region of median (region of appropriateness where the median is situated)	Uncertain	Appropriate
Disagreement (yes if > 30% of votes are situated out of the region of median)	Yes	No
Degree of consensus (NA if > 30% of votes are situated out of the region of median)	NA	Very good
Grade of recommendation (null if any disagreement)	NA	Strong with
Details of votes		
Votes in inappropriate region (1–3)	4	0
Votes in undetermined region (4–6)	6	2
Votes in appropriate region (7–9)	1	9

S3 is the preload responsiveness in spontanenously breathing patients with intra-abdominal hypertension and S19 is the acute coronary syndrome. The table shows disagreement in one of these two recommendations: S3 (> 30% voters voted outside the region of the median). In the absence of disagreement-S19, the statistical results also reflect the degree of the agreement based on the dispersion of the voting around the median. Based on RAND algorithm (Fig. 1), this dispersion will determine the strength of recommendation and degree of consensus.

- *Rationale:* ACP is defined as the clinical setting in which the RV experiences a sudden increase in afterload. It has been shown that ACP in the ICU setting increases mortality and that BCU can help direct management to reduce related mortality (54, 55). BCU provides a rapid means of diagnosing RV failure, and it provides the critical care physician the ability to evaluate several types of associated conditions that may be accompanied by subtle clinical signs and symptoms (56). Systemic venous congestion that may induce ascites/effusion may be present. During systole, special attention should be paid to septal flattening, paradoxical motion, and dyskinesia, whereas during diastole, the ratio of RV end-diastolic area (EDA) should be compared with LV EDA (57).

***Pulmonary Hypertension (Recommended for Expert Level of Training)*.**

- We recommend that BCU should be used to measure pulmonary arterial pressures in all patients with suspected primary or secondary pulmonary hypertension provided that operator has the required training for this. **Grade 1B**
- *Rationale:* BCU allows the critical care physician not only to estimate pulmonary artery (PA) pressure but also to

TABLE 7. Summary of Finding Tables (Complete List is Available in the Digital Content [Supplemental Digital Content 1, http://links.lww.com/CCM/B909])

We Recommend That Bedside Cardiac Ultrasonography Should Be Performed to Diagnose Cardiac Tamponade and to Increase the Effectiveness and Safety of Pericardiocentesis and Guide Performance of the Procedure. Grade 1B (15–26)								
Quality Assessment							Summary of Findings	
							Study Result	
Twelve Studies)	Risk of Bias	Inconsistency	Indirectness	Imprecision	Publication Bias	Overall Quality of Evidence	Sensitivity (%)	Specificity (%)
Complications								
One randomized controlled trial, rest observational studies	Serious risk of bias	No serious inconsistency	No Indirectness	No Imprecision	Undetected	⊕⊕⊕⊖ Moderate	100	95

Summary of findings for recommendation regarding pericardial tamponade is presented in print. Observational studies consistently showed agreement between hand-held with comprehensive echocardiography ($\kappa > 0.85$). Studies done in emergency department was not considered as indirect as it is unlikely that this setting (emergency department) cause overestimation of diagnostic accuracy, but rather it may reduce it when compared with ICU (antagonistic bias).

evaluate valvular, primary myocardial and congenital causes of elevated right-sided pressures (56–60). It also helps the physician to prognosticate outcome as elevated PA pressures carry a significant short-term and long-term mortality risk (60). However, it should be noted that BCU allows only an estimation of PA pressures, and that there have been studies that question the accuracy of these measurements (61).

- We make no recommendation regarding the measurement of tricuspid annular plane systolic excursion (TAPSE) to assess RV motion in pulmonary hypertension, RV function, and to provide prognostic information.
- *Rationale:* RV function is an important determinant of prognosis in pulmonary hypertension. TAPSE may be a useful measure of RV function and may provide prognostic significance in pulmonary hypertension (61–63). However, the group could not reach consensus on whether this should be a component of a basic evaluation of the RV.

***Symptomatic PE (Recommended for All Levels of Training)*.**

- We recommend that in unstable patients with suspected PE, bedside cardiac ultrasonography and a venous examination of the proximal bilateral lower extremities, described in part 1 of the guidelines (64), should be considered prior to the consideration of CT. **Grade 1C**
- *Rationale:* Although the rates of symptomatic PE in the ICU have been shown to be low, PE carries a significant mortality and a high propensity for delayed treatment (65). Although less sensitive than other modalities, BCU is rapid and specific and reduces both delays in treatment and cost in diagnostic testing (66). In emergent cases involving patients with hemodynamic instability, the European Society of Cardiology recommends that therapy with thrombolysis may be justified on the basis of echocardiographic evidence if further testing would result in a delay of treatment (67). BCU and proximal lower extremity venous examinations were found to be useful in the diagnosis of suspected PE (68–71). Disproportionate sparing of the RV apex (McConnell's Sign) is considered by some to be highly suggestive of acute PE in the appropriate clinical setting (72). However, other etiologies such as RV infarct have been shown to have a similar echocardiographic pattern (73).

***RV Infarct (Recommended for All Levels of Training)*.**

- We recommend that any patient suspected of RV infarction should undergo BCU. **Grade 1C**
- *Rationale:* RV infarction as a cause of RV dysfunction is important to be detected early as it carries with it increased hospital mortality (74). BCU evaluation of RV to LV end-diastolic volumes (75), wall motion abnormalities especially in the subcostal short axes view (76), and intra-atrial septum bowing into the LA (77) are important findings for the diagnosis of RV infarction (78, 79). In the absence of an adequate subcostal short-axis view, an apical four-chamber view may be substituted.

Septic Shock

***Fluid Resuscitation in Sepsis (Recommended for All Levels of Training)*.**

- We recommend that BCU should be performed in patients with sepsis and septic shock to assess fluid responsiveness. **Grade 1C**
- *Rationale:* By the time most septic patients arrive in the ICU, one must decide whether to continue volume resuscitation or that the patient is adequately volume resuscitated. Fluid overload prolongs ICU stay in ARDS and has been shown to contribute to increased morbidity and mortality (80). BCU allows the critical care provider to guide volume resuscitation in both mechanically ventilated and spontaneously breathing patients (see *Preload Responsiveness* section) In fact, the National Quality Forum and Center for Medicare and Medicaid Services now assess compliance

with the sepsis resuscitation 6-hour bundle and have determined that echocardiographic assessment of fluid responsiveness is an acceptable tool.

LV Dysfunction in Sepsis (Suggested for All Levels of Training).

- We suggest that all patients admitted for sepsis may receive BCU to evaluate for signs of LV dysfunction to help guide inotropic therapy. **Grade 2C**
- *Rationale:* It is common for septic patients to develop either systolic or diastolic LV dysfunction (49, 81–91). ICU cardiomyopathy can be either nonspecific or present itself as an apical ballooning syndrome, Takutsobo cardiomyopathy. Either will usually resolve spontaneously as the patient's condition improves. Early recognition of LV dysfunction by BCU can help the critical care provider augment decreased cardiac output and stroke volume with inotropic support. Fluid resuscitation of the septic patient is an important component of the initial management. However, excessive fluid resuscitation in the presence of LV dysfunction is likely to aggravate adverse consequences.

RV Dysfunction in Sepsis (Suggested for All Levels of Training).

- We suggest that BCU may be performed to assess RV dysfunction in patients with sepsis to guide therapy. **Grade 2C**
- *Rationale:* There is growing evidence that RV dysfunction can occur in up to 30% of septic patients (92–94). Septic shock may cause RV dysfunction by both direct and indirect depressions of RV function. Early identification of acute RV dysfunction can help the intensivist manage fluids, inotropes, and vasopressor therapy in order to minimize dysfunction.

ACLS (Cardiopulmonary Resuscitation and Advanced Cardiac Life Support)

Electrocardiographic Asystole (Suggested for All Levels of Training).

- We suggest that BCU may be performed during asystole to guide further resuscitative efforts. **Grade 2C**
- *Rationale:* The American Heart Association (AHA) Advanced Cardiac Life Support (ACLS), and European Resuscitation Council and International Liaison Committee on Resuscitation guidelines emphasize detection and treatment of potentially reversible causes of pulseless cardiac arrest. These are referred to as the "six H's and T's" and include hypovolemia, hypoxia, hydrogen (acidosis), hypo/hyperkalemia, hypoglycemia, hypothermia, toxins, tamponade, tension pneumothorax, thrombosis (coronary or pulmonary), and trauma (95, 96). However, prior to detecting potential secondary etiologies and subsequent continuation of a "Pulseless Arrest" algorithm the correct diagnosis that a pulse is indeed absent needs to be made. However, this seemingly simple physical examination finding is often interpreted incorrectly when applied during the emergent evaluation of an arrested patient (97–99). Bedside echocardiography has been shown to be very useful at detecting whether true cardiac contractility is occurring (100, 101). Patients found to be in true cardiac standstill on BCU have a nearly 100% mortality rate (102, 103). This information may be important in deciding if continued resuscitative efforts are useful after oxygenation and other treatment modalities are optimized (104–106).

Pulseless Electrical Activity (Suggested for All Levels of Training).

- We suggest that BCU may be performed in patients with pulseless electrical activity (PEA) to diagnose PEA and to identify potential causes of PEA and to differentiate a pseudo-PEA state with wall motion. **Grade 2C**
- *Rationale:* PEA is a challenging diagnosis. The ability to diagnose it by palpation of the carotid artery has recently been disputed (107–109). The key issue is the description of "pulseless." BCU enables one to accurately diagnose true PEA arrest (107), evaluate for potential causes such as hypovolemia, pericardial effusion/tamponade, PE, and tension pneumothorax, and potentially make prognostic conclusions based on the presence of cardiac activity (108). There are different techniques that have been described to attain cardiac views during ACLS, which have minimal interruption of chest compressions. This is especially important as new AHA, ACLS, and ERC guidelines emphasize increased duration of and early use of high-quality chest compressions. Any approach to evaluate cardiac activity and function should not come at the cost of decreased chest compressions that are necessary to maintain end-organ perfusion and must not take longer than 10 seconds, with a protocolized approach preferable (106–121).

Ventricular Tachycardia/Fibrillation Arrest (Recommended for All Levels of Training).

- We recommend that BCU should be performed in patients with ventricular tachycardia/fibrillation arrest following return of spontaneous circulation (ROSC) to look for segmental wall motion abnormalities as a surrogate for CAD being the primary cause of cardiac arrest. **Grade 1B**
- *Rationale:* BCU can immediately reveal regional wall motion abnormalities indicative of myocardial ischemia (122, 123). Patients with cardiac arrest and ROSC have a high propensity for coronary lesions and tend to do better if they are taken for early coronary angiography and revascularization (124, 125). Structural abnormalities like prior infarction with healed scar, cardiomyopathies, RV dysplasia, and valvular anomalies are frequent causes of ventricular tachycardia/fibrillation arrest. The use of BCU can help identify these conditions. In cases where wall motion abnormality is documented, CAD would be suspected as the primary cause of the arrest and early revascularization would be suggested.

Use of TEE During Cardiopulmonary Resuscitation (Suggested for Expert Levels of Training).

- We suggest that TEE may be helpful when performed during cardiopulmonary resuscitation, especially during intraoperative cardiac arrest (in cardiac surgery patients). **Grade 1C**
- *Rationale:* Some of the initial literature investigating the use of ultrasound in the ICU and even during CPR used transesophageal probes although the transthoracic approach was also used (114, 126, 127). For patients in cardiac arrest, TEE has been shown to change management in over 30% of cases (107). According to the American Society of Anesthesiologists and the Society of Cardiovascular Anesthesiologists, life-threatening hemodynamic disturbances are classified as a category I indication for the intraoperative use of TEE (128).

ACS

ACS and Acute Myocardial Infarction (Recommended for All Levels of Training).

- We recommend that patients with suspected ACS and acute myocardial infarction (AMI) should undergo BCU. **Grade 1C**
- *Rationale:* BCU has been shown to improve diagnostic accuracy for ACS, especially when used in combination with other standard diagnostic tools. BCU is useful to evaluate for segmental wall motion abnormalities, to assess LV function (LVEF), transient mitral valvular dysfunction, and in case of inferior wall myocardial infarction to rule out RV involvement. BCU can also be used for evaluation of mechanical complications of AMI such as acute VSD and papillary muscle rupture (123, 129–132). It can be used to raise suspicion of these conditions to decrease time to formal echocardiography and to decrease clinical uncertainty to the cause of shock to aid in prompt diagnosis and management.

Pericardial Effusion/Cardiac Tamponade

Cardiac Tamponade (Recommended for Expert Levels of Training).

- We recommend that BCU should be performed to diagnose cardiac tamponade and to increase the effectiveness and safety of pericardiocentesis and guide performance of the procedure. **Grade 1B**
- *Rationale:* Classic physical examination findings of cardiac tamponade such as jugular venous distention, hypotension, and diminished heart sounds are usually absent (133); furthermore, symptoms of pericardial effusion/early tamponade are absent or mistaken for congestive heart failure (134–136). BCU can successfully identify this phenomenon even if not suspected clinically (15, 108, 137) and can guide and assess effectiveness of pericardiocentesis (16, 17), especially if contrast-enhanced ultrasound is used (18–20). Chest ultrasound should also be performed in such patients to assist with differential diagnosis of pericardial and left pleural effusions.

Pericardial Effusion (Recommended for All Levels of Training).

- We recommend that BCU should be performed to accurately diagnose pericardial effusion and to identify underlying causes. **Grade 1C**
- *Rationale:* Patients develop pericardial effusions in the ICU setting due to a variety of conditions. BCU can detect the presence of pericardial effusion and identify signs of tamponade (16, 21–23). The diagnosis may be difficult in the early post–cardiac surgery period. Ultrasound of the chest should also be performed in such patients to assist with differential diagnosis of pericardial and left pleural effusions by orienting the collection relative to the position of the aorta.

Hemodynamic Instability

Undifferentiated Hemodynamic Instability (Recommended for All Levels of Training).

- We recommend that BCU should be performed in patients with hemodynamic instability to identify underlying treatable causes and to help guide fluid resuscitation. **Grade 1B**
- *Rationale:* The differential diagnosis for hemodynamic instability is broad. BCU is effective in quickly identifying mechanical etiologies of shock that include valve dysfunction, PE, tamponade, and aortic dissection. The use of goal-directed ultrasound allows clinicians to narrow the differential diagnosis and to decrease the amount of time to diagnose patients with nontraumatic, symptomatic hypotension. Performing BCU in all hemodynamically unstable patients helps to guide real-time decisions regarding fluids status and to evaluate for treatable underlying causes of shock. Extended focused assessment by sonography in trauma examination should also be considered in such patients to exclude thoracoabdominal causes of hemodynamic instability (24, 25).

Valvular Dysfunction

Murmur (Recommended for All Levels of Training).

- We recommend that BCU should be performed in all patients with new murmurs. **Grade 1C**
- *Rationale:* The intensivist should screen patients with new murmurs for clinically significant valvular lesions that could potentially change management. Studies differ in the accuracy of BCU to evaluate valvular lesions such as aortic regurgitation/stenosis, and even mitral regurgitation. Kobal et al (26) demonstrated that medical students with no prior clinical experience could accurately detect the etiology of systolic murmur 93% of the time and of diastolic murmur 75% of the time with BCU. They contrasted this to the physical exam findings of a fellowship trained cardiologist

who could only diagnose these lesions 62% and 16% of the time, respectively. Further studies support the use of hand-carried ultrasound (HCU) to evaluate suspected valvular lesions (138, 139). However, a few studies have reported inaccuracies of this method (140–142). Martin et al (141) reported that the use of HCU and physical examination by hospitalists was actually inferior to physical examination. BCU can be used to raise suspicion of valvular lesions to decrease time to formal echocardiography and to decrease clinical uncertainty to aid in prompt diagnosis and management. Stable murmurs should be evaluated by those with expert level of training only.

Mechanical Valve Dysfunction (Recommended for Expert Levels of Training).

- We recommend that BCU should be performed in patients with hemodynamic instability with suspected mechanical valve dysfunction to identify other contributing causes of hemodynamic instability. Routine evaluation of mechanical valve dysfunction should best be performed by experts. **Grade 1C**
- *Rationale:* The echocardiographic evaluation of mechanical and bioprosthetic valves is difficult and out of the scope of most critical care physicians; therefore, routine evaluation should be left to trained cardiologists. Preferably this should be accomplished by TEE, especially in the setting of suspected endocarditis (143–145). If the patient is hemodynamically unstable, a screening BCU should be performed to evaluate for contributing causes of hemodynamic instability.

Endocarditis (Suggested for All Levels of Training).

- We suggest that patients with suspected endocarditis may be screened with BCU. **Grade 2C**
- *Rationale:* Combining clinical assessment with the echocardiographic results is essential for establishing the diagnosis of infective endocarditis. The intensivist with basic-level training may be able to recognize obvious vegetations. In low-risk patients, BCU could lead the physician to pursue alternative diagnoses, and in high-risk patients, it could help to identify large lesions quickly.

Prosthetic Valve Endocarditis (Recommended for Expert Levels of Training).

- We recommend that the evaluation for prosthetic valve endocarditis should best be performed by a trained cardiologist. A TEE can be performed in the ICU by the critical care physician if the physician has advanced training in echocardiography and is adept at performing TEE. **Grade 1B**
- *Rationale:* Both mechanical and bioprosthetic valves are difficult to image via TTE. Multiple studies have shown benefit of early TEE in these cases (143–146).

A major disadvantage of TEE is that it often requires the presence of a cardiologist or a trained specialist.

Diseases of Large Vessels

Great Vessel Disease and Injury (Suggested for All Levels of Training in the Hemodynamically Unstable Patient, With Clinical Suspicion of Aortic Dissection or Disruption).

- We suggest that a screening bedside TTE may be performed to evaluate the proximal aortic arch, the aortic valve, and a portion of the thoracic descending aorta in patients with suspected great vessel disease or injury if other diagnostic modalities are not immediately available. **Grade 2C**
- *Rationale:* TEE is very accurate in the identification of aortic rupture and other great vessel injuries (147–149). Ninety percent of aortic ruptures occurs at the aortic isthmus, a region that cannot be visualized with a TTE. However, in the proper clinical scenario, bedside TTE can be performed to evaluate the proximal aortic arch, aortic root, the aortic valve, and a portion of the thoracic descending aorta, especially if used in strategies that augment other imaging such as CT (150–155). Even an advanced operator cannot reliably exclude aortic injury, so other diagnostic modalities should also be used. However, if great vessel injury is suspected on BCU, this can heighten awareness and facilitate further timely diagnostic testing and clinical management. Patients with suspected dissection of the thoracic aorta should also be evaluated for the presence of pericardial effusion and should undergo chest ultrasound for evaluation of possible pleural effusion.

Chest Trauma

Blunt Chest Trauma (Suggested for All Levels of Training).

- We suggest bedside TTE to exclude the presence of a significant pericardial effusion in hemodynamically unstable patients with blunt chest trauma. **Grade 2C**
- *Rationale:* The use of BCU in hemodynamically unstable patients with blunt chest trauma is directed at the diagnosis of aortic transection, valvular disruption, cardiac laceration, and significant concussive cardiac injury. Timely discovery and intervention may be lifesaving in such cases. The use of BCU for aortic and valvular injury has been discussed in prior recommendations, and the diagnosis of concussive cardiac injury will be discussed below.

Cardiac laceration or rupture after blunt chest trauma is rare. It may result in pericardial effusion and tamponade that cause hemodynamic instability and may progress to death. Free rupture into the hemithorax, as would occur with concomitant pericardial laceration, is even less common, and is generally associated with death at the scene. Nonetheless, laceration of the atrium or atrial appendage may occur and promote hemodynamic instability by the presence of a pericardial effusion causing tamponade. This is readily apparent on BCU in the hands of critical care providers. In addition, BCU in such patients may lead to a decrease in unnecessary procedures such as emergency thoracotomy (156).

- BCU is of limited value to diagnose blunt cardiac injury (previously referred to as cardiac contusion). **Grade 2C**

- *Rationale:* BCU lacks accuracy for cardiac contusion diagnosis and should be reserved for patients with hemodynamic instability of unclear etiology, an abnormal ECG, or cardiac arrhythmias with documented risk of blunt cardiac injury (155, 157–163). A recent published literature analysis of 35 studies showed electrocardiogram (ECG) and troponin to be of greater utility than BCU although even the significance of elevated enzymes or an abnormal ECG is unclear. Blunt cardiac injury may result in dysrhythmias that may be of little consequence and systolic contractile failure that, although rare, would be of clinical significance. Casting a wide net by imaging asymptomatic blunt injured patients has not been shown to improve outcome and would potentially increase cost.

Penetrating Trauma (Recommended for All Levels of Training).

- We recommend that BCU should be performed in hemodynamically stable patients with penetrating chest trauma. **Grade 1C**
- *Rationale:* Penetrating cardiac injuries are highly lethal injuries that can present with normal hemodynamic parameters or cardiac arrest. A hemodynamically unstable patient should undergo emergent thoracotomy. In hemodynamically stable patients, BCU has proven to be a useful tool in the diagnosis of occult cardiac injury following penetrating chest trauma and can direct the critical care physician to take immediate lifesaving actions (164–169). One caveat is the presence of a cardiac injury decompressing into the hemithorax through a pericardial rent that may result in a large (usually left) hemothorax with a false-negative pericardial view.

TEE (Recommended for Expert Level of Training)

Poor Visualization of Cardiac Structures.

- We recommend that a trained physician should perform TEE in patients with poor visualization of cardiac structures with TTE. **Grade 1B**
- *Rationale:* Suboptimal imaging is common in the ICU during TEE, especially in mechanically ventilated patients, if this occurs TEE should be performed. With training, the critical care physician can perform TEE safely in the ICU setting, and it has been shown to lead to major therapeutic interventions (170–172) In patients at high risk for infective endocarditis, TEE can also be considered if TTE is negative.

The Use of Contrast (Suggested for Expert Level of Training)

RV Microbubbles

- We suggest that RV agitated normal saline contrast be used in all patients where cardiac source of embolic cerebrovascular accident is suspected to rule out paradoxical emboli. **Grade 2C**
- *Rationale:* Agitated normal saline solution can be administered into central or peripheral veins and used as the RV contrast when intracardiac shunting is suspected (173, 174).

LV Contrast 2D

- We recommend that LV ultrasound contrast be used under specific circumstances to improve image quality and diagnostic capability of echocardiography. **Grade 1C**
- *Rationale:* Despite its potential for harm, many studies have shown LV (microbubble) ultrasound contrast administration to be safe (175, 176). The use of LV contrast has also been shown to improve image quality and diagnostic capability of echocardiography for septal defects, infarction, intraventricular clot, and great vessel injury (177–179).

Diagnosis of Hepatopulmonary Syndrome in Patients Under Consideration for Liver Transplantation.

- We recommend that a bubble echocardiography study with agitated saline be used in favor of nuclear scintigraphy to diagnose intrapulmonary shunting in hypoxic patients with chronic liver disease to evaluate hepatopulmonary disease. **Grade 1C**
- *Rationale*: Normal saline is transferred very quickly between two syringes utilizing a stopcock to create bubbles of greater than 10 µm. Under normal conditions, these microbubbles do not pass through pulmonary capillaries with a normal diameter of 8–15 µm. With intracardiac shunting, microbubbles opacification of the LA occurs within three heartbeats after saline administration (180, 181). With microbubble passage through abnormally dilated pulmonary capillaries (transpulmonary shunting-hepatopulmonary syndrome), opacification of the LA occurs three to six beats after administration (182). This test is more sensitive than injection of technetium-99m-labeled albumin microaggregates with subsequent measurement of radioisotope uptake in the brain, requires no ionized radiation or patient transport to the nuclear medicine department (180, 183–187).

The Use of BCU in Pediatric Patients

The panel addressed several key issues related to BCU in pediatric patients. This is not a comprehensive pediatric BCU guidelines statement and literature review, but recognizes several fundamental questions germane to pediatrics and predicates ongoing efforts in generating a pediatric BCU guidelines statement. These recommendations are for intensivists with competency to care for pediatric patients and basic ultrasonography skills unless indicated otherwise.

Cardiac Arrest—Reversible Causes.

- We recommend that BCU be performed to exclude reversible causes of cardiac arrest in critically ill children. **Grade 1B**

- *Rationale*: The 2010 international pediatric basic and advanced life support recommendations state that "bedside cardiac echocardiography may be considered to identify potentially treatable causes of a cardiac arrest when appropriately skilled personnel are available, but the benefits must be carefully weighed against the known deleterious consequences of interrupting chest compressions." (188) Pediatric BCU may detect significant cardiac pathology in children, such as pericardial effusion, cardiac tamponade, severe hypovolemia, marked chamber enlargement, and disproportion in cardiac chamber size. Based on work by Spurney et al (189) pericardial effusion, LV function and diameter can be determined by a pediatric intensivist with only 2 hours of training with 93%, 96%, and 96% concordance to pediatric echocardiographers using traditional diagnostic equipment. This suggests these causes can be readily identified at the bedside in a cardiac arrest. The use of pediatric BCU in cardiac arrest has been described by Tsung and Blaivas (190) in a 14 patient series of pediatric patients, supporting its feasibility in practice.

Cardiac Arrest—Irreversible Causes.

- We recommend that pediatric BCU alone is insufficient to diagnose irreversible pulseless cardiac activity in cardiac arrest in critically ill children. **Grade 1C**
- *Rationale*: Although cardiac standstill and true PEA can be identified on BCU at the bedside, children are known to have several attributes that permit recovery from cardiac standstill. Severe myocardial stun is known to occur in young children after extracorporeal membrane oxygenation (ECMO) cannulation and absence of function may be present for several days following severe cardiac insult (191). Myocardial function slowly recovers following this. This suggests that the injured pediatric heart that appears akinetic initially may be ultimately recoverable. Children experience cardiac arrest primarily from respiratory causes and a rapid restoration of oxygen delivery may lead to a different outcome than adult cardiac standstill. Accurate assessment of cardiac standstill with a sufficient amount of time spent visualizing the heart requires operator efficiency and safety at the bedside during arrest. At this time, efficiency is compromised by a low level of BCU penetrance and low number of expert operators in pediatric critical care.

Preload Responsiveness.

- We recommend that pediatric BCU be used in the assessment and management of hypovolemic shock to determine preload responsiveness in critically ill children. **Grade 1B**
- *Rationale*: BCU is useful for assessing preload responsiveness. There is some existing evidence that suggests evaluation of the IVC in spontaneously breathing pediatric cardiac (192) and neonatal patients (193) correlates with CVP. However, the work by Ng et al (194) shows that IVC collapsibility index and IVC/aorta ratio do not correlate with CVP in a cohort of 51 critically ill children. However, CVP is not an accurate measure of volume status and sonographic assessment of volume status in pediatrics requires further investigation in larger series (195–199). A different assessment technique, peak systolic aortic blood flow variability through the respiratory cycle, has been found to predict preload responsiveness in a meta-analysis of pediatric studies (200). Dynamic transthoracic echocardiographic measurements that account for changes through the cardiac cycle are likely more sensitive than static indicators of preload status. Similar to aortic peak systolic velocity variability, LV outflow tract flow VTI variability assessed in patients undergoing cardiac or neurological surgery predicts fluid responsiveness in a manner superior to CVP (201, 202). SVC flow and collapsibility index have been studied in neonates (and adults) but its utility in critically ill children is not well described (203–205).

Suspected Cardiogenic Shock.

- We suggest that pediatric BCU may be used in the assessment of cardiogenic shock in critically ill children. **Grade 2C**
- *Rationale*: Accuracy of pediatric intensivists in qualitatively assessing LV function and diameter has been demonstrated in a series of pediatric intensivists and emergency medicine specialists examining the heart in good concordance with pediatric cardiology specialists (194, 207).

Suspected Septic Shock.

- We make no recommendations in support of or against using pediatric BCU in the assessment of septic shock in critically ill children.
- *Rationale*: With reassuring pediatric BCU evaluation of intravascular volume status and cardiac contractility, as well as sonographic and clinical signs of shock with high cardiac output/tachycardia, distributive shock could potentially be suspected. However, no specific data on this have been published to allow the panel to formulate a recommendation for or against its use.

Patent Ductus Arteriosus.

- We suggest that practitioners with advanced levels of training may use pediatric BCU to diagnose and evaluate neonatal patent ductus arteriosus (PDA). **Grade 2C**
- *Rationale:* Lee et al (208) have demonstrated in the neonatal population a sensitivity of 87% and specificity of 71% in detecting PDA in the hands of neonatologists with limited training. El-Khuffash et al (209, 210) have described use of BCU to characterize PDA at the bedside though without correlation with observers from imaging specialties. Nonetheless, pediatric intensivists will only have episodic practice of imaging and diagnosing this infrequent pathology. The American Society of Echocardiography recommendations on targeted neonatal echocardiography recommend that PDA should be assessed in the neonate by clinicians experienced in the technique and always be accompanied/followed by a comprehensive study (211, 212).

Congenital Heart Disease.

- We suggest that pediatric BCU not to be used to evaluate or definitively diagnose congenital heart disease (CHD) in pediatric patients. **Grade 2C**
- *Rationale*: Functional assessment of hemodynamic issues in CHD is best performed with an understanding of complex patient physiology. For this reason, evaluation and management of CHD patients are best done in concert with a pediatric cardiology specialist. Definitive CHD diagnosis in children benefits from precise reproducible assessments that can be readily reviewed by pediatric cardiologists trained to diagnosing CHD. In this sense, definitive diagnosis of CHD is best facilitated with involvement of pediatric cardiology specialists.

Acquired Valvular Disease.

- We suggest that pediatric BCU not be used in the evaluation of acquired valvular heart disease. **Grade 2C**
- *Rationale*: Colquhoun et al (213) have demonstrated the feasibility of focused echocardiography evaluations performed by two nurses in resource poor areas of Fiji to identify rheumatic mitral and aortic valve disease, though their quantitative data on mitral regurgitation tended to demonstrate false positives in comparison with data obtained by pediatric cardiology. Due to the risk of having false-positive or false-negative results in this setting, a comprehensive echocardiography by a pediatric cardiologist is necessary for accurate evaluation of valvular heart diseases in this population.

RV Dysfunction.

- We make no recommendation supporting or against using pediatric BCU in the assessment of patients with suspected RV dysfunction.
- *Rationale*: RV failure is frequently seen in the perinatal and early childhood period as a complication of a difficult transition from neonatal circulation, and also as an effect of lung or cardiac disease. Metrics of RV function include morphologic changes of the heart, septal position relative to the center of the LV, elevated regurgitant jet velocity across the tricuspid valve, pressure gradients assessed across the pulmonic valve or septal defects, TAPSE, as well as distention and pulsatility of central venous structures. These can be potentially detected using pediatric BCU. Despite the relatively easy technique for assessing pulmonary hypertension, the pediatric BCU assessment of the right heart by pediatric intensivist has not been well evaluated in the medical literature in children.

ECMO.

- We make no recommendations supporting or against using BCU in the assessment of pediatric patients on ECMO.
- *Rationale*: Assessment of the heart on venoarterial and venovenous ECMO is possible with recommendations published in the literature for diagnostic echocardiography (214). Assessments of cardiac function and chamber size on ECMO are possible and relevant. Cannulas may be visualized in the right atrium using multiple views. Post–cardiac surgery dressings and invasive devices may compromise available windows.

CONCLUSION

A panel of international experts rendered several class 1 recommendations for the use of BCU in the ICU. The most robust of these recommendations includes the use of BCU for the assessment of fluid responsiveness in the mechanically ventilated adult and child and for the detection of pericardial tamponade. Recommendations regarding the assessment of cardiac function of the left and RV were strong, but supported by less robust evidence, undoubtedly related to the dearth of well-trained practitioners at this time.

We recognize that the panel of adult and pediatric intensivists who practice in a wide variety of clinical settings are all trained in the use of ultrasound. Full and appropriate implementation of the technology will require similarly trained practitioners. Furthermore, as noted by the recent guidelines of the American Society of Echocardiography, training, accreditation and credentialing should depend on competency-based, and not volume-based, assessment (215). Evidence-based recommendations regarding the appropriate use of this technology are a step toward improving outcomes in relevant patients.

The heart undergoes dynamic changes in the ICU as a result of time and therapy. The BCU should be thought of as an extension of the critical care physician's physical examination and should be repeated just as the physical exam is repeated.

We are now at the forefront of the "ultrasound revolution." We believe that the BCU and general ultrasound recommendations will evolve rapidly with the field that undergoes remarkable and unprecedented transformation. As noted in part one and two of these guidelines (64), BCU performed and interpreted in real time is appropriate in many clinical settings and should be considered an important part of the clinician's armamentarium. Training to competency in relevant areas and ready availability of ultrasound machines is vital to provide contemporary care of the critically ill and injured patient.

We believe that this set of guidelines will help to establish a new pattern of care in the ICU with greater use of bedside ultrasonography. With more time, this will inevitably result in more outcome centered data on the usefulness of bedside ultrasonography. This, in turn, will result in better acceptance and education that will lead to the generation of more data with the ultimate result of maturation of the field of bedside ultrasonography that will transform the care of patients in the ICU.

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