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CONFERENCE REPORTS AND EXPERT PANEL

The PRICES statement: an ESICM expert consensus on methodology for conducting and reporting critical care echocardiography research studies

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Abstract

Purpose: Echocardiography is a common tool for cardiac and hemodynamic assessments in critical care research. However, interpretation (and applications) of results and between-study comparisons are often difficult due to the lack of certain important details in the studies. PRICES (Preferred Reporting Items for Critical care Echocardiography Studies) is a project endorsed by the European Society of Intensive Care Medicine and conducted by the Echocardiography Working Group, aiming at producing recommendations for standardized reporting of critical care echocardiography (CCE) research studies.

Methods: The PRICE panel identified lists of clinical and echocardiographic parameters (the "items") deemed important in four main areas of CCE research: left ventricular systolic and diastolic functions, right ventricular function and fluid management. Each item was graded using a critical index (CI) that combined the relative importance of each item and the fraction of studies that did not report it, also taking experts' opinion into account.

Results: A list of items in each area that deemed essential for the proper interpretation and application of research results is recommended. Additional items which aid interpretation were also proposed.

Conclusion: The PRICES recommendations reported in this document, as a checklist, represent an international consensus of experts as to which parameters and information should be included in the design of echocardiography research studies. PRICES recommendations provide guidance to scientists in the field of CCE with the objective of providing a recommended framework for reporting of CCE methodology and results.

Keywords: Left ventricle, Right ventricle, Diastolic function, Systolic function, Fluid responsiveness

Introduction

The increasing clinical use of critical care echocardiography (CCE) is paralleled by the growing need for scientific knowledge in the field [1, 2]. *PRICES*, an acronym standing for "Preferred Reporting Items for Critical care Echocardiography Studies", is a project endorsed by the European Society of Intensive Care Medicine (ESICM) and conducted by the Echocardiography Working Group of the Cardiovascular Dynamic section. Its final aim is to improve methodological and reporting consistencies in

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clinical research in the areas of left venticular (LV) systolic function, LV diastolic function, right ventricular (RV) systolic function and fluid management.

Two critical methodological aspects for CCE research influence the knowledge in the field: (1) a well-structured approach to the single CCE exam with detailed information provided together with a well-described clinical context; (2) a detailed description of methodology and reporting of results, producing comparable echocardiography data between research studies.

The present article contains recommendations provided by the panel of echocardiography experts involved in PRICES. Notably, the PRICES recommendations are based not only on the experts' opinion on the importance of each item that may warrant reporting, but also on an extensive systematic review and literature appraisal conducted by the authors on the currently published CCE literature [3]. Such appraisal provided the panel with more objective insights on the necessity of improving reporting of particular items in echocardiography research. It is desirable that the list of recommendations of PRICES will work as "checklists" for authors as to which parameters and information could/should be included in the design of their echocardiography research studies and subsequently reported in their manuscript on CCE. However, it is important to highlight that recommendations on how to conduct the CCE at bedside and the echocardiographic measurements are beyond the scope of PRICES as many valuable international guidelines provide ample direction on these subjects.

Methods

In brief, the PRICES project was initiated by the Echocardiography Working Group of the ESICM and started with a selection of 19 experts in the field of CCE, from Europe ($n=15$), Oceania ($n=3$) and North America ($n=1$); the first internal discussion of the *PRICES* group was held in Vienna (25th–26th September 2017). The experts agreed on a list of items that are of potential interest in CCE research studies. Subsequently, these items were appraised with a systematic approach described in the PRICES part I. The systematic review was registered on PROSPERO (CRD42018094450). The literature searches were performed separately for each topic/area on Medline and Embase including studies published from 1st January 2000 to 31st December 2017, as reported in the PRICES part I. Two experts screened each abstract retrieved from the search, and included articles were appraised for a list of pre-determined items [3]. A total of 43 "common items" were defined as items of interest to all CCE studies, and a variable number of "topic-specific items" according to 5 different areas of CCE interest. Specifically, 15 "topic-specific items" were selected for studies involving the evaluation of left ventricular systolic function (LVSF), 18 for right ventricular function (RVF), 15 for LV diastolic function (LVDF), 7 for fluid management (FM) and 17 for advanced echocardiography techniques (AET, including speckle tracking and 3D echocardiography). However, although the area in AET was initially planned for recommendations and had been reported in the systematic review [3], the panel decided that AET is currently at early stage of its introduction into critical care practice and thus it is premature to give formal recommendations. Instead, recommendations as to the use of AET, such as strain measurements, were left to each area (e.g. LV and RV systolic functions) to deliberate.

Evaluation of the importance of items

The process from starting the project to finally establishing the guidelines is summarized in Fig. 1. Importantly, since each panel expert might opine the importance for any item differently, the experts agreed to rate the relative importance (RI) for each item independently. The RI is a measure, on a Likert scale from 1 to 4 points, of the opined importance of an item. The final overall RI for each item was determined on majority votes. Items were thus dived in "essential" (4 points), "additional" (3 points), "optional" (2 points) and "not important" (1 point). The RI was scored on the basis of clinical utility or likelihood of biased and non-reproducible results if that item was not reported; hence the higher the RI, the greater the propensity for misinterpretation if missing.

The "essential" (RI = 4) and "additional" (RI = 3) reflected "core items" in the interpretation of CCE research findings; on the contrary, items with RI score of 1 or 2 were considered "supplementary", and the decision of reporting them can be left to the authors of scientific studies. This represented a first step based only on the panel's expertise and experience in CCE.

Combining item importance with the frequency of reporting

In a subsequent step, we borrowed the principle of Hand rule (burden of risk calculation) [4] to use a metric that we named "critical index" (CI) with the aim of balancing the importance of each item with its frequency of reporting (FSi), as reported in our systematic literature appraisal on CCE [3]. In brief, the Hand rule provides that the burden (cost) of risk prevention (B) is the product of the probability of events (P) and the gravity of loss if the event happened (L): $B = P \times L$. Applying this principle, the CI can be seen as the burden of prevention of not reporting an item, and can be expressed as

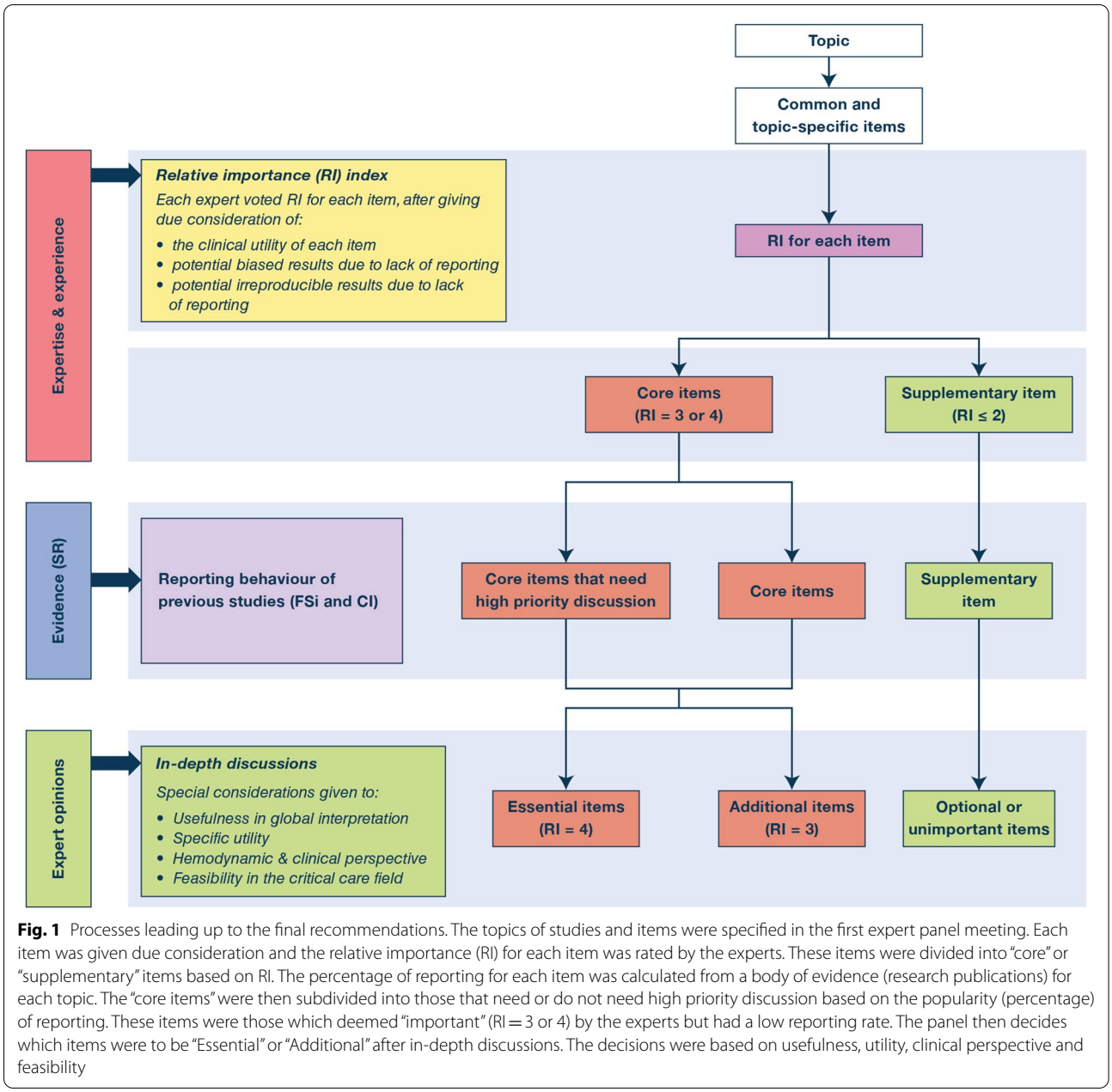

Fig. 1 Processes leading up to the final recommendations. The topics of studies and items were specified in the first expert panel meeting. Each item was given due consideration and the relative importance (RI) for each item was rated by the experts. These items were divided into "core" or "supplementary" items based on RI. The percentage of reporting for each item was calculated from a body of evidence (research publications) for each topic. The "core items" were then subdivided into those that need or do not need high priority discussion based on the popularity (percentage) of reporting. These items were those which deemed "important" (RI = 3 or 4) by the experts but had a low reporting rate. The panel then decides which items were to be "Essential" or "Additional" after in-depth discussions. The decisions were based on usefulness, utility, clinical perspective and feasibility

$$\mathrm{CI} = (1 - \mathrm{FSi}) \times \mathrm{RI},$$

where $(1 - \mathrm{FSi})$ was the fraction of studies that did not report the item and is equivalent to the probability of missing an item, and RI can be read as the impact (gravity) of an item if not reported. Hence, a low CI indicates lesser burden, and high CI indicates larger burden and some "precautions" are warranted. These "precautions" were stated in the form of whether or not an item should be reported more often in this recommendation. When considering the need to increase reporting of an item, we arbitrarily divided the CI values in three categories:

- $\mathrm{CI} \leq 1$: the scientific community is already aware of the importance of reporting the item and/or the RI is low hence the burden to recommend is low (green flag).
- $1 < \mathrm{CI} < 3$, increased reporting is needed (orange flag).
- $\mathrm{CI} \geq 3$, the scientific community is not aware of the importance of reporting the item and/or the RI is

high, hence the burden to recommend is high (red flag).

The advantage of this approach is the combination of an objective measure (1 − FSi) with the experts' opinions (RI). It is the opinion of the panel that the CI gives a balanced idea of the need to increase reporting of each item.

The rationale for the recommendations is discussed in the text, and tables are also provided with summaries of the items. An easy-to-follow PRICES utility checklist is made available to readers (researchers and clinicians) in Fig. 2.

The recommendations

Items common to all topics

Supplementary Material eTable 1 shows the list of the 43 common items divided in six sections, with different symbols according to the RI of each item with regard to CCE interest.

Study characteristics (3 items)

Study characteristics are all essential and well reported in the current literature. The panel reinforces the importance of stating if data are prospectively acquired, and to distinguish the number of exams from the number of patients (same patient may be exposed to more than one echocardiography exam).

Patients characteristics (12 items)

The clinical context should be always clear. In order to increase the reproducibility of the study results, it is essential to describe the baseline characteristics of the study population, in particular of the comorbidities. Knowledge of pre-existing cardiac dysfunction before critical illness is very valuable.

Echocardiography information (6 items)

An increase in the reporting of information on echocardiography exams is highly desirable. Such technical information is mostly judged as essential. Although optional in all fields of recommendations, software version is paramount when reporting AET parameters.

Clinical information at the time of echocardiography (10 items)

The overall reporting of data on ventilation (mode and settings) and on the hemodynamic conditions at the time of the echocardiography exam should increase. Information regarding mechanical ventilation is of greatest importance for the RVF and FM topic. Description of hemodynamic conditions and pharmacological support is essential for all sub-groups. It is of utmost importance to clearly report if patients were all in sinus rhythm, or whether patients with non-sinus rhythm or paced rhythm were excluded.

Measurement reliability (8 items)

Training of the echocardiographers/sonographers and of those who reviewed and interpreted the echocardiography exam are deemed essential to all CCE topics, though reporting was discontinuous across the CCE topics.

Statistics reporting (4 items)

Sample size calculation should be performed and deserves a significant increase in reporting. In the case of pilot studies, authors are encouraged to provide a reasonable estimation of sample size. It is important to state if analysis was blinded and if it addressed for potential confounding; it is of additional value to provide information on any internal validation of the study.

Topic-specific items

Figure 2 is a summary of the main recommendations and Figs. 3, 4, 5, and 6 report the recommendations in detail with items divided into parameters specifically describing the evaluation of the selected topic (LVSF, RVF, LVDF or FM) and those allowing a better understanding of the reported data, providing a better clinical picture.

LV systolic function

We recommend (Fig. 3) more transparent reporting on the technical aspect for estimation of LV ejection fraction (LVEF) i.e. Simpson, Teicholz or 3D. Although LV size is essential for studies on LVSF, the panel does not feel it necessary to recommend one approach over another (diameter, area, volume). If feasible, studies focusing on LVSF are encouraged to integrate their information with data on the LVDF.

Additional parameters provide useful information regarding myocardial function (Mitral Annular Plane Systolic Excursion, LV S' wave on Tissue Doppler Imaging (TDI), LV strain and strain rate) in the context of critical illness. For instance, the LV global longitudinal strain may be of better prognostic value when compared to LVEF in septic patients [5]. While the panel agrees that speckle tracking echocardiography is of great and increasing interest, most ICUs are probably not adequately equipped for strain analysis. For studies evaluating the LV with S' wave on TDI or Mitral Annular Plane Systolic Excursion, it is also important to report regional wall motion abnormalities and the presence of mitral annular calcification/prosthesis.

	Checklist items	LV systolic function	RV function	LV diastolic function	Fluid management
A1	**Research vs clinical study**				
	• Research study				
	• Clinical study				
A2	**Study information**				
	• Specific study type				
	• State study design				
	• Report sample size				
A3	**Patient information**				
	• Age				
	• Gender				
	• Height & weight (or BMI)				
	Comorbidities				
	• Ischaemic heart disease				
	• Atrial fibrillation				
	• Hypertension				
	• HFpEF				
	• HFrEF				
	• Pacemaker implant present				
	• COPD or pulmonary hypertension				
	• CKD or hemodialysis				
A4	**Echocardiography information**				
	• Type of echo (TTE or TEE)				
	• Indicate if data collected at end-expiration				
	• No. of beats used for averaging				
	• Report vendor of ultrasound machine				
	• Indicate if airway pressure trace displayed on screen				
A5	**Clinical information at the time of echo**				
A5.1	***Ventilation***				
	• Mode of ventilation				
	• Tidal volume				
	• Plateau pressure				
	• PEEP				
A5.2	***Hemodynamics***				
	• Cardiac rhythm & heart rate				
	• BP				
	• Inotropes, vasopressors and doses				
A6	**Reliability** (for research study)				
	• Feasibility of echo stated				
	• Intra-observer variability				
	• Inter-observer variability				
	• Indicate if observer blinded to treatment, if applicable				
A7	**Statistics** (for research study only)				
	• Sample size calculation				
	• Indicate if statistician blinded to treatment / group				
	• Address confounders, if applicable				
	• Internal validation provided, if applicable				

Fig. 2 PRICES utility checklist

LV systolic function	**B1**	**LV systolic function indices**	
		• LV ejection fraction	
		• Tissue Doppler S' velocity	
		• Mitral annular systolic plane excursion (MAPSE)	
		• LV strain or strain rate	
	B2	**LV size**	
		• LV end-diastolic diameter or volume	
	B3	**Other functional indices to aid interpretation**	
		• Cardiac output	
		• Stroke volume	
		• Any heart valve dysfunction	
RV systolic function	**C1**	**RV systolic function indices**	
		• Tricuspid annular systolic plane excursion (TAPSE)	
		• RV fractional area change	
		• Tissue Doppler S' velocity	
		• LV strain or strain rate	
	C2	**RV size and wall thickness**	
		• RV end-diastolic diameter or area	
		• RV:LV end-diastolic area ratio	
		• RV wall thickness	
	C3	**Other functional indices to aid interpretation**	
		• PFO or other shunt(s)	
		• Pericardial effusion	
		• Paradoxical septal motion	
		• Inter-atrial septal bowing	
		• IVC diameter	
LV diastolic function	**D1**	**Indices for evaluation of LV diastolic function**	
		• E/A ratio	
		• Tissue Doppler E' velocity	
		• E/E' ratio	
		• PAP or TR peak velocity	
		• LA size	
		• Mitral E deceleration time	
		• Pulmonary venous flow	
	D2	**Other functional indices to aid interpretation**	
		• BP: systolic, diastolic and mean	
		• Related chronic medications	
	D3	**Criteria used for grading diastolic function**	
		• State or quote criteria	
		• Cite reference	
		• Technical details of measurements	
Fluid management	**E1**	**Evaluation of fluid management**	
		• Define the meaning of FR clearly	
		• State parameter(s) used for predicting fluid responsiveness (FR)	
		• Describe parameters used to assess FR (e.g. cut-offs)	
	E2	**Other information to aid interpretation** (research study only)	
		• State reference standard used in diagnostic or validation study	
		• State if echo is used to measure the reference value (e.g. CO)	
		• State technical information on echo measurements	
		• Describe any procedures used for FR assessment	

Fig. 2 continued

Fig. 2 continued

The checklist is provided to assist clinicians and researchers to collect information that we regard as useful and important. We divided the information into several domains, some of which are important in any echo study, others are specific to the aim of the study. There are altogether 5 Tables for data collection. Table A, items that are common to all topics, Table B, items that are deemed important or useful in reporting LV systolic function, Table C, items that are deemed important or useful in reporting RV systolic function, Table D, items that are deemed important or useful in reporting LV diastolic function, Table E, items that are deemed important or useful in studies related to fluid management

This checklist can also be used as data collection form. Checkboxes that are not shaded indicate essential item that should be collected and reported. Shaded checkboxes indicate additional information that are useful for interpretation

Other parameters do not directly describe the LVSF but are essential for a correct interpretation of the research findings. We recommend reporting information on functional heart valve disease. An illustrative example of the presence of heart valve disease might be when mitral valve regurgitation causes significant overestimation of LVEF.

RV function

The assessment of RVF is challenging, in that a single accurate global measurement has not yet been identified. The varied nature of RV pathophysiology necessitates the use of a number of quantitative descriptors (Fig. 4). The majority of parameters were considered essential, including not only specific measurements of RVF but also items allowing accurate interpretation of RVF as evaluated with echocardiography. Three items describing RV contractility (RV fractional area change, tricuspid annular S' with tissue Doppler imaging, tricuspid annular plan systolic excursion) were judged essential. In regard to tricuspid annular S' wave, we recommend reporting the image plane and the location of the sampling point. Subjective RVF rating is optional and indeed a recent study confirmed that it should not be used in isolation [6].

Reporting RV size (including in comparison with the LV size) is a component of RVF [7, 8] and should be accompanied by the echocardiographic plane and the method employed. The reportage of pulmonary artery (PA) pressure is also important in interpreting RVF, and should be clear whether PA pressure is estimated from tricuspid regurgitation or derived from a PA catheter.

Regarding the clinical information at the time of echocardiography, it is important reporting mechanical ventilation strategies (see Fig. 2), and it is valuable to couple the study of RVF with information on LVSF and LVDF (or at least on estimation of LV filling pressure). Although not directly appraised, the value of pH and $PaCO_2$ at the time of echocardiography exam may be valuable for their influence on pulmonary vascular resistances (and on catecholamines responsiveness).

LV diastolic function

The assessment of LVDF in the ICU population is a challenging task and it relies on the integration of several variables. However, there is evidence on the importance of LV diastolic dysfunction in critically ill septic patients [9, 10]. The most recent guidelines included the left atrium (LA) size and the estimation of PA systolic pressure—through the evaluation of the tricuspid regurgitant jet velocity—in their algorithm [11]. As such, the panel considered that the reporting of these two measurements is essential (Fig. 5). However, LA size may be particularly unreliable for acute changes of LVDF in critically ill patients undergoing mechanical ventilation with vasomotor and loading changes. Indeed, the LA is unlikely to dilate for acute worsening of LVDF [12]. If the authors choose to report PA systolic pressure, they should define how the pressure is obtained or calculated, e.g. obtained from PA catheter, calculated from the sum of tricuspid jet gradient and CVP or RAP (clearly stating how RAP is estimated).

The two other parameters derived from TDI (e' and E/e') are essential for the diagnosis of LVDF according to the new guidelines. The authors should clearly report if they investigated lateral, medial or average values of e' velocity, since reference values are different according to the site of sampling [11]. Another essential parameter for grading of LVDF is the E/A ratio, and in case of significant tachycardia with merged flow, authors should clarify how they calculated it.

Pulmonary venous flow and E wave deceleration time are additional measurements, as not recognized by the current guidelines [11] although included in the previous ones [13].

The panel believes that when describing LVDF it is of utmost importance to provide information on the LVSF as patients with known LV systolic dysfunction have by definition impaired LVDF [10]. We believe it is very valuable to provide also data on RVF as since RV dilatation and eventually paradoxical septal motion can impair relaxation process and increase LV filling pressures.

ITEMS		RI of the item and Need for reporting according to CI; RATIONALE	
SPECIFIC ITEMS FOR THE EVALUATION OF THE LV SYSTOLIC FUNCTION			
Contractility	LVEF	E-1	Most commonly used parameter describing LV contractility (CCE and cardiology). Useful for comparison between studies, though it reflects the integration of preload, afterload and contractility.
	MAPSE	A-2	These parameters are less commonly reported. They may be less load-dependent than LVEF and more related to LV contractility, providing additive value to LVEF interpretation. Providing at least one of the three adds value to CCE studies on LV systolic function.
	LV S' TDI		
	LV strain or strain rate		
	LV FAC	O	While graded optional, reporting of these items should not be discouraged. Some are surrogates for overall LV systolic function (Tei index is a surrogate for both systolic and diastolic function). LVFAC is sometime the only available surrogate of LVEF. RWMAs may be of greater interest in studies focusing in patients with acute or chronic ischemic heart disease or cardiogenic shock or in cases such as Takotsubo cardiomyopathy.
	RWMAs	O	
	LV Tei index	O	
	LV dp/dt	O	
Size	LV size	E-2	May be reported as end-diastolic diameter/area/volume. May suggest whether LV dysfunction is acute or chronic, as a chronic LV injury leads to increased size and a non-dilated LV suggest acute injury when its systolic function is depressed.
ITEMS ALLOWING ACCURATE INTERPRETATION OF ECHOCARDIOGRAPHY DATA			
Hemodynamic data	Cardiac output	E-2	For example, understanding of these variables may be useful in differentiating cardiogenic and septic shock. They may reflect the consequences of the LV function alteration. VTI may be used as well as a surrogate and it is crucial in some scenarios of cardiogenic shock.
	Stroke volume	E-2	
Other echo findings	Heart valve dysfunction	E-3	Moderate and severe valve dysfunction affects most echocardiographic measurements (significant confounders). Authors should make clear if they excluded patients with at least moderate valve disease or not
	Pericardial effusion	O	Significant effusions or a large foramen ovale are relatively rare in the critical care. However if these are seen they may confound echocardiographic measurements and interpretation. Nonetheless authors are encouraged to report if they screened for these conditions during their CCE (if so reporting percentage/number) or if they excluded these patients.
	Patent foramen ovale	O	

Fig. 3 Left ventricular (LV) systolic function recommendations

Items are divided into two groups: 1) those specifically evaluating the LV systolic function, and 2) in those allowing a better interpretation of the clinical context when the echocardiography exam is performed. The relative importance (RI) of the item is divided in those essential (E, RI score 4), additional (A, RI score 3) or optional (O, RI score 2). Essential and Additional items are coupled with a graded and coloured scale according to the necessity of increase attention in reporting by the scientific community, as gathered by the results of the critical index (CI). The grades are as follow: 3 - Significant Increase in reporting recommended CI $\geq$ 3 (red); 2 - Increase in reporting recommended 1.0 <CI<3 (orange); 1 - Continue reporting recommended CI $\leq$ 1.0 (green)

CCE: critical care echocardiography; *FAC*: fractional area change; *LVEF*: LV ejection fraction; *MAPSE*: mitral annular plane systolic excursion; *RWMAs*: regional wall motion abnormalities; *TDI*: tissue Doppler imaging; *VTI*: velocity time integral

In order to have a better clinical interpretation of echocardiographic measurements of LVDF, the panel felt that the authors should clarify the values of both systolic, mean and diastolic blood pressure. Although heart rate is an essential common item, the panel highlighted the value of providing this data as tachycardia may further impair LV relaxation during critical illness. The panel felt that it is essential to report not only current treatment with vasoactive drugs, but also longer term chronic cardiovascular drugs taken by the patients at the time of ICU admission. This knowledge may help to understand the burden of pre-existing LV diastolic dysfunction.

The panel judged that it is essential to indicate the technical details of measurement, criteria used for diagnosis and grading of LVDF, and to cite relevant references.

ITEMS		RI of the item and Need for reporting according to CI; RATIONALE	
SPECIFIC ITEMS FOR THE EVALUATION OF THE RV FUNCTION			
Contractility	RV FAC	E-2	Most commonly used parameters describing RV contractility (CCE and cardiology). Providing at least one them is essential for CCE studies on the RV. The more parameters provided the easier comparing studies. Authors are encouraged to report all of them.
	RV S' TDI		
	TAPSE		
	RV strain/strain rate	O	According to current knowledge, these informations do not add significant value to the interpretation of RV function. However, we acknowledge that strain may become more important in the future, once more commonly used. Tei index is less popular in CCE. Subjective assessment has large intra- and inter-observer variability.
	RV Tei index	O	
	Subjective assessment	O	
Size	RV wall thickness	E-3	Provides insights on the presence of chronic RV pressure overload.
	RVEDA	E-2	RV size can be reported as diameter/area. It yields information on loading conditions. Reporting at least one parameter is essential.
	RVEDD		
	RV-to-LVEDA ratio	E-2	The ratio is a useful parameter on RV pressure and/or volume overload and part of the definition of RV failure.
PAPs	TR peak velocity and/or PAPs	E-2	To interpret RV function, it is essential to evaluate the presence (and degree) of pulmonary hypertension, directly or with its surrogates. Providing at least one measurement is essential.
	PAAT		
ITEMS ALLOWING ACCURATE INTERPRETATION OF ECHOCARDIOGRAPHY DATA			
Other echo findings	Pericardial effusion	E-3	May affect RV size and systolic function. Authors should state if there was pericardial effusion (reporting percentage/number).
	Patent foramen ovale (and other intracardiac shunts)	E-3	Presence of significant shunts should be clearly reported to clarify the presence of RV volume overload.
	Paradoxical septal motion	E-3	Provide information on the presence of volume/pressure overload.
	IVC diameter and/or variation	E-2	It can give information on RV preload conditions and right sided congestion.
	IAS bowing	A-2	The shift of the IAS can provide some qualitative information on the difference of atrial pressures between left and right side. Helpful in cases of RV dysfunction or pulmonary hypertension.

Fig. 4 Right ventricular (RV) function recommendations

Items are divided into two groups: 1) those specifically evaluating the RV function, and 2) in those allowing a better interpretation of the clinical context when the echocardiography exam is performed. The relative importance (RI) of the item is divided in those essential (E, RI score 4), additional (A, RI score 3) or optional (O, RI score 2). Essential and Additional items are coupled with a graded and coloured scale according to the necessity of increase attention in reporting by the scientific community, as gathered by the results of the critical index (CI) The grades are as follow: 3 - Significant Increase in reporting recommended CI $\geq$ 3 (red); 2 - Increase in reporting recommended 1.0 <CI<3 (orange); 1 - Continue reporting recommended CI $\leq$ 1.0 (green)

CCE: critical care echocardiography; *EDA*: end-diastolic area; *EDD*: end-diastolic diameter; *FAC*: fractional area change; *IAS*: inter-atrial septum; *IVC*: inferior vena cava; *LV*: left ventricle; *PAAT*: pulmonary artery acceleration time; *PAPs*: pulmonary artery systolic pressure; *TAPSE*: tricuspid annular plane systolic excursion; *TDI*: tissue Doppler imaging; *TR*: tricuspid regurgitation

Fluid management

In studies assessing fluid responsiveness (FR), it is essential to clarify whether or not echocardiography was used as a reference standard. If so, it is essential to report the methodology of echocardiographic measurement to assess the variation of cardiac output (or its surrogate such as stroke volume or aortic velocity–time integral) after the intervention aimed at increasing venous return. The method used to increase venous return also remains essential in reporting, in particular the type of

ITEMS		RI of the item and Need for reporting according to CI; RATIONALE	
SPECIFIC ITEMS FOR THE EVALUATION OF THE LV DIASTOLIC FUNCTION			
Parameters recommended by current guidelines on cardiology outpatients	PAPs or TR peak velocity	E-3	These parameters are recommended by current (2016) guidelines for diagnosis and grading of LV diastolic dysfunction. Atrial size should be indexed to body surface area but LA size is not likely to change as result of acute worsening of LV diastolic function. When reporting the e' velocity, authors should make clear if they used lateral, medial or average values. The panel acknowledges that it is challenging to appreciate LV diastolic function when current guidelines are applied to critically ill patients.
	Left atrial size	E-3	
	E/A ratio	E-2	
	e' TDI	E-2	
	E/e' ratio	E-2	
Other parameters for assessing LV diastolic function	Pulmonary venous flow	A-2	Not currently used under the current guidelines. They may add value for comparison with previous studies.
	E wave deceleration time	A-2	
	Mitral E/Vp	O	Does not add value. Outdated and suffers from high variability.
ITEMS ALLOWING ACCURATE INTERPRETATION OF ECHOCARDIOGRAPHY DATA			
Hemodynamic data	Diastolic arterial pressure	E-3	Detailed hemodynamic conditions are useful for the evaluation of LV diastolic function. Among the values of blood pressure, the diastolic pressure has been less reported than mean or systolic arterial pressure.
	Mean arterial pressure	E-2	
	Systolic arterial pressure	E-2	
	On-going medications	E-2	Knowledge of previous medications can suggest chronic ischemic or hypertensive cardiac disease, which have impact on LV diastolic function.
Technical information for the interpretation	Criteria for grading LV diastolic function	E-2	Clear reporting of guidelines or criteria followed for diagnosis and grading of LV diastolic function are essential. We suggest following established guidelines rather than implementing own's or other's criteria.
	Guidelines or reference for criteria cited	E-2	
	Technical details of measurements	E-1	Reporting how measurements were performed increases the comparability between studies and improves reproducibility.

Fig. 5 Left ventricle (LV) diastolic function recommendations

Items are divided into two groups: 1) those specifically evaluating the LV diastolic function, and 2) in those allowing a better interpretation of the clinical context when the echocardiography exam is performed. The relative importance (RI) of the item is divided in those essential (E, RI score 4), additional (A, RI score 3) or optional (O, RI score 2). Essential and Additional items are coupled with a graded and coloured scale according to the necessity of increase attention in reporting by the scientific community, as gathered by the results of the critical index (CI). The grades are as follow: 3 - Significant Increase in reporting recommended CI $\geq$ 3 (red); 2 - Increase in reporting recommended 1.0 <CI<3 (orange); 1 - Continue reporting recommended CI $\leq$ 1.0 (green)

PAPs: pulmonary artery systolic pressure; *TDI*: tissue Doppler imaging; *TR*: tricuspid regurgitation.

fluid challenge (nature of fluid, volume administered, duration of administration, safety limits) or the details of other manoeuvers such as passive leg raising. Authors should report technical details of the echocardiographic approach and the measurements performed to assess FR. When a new echocardiographic index is being developed, it is important to report the reference (gold) standard used for comparison.

The panel considers of paramount importance reporting cardiovascular and respiratory conditions for their profound influence on FR (Fig. 6). Although one must assume that FR is evaluated in patients in sinus rhythm, the cardiac rhythm should be clearly reported, and the timing of data acquisition within the cardiac cycle (i.e. end-expiration vs. end-inspiration) should be stated when evaluating stroke volume and velocity–time integral. RV size and presence of RV failure are also pivotal aspects since the ventricular interaction may lead to false-positive results regarding FR [14]. Respiratory parameters are essential as it is clear that FR is influenced by the mode of ventilation, tidal volume, respiratory rate and compliance.

ITEMS			RI of the item and Need for reporting according to CI; RATIONALE
SPECIFIC ITEMS FOR THE EVALUATION OF FLUID MANAGEMENT			
Methods	State the parameters used to predict FR	E-1	Describe the methods used to abruptly increase preload (PLR, FC). Describe the parameters used to assess FR and define responders and non-responders. These recommendations are not specific to echocardiography.
	Description of parameters used to assess FR	E-1	
ITEMS ALLOWING ACCURATE INTERPRETATION OF ECHOCARDIOGRAPHY DATA			
Reference standard and technical info	State the reference standard used for comparison in validation studies (i.e. PLR, FC)	E-1	When evaluating a new parameter or method for FR assessment, it is important to define which reference standard was used. Reference standard could be echocardiographic parameter(s) or other hemodynamic variable(s) (such as pulse pressure or SV variation). For example, authors should make clear when a new echocardiography window is used to acquire a parameter, what are the machine settings and the technique of measurement.
	Detailed technical information on echocardiographic measurements	E-1	
	Sufficiently describe the reference method used (how was PLR or FC performed, how was SV measured, etc)	E-2	
	State if echocardiography is used to measure the change in the reference standard	E-2	
	Clearly define FR	E-2	Always define the parameters and cut-offs used to define FR in the reference standard.

Fig. 6 Fluid management recommendations

Items are divided into two groups: 1) those specifically describing the methods of preload variation and of fluid responsiveness (FR) assessment, and 2) in those allowing a better interpretation providing data on the reference standard methods and technical info. The relative importance (RI) of the item is divided in those essential (E, RI score 4), additional (A, RI score 3) or optional (O, RI score 2). Only Essential items were graded in this topic. Such items are coupled with a graded and coloured scale according to the necessity of increase attention in reporting by the scientific community, as gathered by the results of the critical index (CI). The grades are as follow: 3 - Significant Increase in reporting recommended CI $\geq$ 3 (red); 2 - Increase in reporting recommended 1.0 <CI<3 (orange); 1 - Continue reporting recommended CI $\leq$ 1.0 (green)

PLR: passive leg raising; *SV*, stroke volume; *VC*: volume challenge

Use of the recommendations

The PRICES recommendations are most useful when conducting prospective CCE research studies. Researchers are encouraged to collect and report "essential" and (possibly) "additional" items, according to the topic(s) investigated. On the other hand, PRICES recommendations should not refrain authors from publishing repositories of historical CCE information and these recommendations may be less useful in case of retrospective studies as some data might not be stored in the database. Therefore, we acknowledge potential challenges in the practical implementation of our PRICES guidelines. The goal of PRICES is not to exclude retrospective studies from the pathway of CCE research, but rather to provide researchers with some guidance in reporting, in the hope to limit biases in CCE research. In general, we believe that the PRICES recommendations are a useful guide as to what and which data to collect, if available. If unavailable, the researchers can simply report that some of the items were not available (for instance due to the retrospective study design).

Limitations

The recommendations presented in this document are the results of huge efforts of integrating information gathered from the systematic appraisal of the published literature subject to expert opinion [3]. We believe that this method is a significant strength of our approach but

due to its novelty it may be subsequently refined. In this regard, we hope that it will be adopted and refined by other expert groups. Another limitation is that selected items were determined in advance and therefore some other items of interest may have not been considered.

However, we believe that the RI for these latter items would have not been rated as essential, but most likely as additional or optional. The authors fully acknowledge they did not entirely follow the approach suggested in the PRICES guidelines in their previous studies. Finally, this statement does not aim to guide researchers in the field of CCE on how they have to measure echocardiographic parameters but rather to give them a checklist of items that should be reported by prospective studies.

Conclusion

We report the PRICES recommendations, with an international consensus and a checklist for standardized reporting of CCE research studies. The intention is to provide guidance to researchers in the field of CCE with respect to methodology when developing research studies, and subsequently for a more standardized reporting of research findings.

Electronic supplementary material
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Compliance with ethical standards

Conflicts of interest
The authors declare that they have no conflict of interest statement.

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