Check for updates

Received: 17 December 2023 | Revised: 19 January 2024 | Accepted: 20 January 2024

DOI: 10.1111/echo.15773

Echocardiography WILEY

REVIEW

Diastology in the intensive care unit: Challenges for the assessment and future directions

Filipe A. Gonzalez MD[1,2] | Cristina Santonocito MD[3] | Marc O. Maybauer MD, PhD[4] | Luís Rocha Lopes MD, PhD[5,6] | Ana G. Almeida MD, PhD[2] | Filippo Sanfilippo MD, PhD[3,7]

[1]Intensive Care Department of Hospital Garcia de Orta, Almada, Portugal

[2]Centro Cardiovascular da Universidade de Lisboa, Faculdade de Medicina, Universidade de Lisboa, Lisbon, Portugal

[3]Department of Anesthesia and Intensive Care, "Policlinico-San Marco" University Hospital, Catania, Italy

[4]Department of Anesthesiology, Division of Critical Care Medicine, University of Florida College of Medicine, Gainesville, Florida, USA

[5]Inherited Cardiac Disease Unit, Bart's Heart Centre St Bartholomew's Hospital London, London, UK

[6]Institute of Cardiovascular Science, University College London, London, UK

[7]Department of Surgery and Medical-Surgical Specialties, University of Catania, Catania, Italy

Correspondence
Filipe André Gonzalez, Centro Cardiovascular da Universidade de Lisboa, Faculdade de Medicina, Universidade de Lisboa, Lisbon, Portugal; Intensive Care Department, Hospital Garcia de Orta, Almada, Portugal.
Email: filipeandregonzalez@edu.ulisboa.pt, filipeandregonzalez@gmail.com

Abstract

Myocardial dysfunction is common in patients admitted to the intensive care unit (ICU). Septic disease frequently results in cardiac dysfunction, and sepsis represents the most common cause of admission and death in the ICU. The association between left ventricular (LV) systolic dysfunction and mortality is not clear for critically ill patients. Conversely, LV diastolic dysfunction (DD) seems increasingly recognized as a factor associated with poor outcomes, not only in sepsis but also more generally in critically ill patients. Despite recent attempts to simplify the diagnosis and grading of DD, this remains relatively complex, with the need to use several echocardiographic parameters. Furthermore, the current guidelines have several intrinsic limitations when applied to the ICU setting. In this manuscript, we discuss the challenges in DD classification when applied to critically ill patients, the importance of left atrial pressure estimates for the management of patients in ICU, and whether the study of cardiac dysfunction spectrum during critical illness may benefit from the integration of left ventricular and left atrial strain data to improve diagnostic accuracy and implications for the treatment and prognosis.

KEYWORDS
critically ill, diastolic dysfunction, echocardiography, intensive care, left atrial strain, myocardial dysfunction

1 | INTRODUCTION

Myocardial dysfunction is a common finding in patients admitted to the intensive care unit (ICU).[1] Patients with cardiogenic shock have profound cardiovascular compromise and consequently high mortality. However, also other critically ill patients frequently suffer from cardiac dysfunction; for instance, this is the case of patients with septic shock. Importantly, sepsis represents the most common cause of admission

Abbreviations: ASE/EACVI, American Society of Echocardiography/European Association of Cardiovascular Imaging; DD, diastolic dysfunction; EDP, end-diastolic pressure; EF, ejection fraction; FP, filling pressure; GLS, global longitudinal strain; ICU, intensive care unit; LA, left atrium; LV, left ventricle; MV, mechanical ventilation; PALS, peak atrial longitudinal strain; RV, right ventricle; TDI, tissue doppler imaging; TRV, tricuspid regurgitant jet velocity; VEXUS, venous excess ultrasound.

This is an open access article under the terms of the Creative Commons Attribution License, which permits use, distribution and reproduction in any medium, provided the original work is properly cited.
© 2024 The Authors. *Echocardiography* published by Wiley Periodicals LLC.

to ICU with mortality further increasing when cardiac dysfunction develops.[2]

Cardiac involvement in patients admitted to ICU has been typically classified as left, right or biventricular systolic function. However, recently, the association between left ventricular (LV) diastolic dysfunction (DD) has received more attention, being increasingly recognized for its association with poor outcomes. Such observation was primarily seen in the context of septic patients,[3] but the negative effects of DD on outcomes have also been found in other circumstances, such as the weaning process from mechanical ventilation (MV).[4]

Our review will focus on introducing the importance of DD in the ICU with particular attention to the septic critically ill patients, leaving apart the cardiogenic shock and the cardiac surgery setting. We will summarize first the challenges in the current classification of DD on critically ill patients, despite its recognized impact on prognosis and mortality. Then, we will describe new tools for the assessment of DD with a focus on strain echocardiography.

2 | MYOCARDIAL DYSFUNCTION IN ICU–SYSTOLIC DYSFUNCTION

Several factors influence myocardial function in the general ICU population, and sepsis is probably the best example as it is one of the most encountered causes of admission; moreover, in terms of research on the impact of myocardial dysfunction in ICU patients, sepsis is also the most explored setting. Circulatory compromise is a hallmark of the disease, and even more, if septic shock develops.[5] The reduction in venous and arterial tone is a well-known factor leading to a reduction in preload and afterload in septic patients with consequent hypotension and hypoperfusion. However, the clinical scenario can be additionally complicated by the occurrence of cardiac dysfunction, which further increases the risk of death.[6] Nonetheless, its characteristics and frequency, as well as its long-term consequences, remain very unclear. Indeed, while it has been widely accepted that the occurrence of myocardial involvement in the context of sepsis, and particularly in patients with septic shock- septic cardiomyopathy, has not yet found an accepted definition since its clinical manifestations may variably involve the LV, the right ventricle (RV), or both, as well as simultaneously affecting systolic and/or diastolic function.[7] Not only may sepsis grossly influence myocardial dysfunction in the ICU, but other factors, such as MV with positive pressure and other clinical conditions, may have a significant clinical impact. Indeed, other populations of critically ill patients have been explored, but the consistency of the results and the grade of evidence reported is very low, as in the case of cardiac dysfunction in patients affected by subarachnoid hemorrhage.[8]

Recently, DD was associated with poor outcomes in sepsis, whilst the association is more unclear when looking at LV systolic dysfunction. Before entering the discussion on the clinical impact of DD, we believe it is important to have a preliminary summary of the most recent findings regarding the influence of LV systolic function on patients' outcomes.

Recently, a clustering approach was developed using the multicenter French cohort of septic shock patients (4); based on clinical and echocardiographic parameters, the authors characterized five different cardiovascular phenotypes, as summarized in Table 1.

Hence, as it can be observed, the highest mortality was reported in those with LV systolic dysfunction, followed by RV failure and persistent hypovolemia, while the LV hyperkinetic profile did not seem associated with an increase in mortality. However, this is a controversial matter since a recent retrospective study conducted on over 3,000 patients showed a U-shape association between LV ejection fraction (EF) and in-hospital mortality in septic patients; indeed, both severe systolic dysfunction (LVEF $< 25\%$) and hyperdynamic conditions (LVEF $\geq 70\%$) were independently associated with higher mortality.[10] Hence, the latter study confirms the poor outcomes of patients with severe LV systolic dysfunction but also highlights the impact of a hyperdynamic profile. Further, metanalyses conducted so far have not shown an association between LVEF and mortality in sepsis.[3,11] Similarly, the prognostic role of s' wave obtained with Tissue Doppler Imaging (TDI) has not shown an association with mortality,[12] whilst data on mitral annular plane systolic excursion is growing but yet scarce in the literature.[13]

3 | DIASTOLIC DYSFUNCTION–THE PREVIOUSLY FORGOTTEN PHENOTYPE

Diastolic function in critically ill patients has been receiving more attention only in the past decade. Assessing LV diastolic function is more complex and requires advanced echocardiography competencies as compared to evaluating LV systolic function.[14] A recent meta-analysis demonstrated a strong association between the diagnosis of DD and mortality in septic patients and confirmed no association between LV systolic dysfunction and mortality.[3] Subsequently, another metanalysis showed that worse TDI diastolic-related parameters (lower e' and higher E/e' ratio) are associated with mortality in septic patients[15]; later, the same findings were reported for the weaning from MV, where DD was associated with greater risk of weaning failure.[15] Also, another study reported in a group of cardiac surgery patients that any grade of diastolic dysfunction was associated with greater all-cause morbidity compared with patients with normal diastolic function.[16] So, these findings suggest the overall importance of properly assessing DD in critically ill patients.

4 | DIASTOLIC DYSFUNCTION ASSESSMENT AND THE CHALLENGES IN THE ICU PATIENTS

Echocardiography is essential for the noninvasive evaluation of LV diastolic function. The term diastolic function comprehends several mechanisms and measurements, including active myocardial relaxation (which significantly influences early ventricular filling), LV compliance, which is related to the ability to accept volume (filling) from the left atrium (LA) depending on "LV stiffness," and finally the estimation of

15408175, 2024, 2, Downloaded from https://onlinelibrary.wiley.com/doi/10.1111/echo.15773 by Universitá Di Catania, Wiley Online Library on [08/06/2026]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

TABLE 1 Prevalence and mortality of the patients included in the analysis according to cluster partition on the French cohort.[9]

Cluster and characteristics	Prevalence	Day 7 mortality	ICU mortality
1-well resuscitated with no LV systolic dysfunction, RV failure or fluid responsiveness	16.9%	9.8%	21.3%
2-LV systolic dysfunction	17.7%	32.8%	50.0%
3-LV hyperkinetic profile	23.3%	8.3%	23.8%
4-RV failure	22.5%	27.2%	42.0%
5-Persistent hypovolemia	19.4%	23.2%	38.6%

Abbreviations: ICU: Intensive Care Unit; LV: Left Ventricular; RV: Right Ventricular.

LA pressures as a pathophysiological consequence of worsening LV diastolic function.[17]

Over the years, there has been an evolution in the diagnosis and grading of DD. The 2016 American Society of Echocardiography/European Association of Cardiovascular Imaging (ASE/EACVI) guidelines were the latest published document and have proposed a new algorithm for diagnosis and grading of DD (reported in supplementary material), for the first time separating patients with depressed LVEF from those with normal systolic function.[18] This algorithm relies on four diastolic variables for the diagnosis of DD, and it is mostly dependent on expert consensus-based categorization schemes, with an overall accuracy of 67%—75% but with higher specificity for detecting elevated LV filling pressure (FP) than the previous 2009 guidelines.[19] Although it is not the focus of our review to enter details of the value of each variable, we think that the four parameters used by the latest guidelines for the diagnosis of DD[18] deserve some brief considerations on their value for critically ill patients:

A. The e' values (where e' is the TDI of mitral annulus early diastolic velocity) are sampled at basal myocardial segments. The hemodynamic determinants of the e' wave are LV relaxation, the restoring forces and the FP and are affected by several conditions, including the presence of mitral valve disease (i.e., calcifications) and myocardial ischemia (acute or chronic),[18] but more importantly it may be modified by the increase in heart rate,[20] especially in the ICU population where heart rate may reach extreme values in certain circumstances.
B. The mitral E/e' ratio, which seems one of the best parameters to estimate LA pressure, is influenced by the conditions affecting both the E (arrhythmias, age, mitral and coronary artery disease, to name a few) and the e' waves (see above); in general, this parameter is useful as it corrects the E wave for the effect of LV relaxation. The E/e' ratio relates directly to LA pressure, but the cut-off in the ICU may be different from those in other settings.
C. The LA volume gained importance in the recent guidelines, but ICU physicians must be aware that it provides more useful indications regarding a chronic elevation of LA pressure,[18] hence its usefulness in critically ill patients to describe acute changes of LA pressure is doubtful.
D. The tricuspid regurgitation jet velocity (TRV) has been introduced because it delivers information on the impact of increased LA pressure on the right-side circulation in the absence of precapillary pulmonary hypertension. However, exacerbation of chronic pulmonary disease and the effects of MV with positive pressure have a profound influence on TRV, and this parameter cannot differentiate the overload on pulmonary circulation from pre- or postcapillary origin.

5 | WHAT SHOULD YOU QUESTION ABOUT THE BEDSIDE MANAGEMENT OF LEFT VENTRICULAR DIASTOLIC DYSFUNCTION IN THE ICU?

ICU clinicians understanding the relevance of LV diastolic function for the outcome of their patients should consider two main questions that could influence their decision-making:

1. Can I use the parameters and cut-offs suggested by the current recommendations in the ICU setting to reach a diagnosis and a grading?
2. Are the LA and LVFP of my patients elevated?

To answer the first question, it should be considered that parameters used for the assessment of DD become even more challenging when applied to critical illness due to fluid shifts with variation in preload, changes in afterload and use of vasoactive drugs, the influence of sedation and of MV, just to name a few. Hence, a fair amount of patients may remain in a grey zone between normal and abnormal LV diastolic function. The most recent 2016 ASE/EACVI guidelines[18] represent an improvement, which has also been confirmed when applying these recommendations to the ICU setting. For instance, in a population of septic patients, Clancy et al.[21] compared the assessment obtained with the most recent guidelines (2016) to the previous ones (2009) and demonstrated a significant difference in the prevalence of DD (for instance, on the first day the authors found 60% with the 2016 guidelines as compared to 21% with the older 2009 recommendations). Furthermore, the authors found a much lower prevalence of indeterminate LV diastolic function (23%) as compared to a three times higher with previous guidelines (74%). Cavefors et al. found that general ICU patients with indeterminate LV diastolic function (2016 guidelines) had the same four-fold increased risk of death as those who had fulfilled the criteria for isolated DD.[22] On reflection, it is likely that

15408175, 2024, 2, Downloaded from https://onlinelibrary.wiley.com/doi/10.1111/echo.15773 by Università Di Catania, Wiley Online Library on [08/06/2026]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

a significant proportion of patients classified as indeterminate had indeed DD that could not be verified with current criteria; consistently, increased mortality has also been seen in patients with indeterminate DD in other cohorts.[23,24]

The second clinically oriented question for ICU clinicians is to estimate if DD has resulted in an increase in LA and LVFP. Addressing such questions is far more complex with noninvasive methods, but the answer has significant clinical implications in the management of critically ill patients, with consequences on the interpretation of hemodynamic and respiratory parameters, on the appropriateness of performing fluid challenges, or to apply a more restrictive approach.[25] Also, in this regard, the newest guidelines (2016) seem an improvement. According to the Euro-Filling study,[26] the latest guidelines[18] have represented a simplification and improvement[19] for the prediction of invasively measured LVFP.

Considering the challenges of DD assessment in critically ill patients and the influence of several conditions on each of the echocardiographic parameters used, a simplified definition for DD in ICU was proposed, using only two parameters (septal e′ < 8 cm/s for diagnosis of DD; values of E/e′ for DD grading).[27] In this study. such a simplified definition categorized more septic patients than the ASE 2009 definition, but without differences in clinical outcome or comorbidities. Notably, after the publication of the 2016 guidelines,[18] the authors subsequently explored their simplified definition of septic patients and showed that it guaranteed a characterization of a significantly higher number of septic patients with respect to their LV diastolic function (78%), as compared to the 2016 and 2009 guidelines (71% vs. 34%, respectively). Moreover, they highlighted that ASE/EACVI 2016 guidelines designate many patients with normal LV diastolic function despite having an elevated E/e' ratio, hence with a high likelihood of increased LA pressure.[28] Such discrepancy has been confirmed in patients with COVID-19, where a fair proportion of patients with normal LV diastolic function (2016) had grade II or grade III DD according to the simplified definition.[29] In another COVID-19 cohort, cardiac dysfunction was detected by speckle tracking echocardiography in 73% of patients, 60% of which with DD that correlated with immuno-inflammatory biomarkers.[30]

From the above literature summary, it seems apparent that there are several concerns in applying the guidelines for the assessment of DD in the ICU setting, which could be summarized as follows.

A. First, the cut-off validated for self-breathing patients cannot be easily translated into the typical ICU patients supported with inotropes and/or vasopressors, sedated and ventilated, and eventually exposed to large fluid shifts.[31] In critically ill patients supported by MV, the cut-off values of E/e' ratio to predict an increase in LA pressure have consistently differed from those suggested in outpatients, and a ratio of 8 seems the most likely appropriate threshold in predicting an increase in LA pressures, rather than the cut-offs ranging between 13 and 15 used for the outpatient population.[32,33] Similarly, even though TRV is an excellent parameter to describe the presence of pulmonary hypertension, it cannot distinguish between pre- and postcapillary increase in vascular resistances, and in critically ill patients, it is particularly challenging to balance the effects of MV on the values of TRV.[34]
B. Second, the guidelines are not set for identifying acute deterioration of the LV diastolic function,[35] and ICU patients suffering from acute conditions may experience rapid clinical evolutions (in minutes or hours) that cannot be detected by guidelines developed for patients undergoing follow-up over the years.
C. Third, premorbid (chronic) LV diastolic function is most often unknown before admission to ICU, making it difficult to value and interpret the worsening or the reversibility of DD in critically ill patients and its potential impact on prognosis.[36]
D. Finally, it must be acknowledged that neither LVFP nor outcomes have consistently been linked with the four major parameters used to diagnose DD.[12,26,37–39] For instance, the accuracy of E/e' ratio in predicting elevated LVFP has been questioned in patients with advanced heart failure.[40] However, in critically ill patients, besides the difference in reference values, e' and E/e' ratio was associated with mortality.[31]

6 | BEYOND CLASSIFICATION! ESTIMATING LA PRESSURE, THE MOSTLY NEEDED DIASTOLIC INFORMATION IN THE ICU

Given the crucial clinical relevance of understanding LA pressure for the estimation of the pathophysiological impact of DD, parameters that provide information about LA properties may be very useful and new parameters of interest have been introduced.

Apart from the four parameters discussed for the diagnosis of LVDD, once the diagnosis of DD is made, the E/A ratio is still a pivotal variable to classify in grades I, II or III. During isovolumic relaxation, LV pressure falls rapidly, and when it has declined below LA pressure, a positive LA-to-LV gradient is established, the mitral valve opens and the LV fills rapidly, originating E-velocity. During this passive LV filling (diastasis), LA and LV pressures tend to equilibrate and mitral valve leaflets approach closure. However, the beginning of LA contraction causes an increase in LA pressure with a new LA-to-LV gradient and late diastolic filling occurs, originating A-velocity.[41] However, the E/A ratio interpretation may have several pitfalls because it is influenced not only by myocardial relaxation and LV ventricular stiffness but also by the LA pressure itself. The LA pressure is affected by LV properties, and it rises as a physiological adaptation to LV stiffness due to fluid retention. Indeed, the E/A ratio decreases to values below .8 (depending also on other factors such as age and gender) when LV relaxation is impaired. However, the adaptation to the DD progression involves an increase in LA pressure that restores the "normal" LA-to-LV gradient and the values of E/A ratio (hence this condition is termed "pseudonormalization," despite being a relatively advanced DD, grade II). With further progression of the DD and increase in LV stiffness, additional changes in E/A ratio are observed, with a predominantly early filling pattern and abrupt termination of LV filling even in the presence of active LA contraction—the so-called "restrictive" pattern (grade III). For these reasons, the evaluation of the E/A ratio cannot be used on its own

15408175, 2024, 2, Downloaded from https://onlinelibrary.wiley.com/doi/10.1111/echo.15773 by Università Di Catania, Wiley Online Library on [08/06/2026]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

to estimate DD and LA pressures, especially in critically ill patients, and this parameter requires contextualization to clinical conditions (i.e., the presence of tachycardia).

To further complicate matters, even though they are frequently used interchangeably, the mean LA pressure and the LV end-diastolic pressure (EDP) do not, from a physiological standpoint, convey the same information. The closest estimate of LV preload serving as a proxy for LV end-diastolic volume is provided by the LVEDP, which also gives information regarding LV operating compliance. Patients with similar LVEDP can experience significantly varying LA pressure, which is also affected by the operating compliance of the LA.[42] This idea is extremely important in the ICU because, for instance, fluid challenges and modifications to MV settings can result in changes to LA compliance. The LA should not be thought of as a passive conduit, and the mean LA pressure integrates the values from both systole and diastole to provide a measurement of the hemodynamic load determined by the LA operating compliance (and indirectly, the LV operating compliance through atrioventricular coupling). Naturally, the pulmonary venous circulation receives a reflection of the mean LA pressure, which affects RV function and gas exchanges.[42] Hence, a more detailed study of the LA function may be desirable to manage critically ill patients.

7 | NEW PARAMETERS FOR MYOCARDIAL DYSFUNCTION: THE ROLE OF STRAIN

Considering the differences in cut-off seen between the cardiology patient population and the critically ill patients, as well as the complexity of LA function, estimating the bedside mean LA pressure remains a challenge. An alternative echocardiographic modality, speckle-tracking echocardiography, has gradually emerged as a better marker of intrinsic cardiac function with the description of myocardial strain.[43] In the case of the LV, strain represents the difference between the final length of each segment relative to its resting length and can be measured in different planes, mainly longitudinal (from base to apex) and circumferential (rotational short axis). A third form of strain (radial) evaluates inward short-axis movement, but it is less commonly described and infrequently used. The assessment of LV strain can be performed during bedside echocardiography with software-equipped machines, although its clinical feasibility in MV patients seems suboptimal as compared to self-breathing patients.[44] Global longitudinal strain (GLS) is the most commonly reported strain measure and averages the strain values of all segments visualized from the three apical windows. More negative GLS values indicate better LV performance. Interestingly, LV strain's ability to predict prognosis in septic patients has been shown by a meta-analysis,[45] and GLS seems to identify patients with deterioration of LV systolic function earlier than LVEF may do (Figure 1 and Video 1-supplementary material).[44] Further, within the context of sepsis, GLS may better quantify cardiac dysfunction. Indeed, Ng et al.[46] compared patients with septic shock (90-day mortality 41.9%) with a control group of septic patients without shock (90-day mortality 0%), showing a higher degree of myocardial dysfunction in those with septic shock (GLS −14.5%) as compared with controls (−18.3%); on the contrary, LVEF was similar between groups. Another study compared critically ill adult patients with early severe sepsis/septic shock to a control population of major trauma patients with no sepsis; the authors found that half of the septic patients with preserved LVEF (>50%) had depressed values of GLS, as compared to only 8.7% in the nonseptic trauma group.[47]

The assessment of LA deformation via strain has been gradually investigated as an accurate and reproducible analysis of the LA function[48] (Figure 2). The better the LA function, the more positive will be the LA strain values (Figure 3 and Video 2-supplementary material). In a multicenter study using invasive hemodynamic monitoring, progressively lower LA strain values were associated with increasingly higher LVFP, and this association was even stronger for patients with reduced LVEF and depressed LV-GLS values.[49] The optimal cut-off to differentiate between normal and elevated LVFP was <18% for LA reservoir strain (when using >12 mmHg as a marker of elevated "wedge pressure"); alternatively, a peak atrial longitudinal strain (PALS) cut-off of <16% has been identified when referring to a "wedge pressure" ≥15 mmHg or to an LVEDP ≥16 mmHg. On the other hand, when PALS exceeds 24% few patients have elevated LV filling pressure. Another study showed striking differences between DD evaluation by classic criteria as compared to the use of LA strain values, namely PALS (28.6% vs. 57.1%, $p = .0006$). Of note, when comparing the classic algorithm for DD assessment with the LA strain, the latter was also able to discriminate patients with worse RV systolic function as evaluated by RV-GLS (21.8% vs. 26.9%) and lower cardiac index (2.5 L/min/m^2 vs. 2.8 L/min/m^2).[50]

8 | FUTURE DIAGNOSTIC APPROACHES TO LVDD AND LA PRESSURE IN ICU

Multivariable models integrating more recent markers, such as the LA strain, seem to outperform other algorithms in terms of prognosis accuracy.[51–53] It has been recently demonstrated that LA strain is a better predictor of LVFP and pulmonary pressure than other conventional indices,[54–56] with a strong association with the severity of DD[57–59] and with prognosis in different clinical scenarios, including heart failure.[51,52] However, PALS has only been recommended in circumstances of ambiguous assessments or inconclusive DD, restricting its clinical usefulness to a relatively small number of instances; hence, it remains unclear its potential benefit for everyday use. In a recent study,[60] in order to identify phenotypes with comparable behavior for forecasting unfavorable outcomes, the authors looked at unsupervised clustering to categorize directly recorded LV diastolic function measures in patients with heart failure, including PALS, only slightly agreeing with the classification determined by the 2016 guidelines.[18] This analysis yielded three separate groups that outperformed guideline-based categorization for forecasting unfavorable occurrences during follow-up (66) and corresponded to greater DD severity. Numerous research that used similar DD variables, PALS, and the 2016 ASE/EACVI classification to compare it to machine

15408175, 2024, 2, Downloaded from https://onlinelibrary.wiley.com/doi/10.1111/echo.15773 by Università Di Catania, Wiley Online Library on [08/06/2026]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

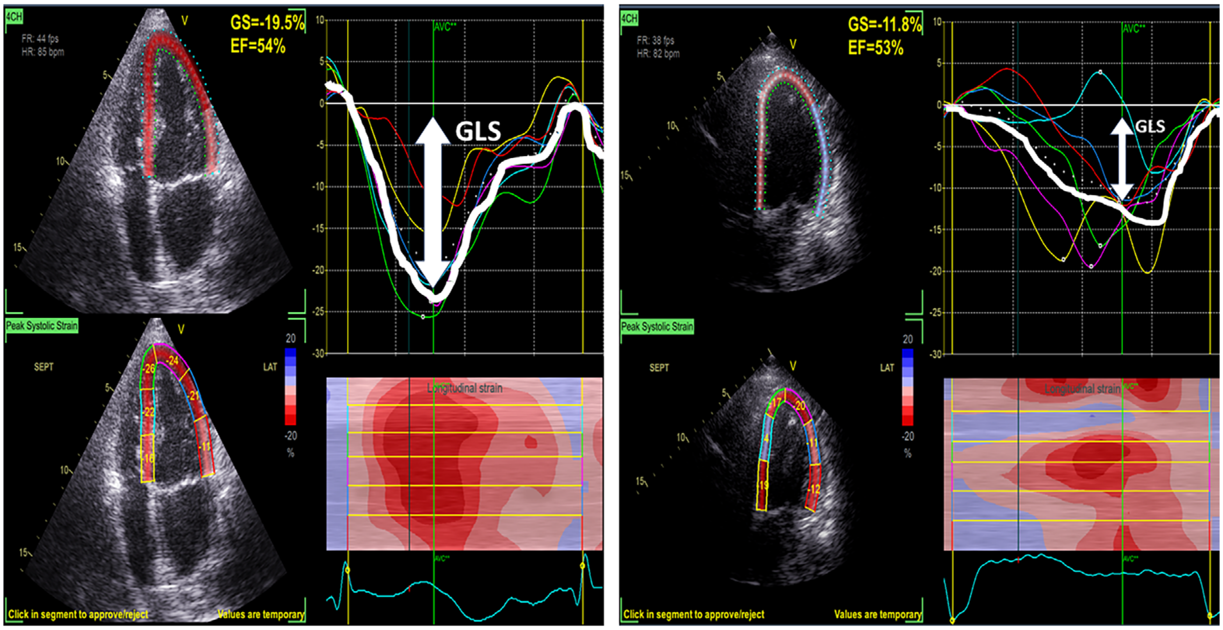

FIGURE 1 LV GLS image representation in two different settings: first (left), good LV GLS with preserved LVEF; second (right), depressed LV GLS with preserved LVEF, demonstrating that LV GLS can be an earlier marker of cardiac dysfunction than LVEF. LV: left ventricle; GLS: global longitudinal strain; LVEF: left ventricle ejection fraction.

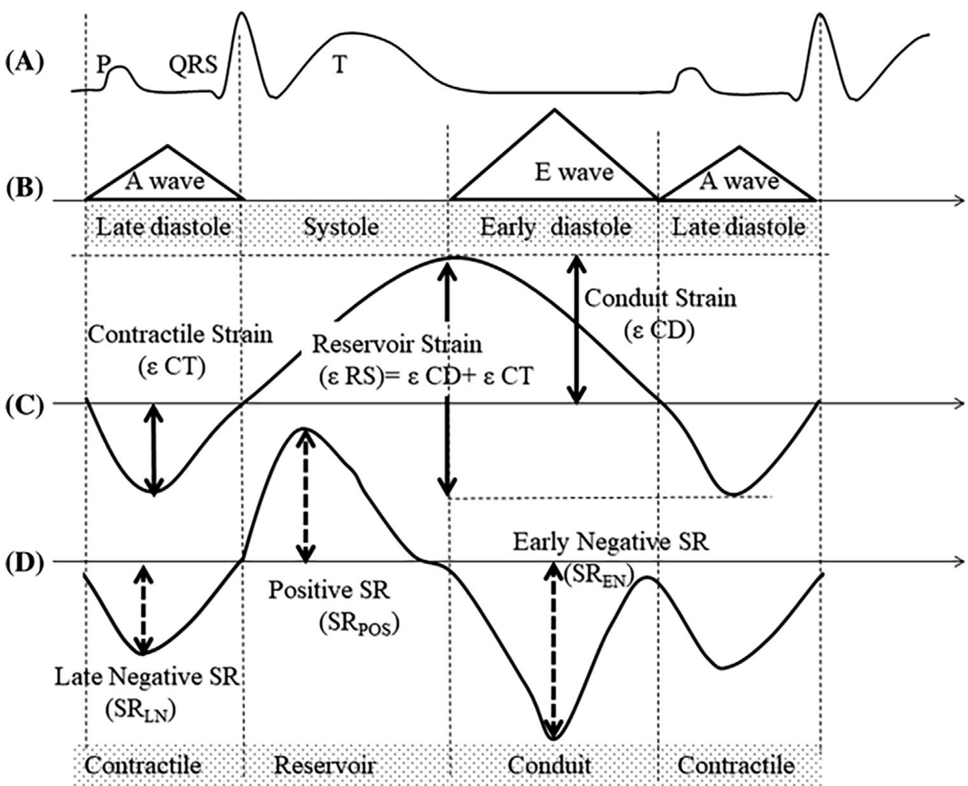

FIGURE 2 Schematic representation of LA functions during the cardiac cycle. (A) ECG. (B) Transmitral Doppler flow velocity profiles. (C) LA strain curve. (D) LA strain rate curve. *εCD* conduit strain, *εCT* contractile strain, *εRS* reservoir strain, *SR* strain rate, SR_{EN} early negative strain rate, SR_{LN} late negative strain rate, SR_{POS} positive strain rate.

15408175, 2024, 2, Downloaded from https://onlinelibrary.wiley.com/doi/10.1111/echo.15773 by Università Di Catania, Wiley Online Library on [08/06/2026]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

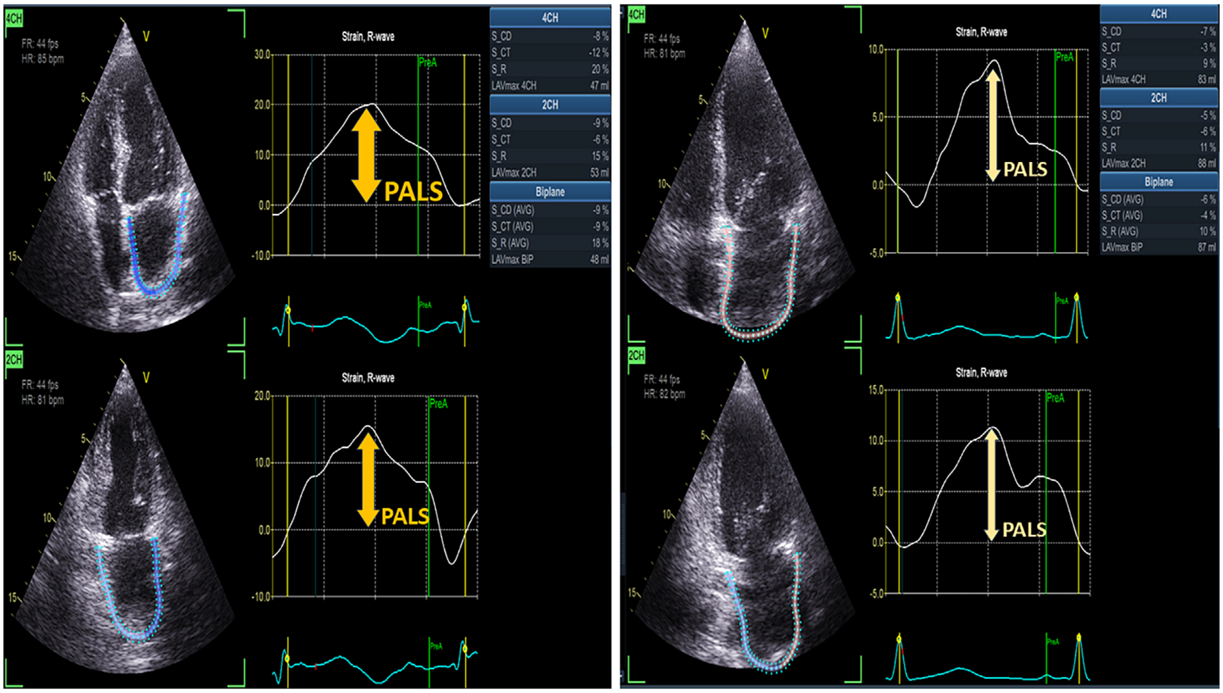

FIGURE 3 PALS image representation in two different settings: preserved PALS (left) versus compromised PALS (right). PALS: peak atrial longitudinal strain.

learning-based methodologies have adequately demonstrated that a cluster-based classification works better than a consensus-based classification.[61–63]

At the same time, the proposed algorithm[60] draws attention to the possible value of PALS in DD grading. According to the 2016 ASE/EACVI consensus, patients with E/A ratios between .8 and 2.0 who are categorized as having DD grade-1 may be able to be identified using PALS. Surprisingly, the TRV (one of the four pillars of current recommendations) was omitted from the classification and regression tree analysis, raising the possibility that this parameter could be a misleading indicator of DD, given that elevated pulmonary pressure may also be associated with other conditions that are not primarily heart-related. Additionally, this is possible with MV patients. The classification and regression tree analysis also revealed that the cut-off values for the pertinent DD factors changed based on the characteristics and combination of features of the patient and other echocardiographic diastolic variables and were also different from that proposed by current consensus documents, especially for LA volume index and PALS.

Hence, we think that it is likely that the current cardiology guidelines will be at some point revised with the chance to introduce PALS or other strain-based parameters describing LA function, and possibly with a contribution from artificial intelligence.[64] Much literature already exists regarding systolic function and fluid status assessment using machine learning algorithms applying automatic measurements of LVEF and left ventricular outflow tract velocity time integral.[65–67] Considering all the pitfalls described for the assessment of DD in critically ill patients, we consider a more holistic approach to the diastolic function in the ICU more valuable. Experienced clinicians should integrate the hemodynamic information (based not only on echocardiographic variables) with other data from like lung ultrasound (LUS), the venous excess ultrasound (VExUS), and the ventriculo-arterial coupling,[68,69] to better stratify critically ill patients according to their pathophysiologic profile and prognostic impact. Briefly, LUS has been confirmed to be a rapid, noninvasive, and reproducible bedside tool to estimate the extravascular lung water,[70] and it is turning into a key component for determining the presence of pulmonary edema and estimating its severity in different clinical contexts[71,72]; hence, it could help to understand whether there is a clinically relevant impact of increased LA pressure. The use of VExUS relies on the measurement of the inferior vena cava's size in conjunction with Doppler flow interrogation at the level of the hepatic, portal, and intrarenal veins, and it may be useful in assessing the systemic venous congestion and directing fluid management,[73] helping the clinical decision-making regarding fluid tolerance. Finally, the ventriculo-arterial "decoupling," which is present in most septic patients,[74] either from increased vasomotor tone, decreased LV contractility, or both, can lead to heart failure, loss of volume responsiveness and, if sustained, increased mortality.[75] In these patients, knowledge of LV systolic and diastolic function with an estimation of LA pressure may help in tailoring treatment regarding fluids and possibly vasoactive drugs (i.e., beta-blockers). In short, a more integrative approach is needed in critically ill patients, beginning with data gathered from the classic DD guidelines and integrating clinical variables with other more advanced information, including the LA strain, such as the proposed algorithm in Figure 4.

15408175, 2024, 2, Downloaded from https://onlinelibrary.wiley.com/doi/10.1111/echo.15773 by Università Di Catania, Wiley Online Library on [08/06/2026]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

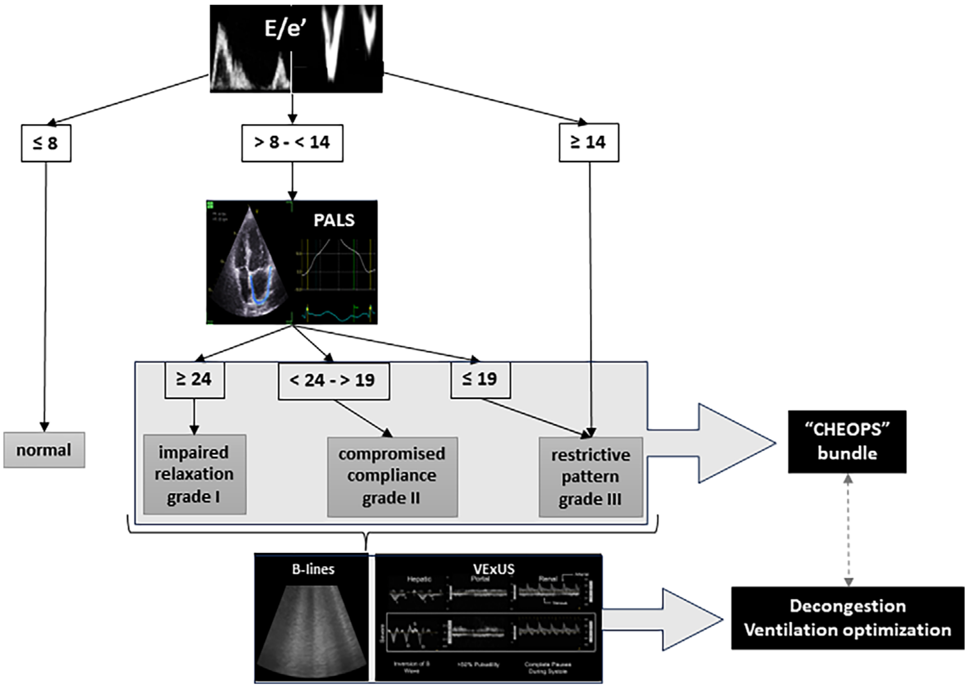

FIGURE 4 Proposed algorithm for diastolic dysfunction classification and management for the critically ill patient. PALS—peak atrial longitudinal strain; VExUS—venous excess ultrasound; CHEOPS[68] - Chest Ultrasound, combining information from echocardiography and lung ultrasound; HEmodynamics assessment, with careful evaluation of heart rate and rhythm, as well as afterload and vasoactive drugs; OPtimization of mechanical ventilation and pulmonary circulation, considering the effects of positive end-expiratory pressure on both right and left heart function; Stabilization, with cautious fluid administration and prompt fluid removal whenever judged safe and valuable.

9 | CONCLUSION

The classification of DD relies on several parameters that are significantly affected by several factors in critically ill patients, and currently we lack standardized DD criteria in the ICU. This can lead to inconsistent diagnoses and possibly inappropriate management strategies. More importantly, the key question on the presence of increased LA pressure remains often unanswered. Therefore, there is a need to develop tailored classification criteria for DD in critically ill patients. We envisage that the gradual integration of the LA strain values as well as the use of artificial intelligence, may both help in the near future with the diastolic assessment in ICU.

CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

Data sharing not applicable to this article as no datasets were generated or analyzed during the current study

ORCID

Filipe A. Gonzalez MD https://orcid.org/0000-0002-8539-1092
Filippo Sanfilippo MD, PhD https://orcid.org/0000-0001-5144-0776

REFERENCES

1. Walley KR. Sepsis-induced myocardial dysfunction. *Curr Opin Crit Care*. 2018;24(4):292-299. doi:10.1097/MCC.0000000000000507
2. Vieillard-Baron A. Septic cardiomyopathy. *Ann Intensive Care*. 2011;1(1). doi:10.1186/2110-5820-1-6
3. Sanfilippo F, Corredor C, Fletcher N, et al. Diastolic dysfunction and mortality in septic patients: a systematic review and meta-analysis. *Intensive Care Med*. 2015;41(6):1004-1013. doi:10.1007/s00134-015-3748-7
4. Sanfilippo F, Di Falco D, Noto A, et al. Association of weaning failure from mechanical ventilation with transthoracic echocardiography parameters: a systematic review and meta-analysis. *Br J Anaesth*. 2021;126(1):319-330. doi:10.1016/j.bja.2020.07.059
5. Drosatos K, Lymperopoulos A, Kennel PJ, Pollak N, Schulze PC, Goldberg IJ. Pathophysiology of sepsis-related cardiac dysfunction: driven by inflammation, energy mismanagement, or both? *Curr Heart Fail Rep*. 2015;12(2):130-140. doi:10.1007/s11897-014-0247-z
6. Lin YM, Lee MC, Toh HS, et al. Association of sepsis-induced cardiomyopathy and mortality: a systematic review and meta-analysis. *Ann Intensive Care*. 2022;12(1):1-14. doi:10.1186/S13613-022-01089-3/FIGURES/5
7. Sanfilippo F, Orde S, Oliveri F, Scolletta S, Astuto M. The challenging diagnosis of septic cardiomyopathy. *Chest*. 2019;156(3):635-636. doi:10.1016/j.chest.2019.04.136
8. Messina A, Longhitano Y, Zanza C, et al. Cardiac dysfunction in patients affected by subarachnoid haemorrhage affects in-hospital mortality: a systematic review and metanalysis. *Eur J Anaesthesiol*. 2023;40(6):442-449. doi:10.1097/EJA.0000000000001829
9. Geri G, Vignon P, Aubry A, et al. Cardiovascular clusters in septic shock combining clinical and echocardiographic parameters: a post hoc anal-

15408175, 2024, 2, Downloaded from https://onlinelibrary.wiley.com/doi/10.1111/echo.15773 by Universitá Di Catania, Wiley Online Library on [08/06/2026]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

ysis. *Intensive Care Med*. 2019;45(5):657-667. doi:10.1007/s00134-019-05596-z
10. Dugar S, Sato R, Chawla S, et al. Is left ventricular systolic dysfunction associated with increased mortality among patients with sepsis and septic shock? *Chest*. 2023;163(6):1437-1447. doi:10.1016/j.chest.2023.01.010
11. Huang SJ, Nalos M, McLean AS. Is early ventricular dysfunction or dilatation associated with lower mortality rate in adult severe sepsis and septic shock? A meta-analysis. *Crit Care*. 2013;17(3):R96. doi:10.1186/cc12741
12. Sanfilippo F, Huang S, Messina A, et al. Systolic dysfunction as evaluated by tissue Doppler imaging echocardiography and mortality in septic patients: a systematic review and meta-analysis. *J Crit Care*. 2021;62:256-264. doi:10.1016/j.jcrc.2020.12.026
13. Bergenzaun L, Öhlin H, Gudmundsson P, Willenheimer R, Chew MS. Mitral annular plane systolic excursion (MAPSE) in shock: a valuable echocardiographic parameter in intensive care patients. *Cardiovasc Ultrasound*. 2013;11(1):16. doi:10.1186/1476-7120-11-16
14. Gudmundsson P, Rydberg E, Winter R, Willenheimer R. Visually estimated left ventricular ejection fraction by echocardiography is closely correlated with formal quantitative methods. *Int J Cardiol*. 2005;101(2):209-212. doi:10.1016/j.ijcard.2004.03.027
15. Sanfilippo F, Corredor C, Arcadipane A, et al. Tissue Doppler assessment of diastolic function and relationship with mortality in critically ill septic patients: a systematic review and meta-analysis. *Br J Anaesth*. 2017;119(4):583-594. doi:10.1093/bja/aex254
16. Kyle B, Zawadka M, Shanahan H, et al. Consensus defined diastolic dysfunction and cardiac postoperative morbidity score: a prospective observational study. *J Clin Med*. 2021;10(21):5198. doi:10.3390/jcm10215198
17. Sanfilippo F, Bignami EG, Astuto M, et al. Understanding left ventricular diastolic dysfunction in anesthesia and intensive care patients: a glass with progressive shape change. *Minerva Anestesiol*. 2022;88(11). doi:10.23736/S0375-9393.22.16425-4
18. Nagueh SF, Smiseth OA, Appleton CP, et al. Recommendations for the evaluation of left ventricular diastolic function by echocardiography: an update from the American society of echocardiography and the European association of cardiovascular imaging. *J Am Soc Echocardiogr*. 2016;29(4):277-314. doi:10.1016/j.echo.2016.01.011
19. Nagueh SF, Appleton CP, Gillebert TC, et al. Recommendations for the evaluation of left ventricular diastolic function by echocardiography. *Eur J Echocardiogr*. 2009;10(2):165-193. doi:10.1093/ejechocard/jep007
20. Burns AT, Connelly KA, La Gerche A, et al. Effect of heart rate on tissue Doppler measures of diastolic function. *Echocardiography*. 2007;24(7):697-701. doi:10.1111/J.1540-8175.2007.00466.X
21. Clancy DJ, Scully T, Slama M, Huang S, McLean AS, Orde SR. Application of updated guidelines on diastolic dysfunction in patients with severe sepsis and septic shock. *Ann Intensive Care*. 2017;7(1):121. doi:10.1186/s13613-017-0342-x
22. Cavefors O, Ljung Faxén U, Bech-Hanssen O, et al. Isolated diastolic dysfunction is associated with increased mortality in critically ill patients. *J Crit Care*. 2023;76:154290. doi:10.1016/j.jcrc.2023.154290
23. Playford D, Strange G, Celermajer DS, et al. Diastolic dysfunction and mortality in 436 360 men and women: the National Echo Database Australia (NEDA). *Eur Heart J Cardiovasc Imaging*. 2021;22(5):505-515. doi:10.1093/ehjci/jeaa253
24. Chung YJ, Choi KH, Lee SH, et al. Prognostic impact of indeterminate diastolic function in patients with functionally insignificant coronary stenosis. *J Am Soc Echocardiogr* . 2023;36(3):295-306.e5. doi:10.1016/j.echo.2022.11.014
25. Kattan E, Castro R, Miralles-Aguiar F, Hernández G, Rola P. The emerging concept of fluid tolerance: a position paper. *J Crit Care*. 2022;71:154070. doi:10.1016/j.jcrc.2022.154070
26. Lancellotti P, Galderisi M, Edvardsen T, et al. Echo-Doppler estimation of left ventricular filling pressure: results of the multicentre EACVI Euro-Filling study. *Eur Heart J Cardiovasc Imaging*. 2017;18(9):961-968. doi:10.1093/ehjci/jex067
27. Lanspa MJ, Gutsche AR, Wilson EL, et al. Application of a simplified definition of diastolic function in severe sepsis and septic shock. *Crit Care*. 2016;20(1):243. doi:10.1186/s13054-016-1421-3
28. Lanspa MJ, Olsen TD, Wilson EL, et al. A simplified definition of diastolic function in sepsis, compared against standard definitions. *J Intensive Care*. 2019;7(1):14. doi:10.1186/s40560-019-0367-3
29. La Via L, Dezio V, Santonocito C, et al. Full and simplified assessment of left ventricular diastolic function in covid-19 patients admitted to ICU: feasibility, incidence, and association with mortality. *Echocardiography*. 2022;39(11):1391-1400. doi:10.1111/echo.15462
30. Gonzalez FA, Ângelo-Dias M, Martins C, et al. Characteristic immune dynamics in COVID-19 patients with cardiac dysfunction. *J Clin Med*. 2022;11(7):1880. doi:10.3390/jcm11071880
31. Sanfilippo F, Scolletta S, Morelli A, Vieillard-Baron A. Practical approach to diastolic dysfunction in light of the new guidelines and clinical applications in the operating room and in the intensive care. *Ann Intensive Care*. 2018;8(1):100. doi:10.1186/s13613-018-0447-x
32. Combes A, Arnoult F, Trouillet JL. Tissue Doppler imaging estimation of pulmonary artery occlusion pressure in ICU patients. *Intensive Care Med*. 2004;30(1):75-81. doi:10.1007/s00134-003-2039-x
33. Vignon P, AitHssain A, François B, et al. Echocardiographic assessment of pulmonary artery occlusion pressure in ventilated patients: a transoesophageal study. *Crit Care*. 2008;12(1):R18. doi:10.1186/cc6792
34. La Via L, Merola F, Schembari G, Liotta C, Sanfilippo F. The interplay between left ventricular diastolic and right ventricular dysfunction: challenges in the interpretation of critical care echocardiography studies. *Egypt Heart J* . 2023;75(1):7. doi:10.1186/s43044-023-00333-w
35. Hollenberg SM, Singer M. Pathophysiology of sepsis-induced cardiomyopathy. *Nat Rev Cardiol*. 2021;18(6):424-434. doi:10.1038/s41569-020-00492-2
36. Wu VCC, Huang YC, Wang CL, et al. Association of echocardiographic parameter E/e' with cardiovascular events in a diverse population of inpatients and outpatients with and without cardiac diseases and risk factors. *J Am Soc Echocardiogr* . 2023;36(3):284-294. doi:10.1016/j.echo.2022.10.016
37. Balaney B, Medvedofsky D, Mediratta A, et al. Invasive validation of the echocardiographic assessment of left ventricular filling pressures using the 2016 diastolic guidelines: head-to-head comparison with the 2009 guidelines. *J Am Soc Echocardiogr* . 2018;31(1):79-88. doi:10.1016/j.echo.2017.09.002
38. Jones R, Varian F, Alabed S, et al. Meta-analysis of echocardiographic quantification of left ventricular filling pressure. *ESC Heart Fail*. 2021;8(1):566-576. doi:10.1002/ehf2.13119
39. Garry D, Newton J, Colebourn C. Tissue Doppler indices of diastolic function in critically ill patients and association with mortality—a systematic review. *J Intensive Care Soc*. 2016;17(1):51-62. doi:10.1177/1751143715595641
40. Mullens W, Borowski AG, Curtin RJ, Thomas JD, Tang WH. Tissue doppler imaging in the estimation of intracardiac filling pressure in decompensated patients with advanced systolic heart failure. *Circulation*. 2009;119(1):62-70. doi:10.1161/CIRCULATIONAHA.108.779223
41. Nagueh SF. Left ventricular diastolic function: understanding pathophysiology, diagnosis, and prognosis with echocardiography. *JACC Cardiovasc Imaging*. 2020;13:228-244. doi:10.1016/j.jcmg.2018.10.038
42. Bowcock EM, Mclean A. Bedside assessment of left atrial pressure in critical care: a multifaceted gem. *Crit Care*. 2022;26(1):247. doi:10.1186/s13054-022-04115-9

15408175, 2024, 2, Downloaded from https://onlinelibrary.wiley.com/doi/10.1111/echo.15773 by Universita Di Catania, Wiley Online Library on [08/06/2026]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

43. Vignon P, Huang SJ. Global longitudinal strain in septic cardiomyopathy: the hidden part of the iceberg? *Intensive Care Med*. 2015;41(10):1851-1853. doi:10.1007/s00134-015-3962-3
44. Boissier F, Razazi K, Seemann A, et al. Left ventricular systolic dysfunction during septic shock: the role of loading conditions. *Intensive Care Med*. 2017;43(5):633-642. doi:10.1007/s00134-017-4698-z
45. Sanfilippo F, Corredor C, Fletcher N, et al. Left ventricular systolic function evaluated by strain echocardiography and relationship with mortality in patients with severe sepsis or septic shock: a systematic review and meta-analysis. *Crit Care*. 2018;22(1):183. doi:10.1186/s13054-018-2113-y
46. Ng PY, Sin WC, Ng AKY, Chan WM. Speckle tracking echocardiography in patients with septic shock: a case control study (SPECKSS). *Crit Care*. 2016;20(145). doi:10.1186/s13054-016-1327-0
47. Dalla K, Hallman C, Bech-Hanssen O, Haney M, Ricksten SE. Strain echocardiography identifies impaired longitudinal systolic function in patients with septic shock and preserved ejection fraction. *Cardiovasc Ultrasound*. 2015;13(1):30. doi:10.1186/s12947-015-0025-4
48. Badano LP, Kolias TJ, Muraru D, et al. Standardization of left atrial, right ventricular, and right atrial deformation imaging using two-dimensional speckle tracking echocardiography: a consensus document of the EACVI/ASE/Industry Task Force to standardize deformation imaging. *Eur Heart J Cardiovasc Imaging*. 2018;19(6):591-600. doi:10.1093/ehjci/jey042
49. Inoue K, Khan FH, Remme EW, et al. Determinants of left atrial reservoir and pump strain and use of atrial strain for evaluation of left ventricular filling pressure. *Eur Heart J Cardiovasc Imaging*. 2021;23(1):61-70. doi:10.1093/ehjci/jeaa415
50. Gonzalez FA, Ângelo-Dias M, Martins C, et al. Left atrial strain is associated with distinct inflammatory and immune profile in patients with COVID-19 pneumonia. *Ultrasound J*. 2023;15(1):2. doi:10.1186/s13089-022-00302-5
51. Carluccio E, Biagioli P, Mengoni A, et al. Left atrial reservoir function and outcome in heart failure with reduced ejection fraction. *Circ Cardiovasc Imaging*. 2018;11(11); e007696. doi:10.1161/CIRCIMAGING.118.007696
52. Rossi A, Carluccio E, Cameli M, et al. Left atrial structural and mechanical remodelling in heart failure with reduced ejection fraction. *ESC Heart Fail*. 2021;8(6):4751-4759. doi:10.1002/ehf2.13654
53. Carluccio E, Pugliese NR, Biagioli P, et al. Global longitudinal strain in heart failure with reduced ejection fraction: prognostic relevance across disease severity as assessed by automated cluster analysis. *Int J Cardiol*. 2021;332:91-98. doi:10.1016/j.ijcard.2021.02.072
54. Deferm S, Martens P, Verbrugge FH, et al. LA mechanics in decompensated heart failure. *JACC Cardiovasc Imaging*. 2020;13(5):1107-1115. doi:10.1016/j.jcmg.2019.12.008
55. Fan JL, Su B, Zhao X, et al. Correlation of left atrial strain with left ventricular end-diastolic pressure in patients with normal left ventricular ejection fraction. *Int J Cardiovasc Imaging*. 2020;36(9):1659-1666. doi:10.1007/s10554-020-01869-7
56. Mandoli GE, Sisti N, Mondillo S, Cameli M. Left atrial strain in left ventricular diastolic dysfunction: have we finally found the missing piece of the puzzle? *Heart Fail Rev*. 2020;25(3):409-417. doi:10.1007/s10741-019-09889-9
57. Frydas A, Morris DA, Belyavskiy E, et al. Left atrial strain as sensitive marker of left ventricular diastolic dysfunction in heart failure. *ESC Heart Fail*. 2020;7(4):1956-1965. doi:10.1002/ehf2.12820
58. Kuwaki H, Takeuchi M, Chien-Chia Wu V, et al. Redefining diastolic dysfunction grading. *JACC Cardiovasc Imaging*. 2014;7(8):749-758. doi:10.1016/j.jcmg.2014.05.002
59. Singh A, Addetia K, Maffessanti F, Mor-Avi V, Lang RM. LA strain for categorization of LV diastolic dysfunction. *JACC Cardiovasc Imaging*. 2017;10(7):735-743. doi:10.1016/j.jcmg.2016.08.014
60. Carluccio E, Cameli M, Rossi A, et al. Left atrial strain in the assessment of diastolic function in heart failure: a machine learning approach. *Circ Cardiovasc Imaging*. 2023;16(2):e014605. doi:10.1161/CIRCIMAGING.122.014605
61. Kameshima H, Uejima T, Fraser AG, et al. A phenotyping of diastolic function by machine learning improves prediction of clinical outcomes in heart failure. *Front Cardiovasc Med*. 2021;8:755109. doi:10.3389/fcvm.2021.755109
62. Lancaster MC, Salem Omar AM, Narula S, Kulkarni H, Narula J, Sengupta PP. Phenotypic clustering of left ventricular diastolic function parameters. *JACC Cardiovasc Imaging*. 2019;12(7):1149-1161. doi:10.1016/j.jcmg.2018.02.005
63. Omar AMS, Narula S, Abdel Rahman MA, et al. Precision phenotyping in heart failure and pattern clustering of ultrasound data for the assessment of diastolic dysfunction. *JACC Cardiovasc Imaging*. 2017;10(11):1291-1303. doi:10.1016/j.jcmg.2016.10.012
64. Bellini V, Sanfilippo F, Vetrugno L, Bignami E. Artificial intelligence and left ventricular diastolic function assessment: a new tool for improved practice? *J Cardiothorac Vasc Anesth*. 2021;35(9):2834. doi:10.1053/j.jvca.2021.02.037
65. Varudo R, Gonzalez FA, Leote J, et al. Machine learning for the real-time assessment of left ventricular ejection fraction in critically ill patients: a bedside evaluation by novices and experts in echocardiography. *Crit Care*. 2022;26(1):386. doi:10.1186/s13054-022-04269-6
66. Gonzalez FA, Varudo R, Leote J, et al. Automation of sub-aortic velocity time integral measurements by transthoracic echocardiography: clinical evaluation of an artificial intelligence-enabled tool in critically ill patients. *Br J Anaesth*. 2022;129(5):e116-e119. doi:10.1016/j.bja.2022.07.037
67. Bacariza J, Gonzalez FA, Varudo R, et al. Smartphone-based automatic assessment of left ventricular ejection fraction with a silicon chip ultrasound probe: a prospective comparison study in critically ill patients. *Br J Anaesth*. 2023;130(6):e485-e487. doi:10.1016/j.bja.2023.02.032
68. Sanfilippo F, Messina A, Scolletta S, et al. The "CHEOPS" bundle for the management of Left Ventricular Diastolic Dysfunction in critically ill patients: an experts' opinion. *Anaesth Crit Care Pain Med*. 2023;42(6):101283. doi:10.1016/j.accpm.2023.101283
69. Guarracino F, Bertini P, Pinsky MR. Cardiovascular determinants of resuscitation from sepsis and septic shock. *Crit Care*. 2019;23(1):118. doi:10.1186/s13054-019-2414-9
70. Enghard P, Rademacher S, Nee J, et al. Simplified lung ultrasound protocol shows excellent prediction of extravascular lung water in ventilated intensive care patients. *Crit Care*. 2015;19(1):36. doi:10.1186/s13054-015-0756-5
71. Ferré A, Guillot M, Lichtenstein D, et al. Lung ultrasound allows the diagnosis of weaning-induced pulmonary oedema. *Intensive Care Med*. 2019;45(5):601-608. doi:10.1007/s00134-019-05573-6
72. Yang F, Wang Q, Zhang L, Ma Y, Chen Q. Prognostic value of pulmonary oedema assessed by lung ultrasound in patient with acute heart failure. *Heart Vessels*. 2021;36(4):518-527. doi:10.1007/s00380-020-01719-5
73. Beaubien-Souligny W, Rola P, Haycock K, et al. Quantifying systemic congestion with Point-Of-Care ultrasound: development of the venous excess ultrasound grading system. *Ultrasound Journal*. 2020;12(1):16. doi:10.1186/s13089-020-00163-w
74. Morelli A, Romano SM, Sanfilippo F, et al. Systolic-dicrotic notch pressure difference can identify tachycardic patients with septic shock at risk of cardiovascular decompensation following pharmacological heart rate reduction. *Br J Anaesth*. 2020;125(6):1018-1024. doi:10.1016/j.bja.2020.05.058
75. Pinsky MR, Guarracino F. How to assess ventriculoarterial coupling in sepsis. *Curr Opin Crit Care*. 2020;26(3):313-318. doi:10.1097/MCC.0000000000000721

15408175, 2024, 2, Downloaded from https://onlinelibrary.wiley.com/doi/10.1111/echo.15773 by Universitá Di Catania, Wiley Online Library on [08/06/2026]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

How to cite this article: Gonzalez FA, Santonocito C, Maybauer MO, Lopes LR, Almeida AG, Sanfilippo F. Diastology in the intensive care unit: Challenges for the assessment and future directions. *Echocardiography*. 2024;41:e15773. https://doi.org/10.1111/echo.15773

15408175, 2024, 2, Downloaded from https://onlinelibrary.wiley.com/doi/10.1111/echo.15773 by Università Di Catania, Wiley Online Library on [08/06/2026]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License