Cardiac Ultrasound Examination in Shock

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Learning Objectives

Critical care echocardiography (CCE) is very suitable to manage patients with circulatory failure, especially when associated with respiratory failure.

Transesophageal echocardiography (TEE) is more suitable than transthoracic echocardiography (TTE) for hemodynamic monitoring when performed in intubated patients, allowing reproducible and sequential hemodynamic assessments. TEE allows an easy evaluation of four important parameters: the respiratory variation of the superior vena cava (SVC), the LV systolic function, the RV size, and the existence of a paradoxical septal motion. Since echocardiography only allows a discontinuous hemodynamic monitoring, it has to be associated with a more continuous device as invasive blood pressure monitoring.

In this chapter, we will describe different ICU situations where TEE is useful to evaluate hemodynamic instability in ICU mechanically ventilated patients treated for respiratory and circulatory failures.

18.1 Introduction

Echocardiography is increasingly being used in the critically ill patients. Papolos et al. recently reported a 3.4% increase per year of hospital use of echocardiography in the USA between 2001 and 2011 and a global volume of more than 7,000,000 echocardiographic (echo) examinations performed in the Nationwide Inpatient Sample (NIS) population [1]. Interestingly, critical care echocardiography (CCE) was more frequently used than the pulmonary artery catheter in patients with sepsis or congestive heart failure [1]. Similar results were obtained from French data in ARDS patients with a significant increase over time [2]. CCE is very suitable to manage patients with respiratory or circulatory failure [3]. It may have a direct diagnostic and therapeutic impact. In a mini review, including 2508 patients, on the use and safety of transesophageal echocardiography (TEE) in general ICU, TEE was mostly performed in the case of hemodynamic instability and had a diagnostic impact in 88.4% of cases [4]. TEE diagnosed left ventricular (LV) dysfunction in 27% and right ventricular (RV) dysfunction and hypovolemia in 11% and 16%, respectively. In 68.5% of patients, the findings had therapeutic implications, either surgical interventions or changes in medical therapy. A surgical intervention without additional investigations was performed in 5.6% [4].

In 2011, a consensus of 16 experts in the field of hemodynamic monitoring has recognized CCE as a true hemodynamic monitoring device, although discontinuous [5]. An echo study has to be done very quickly in case of hemodynamic instability after having evaluated whether the patient is obviously fluid responsive with a low central venous pressure [5]. While echocardiography is operator-dependent, TEE is expected to be less operator-dependent than transthoracic echocardiography (TTE) because the windows for

visualization, movement artifact, and anatomical landmark are more precise and regular. Thus, TEE is more suitable than TTE for hemodynamic monitoring when performed in intubated patients, allowing reproducible and sequential hemodynamic assessments [6]. Rather than performing many measurements, it has also been reported that TEE may allow the intensivist to obtain a qualitative and accurate hemodynamic evaluation based on four main parameters to know the respiratory variation of the superior vena cava (SVC), the LV systolic function, the RV size, and the existence of a paradoxical septal motion [7].

Since echocardiography only allows a discontinuous hemodynamic monitoring, it has to be associated with a more continuous device. Then, combining invasive blood pressure monitoring and CCE is mandatory, especially in mechanically ventilated ARDS patients [8]. While the former may be used as a "warning" signal, the latter helps intensivists to understand the reason of a low blood pressure or pulse pressure variations (PPV). Furthermore, CCE is not blindly performed because of abnormal vital signs suggesting poor organ perfusion, as skin mottling, elevated lactate, oliguria, etc. Thus, CCE really led to a paradigm shift from an invasive, quantitative, and continuous hemodynamic monitoring to a less invasive, qualitative, discontinuous, and functional one [9, 10]. This is why single measurement of cardiac output is probably less informative than longitudinal evaluation (before/after fluids, before/after dobutamine) for hemodynamic monitoring using CCE. In a systematic review, Wetterslev et al. reported that cardiac output measurements using either echocardiography or thermodilution were not interchangeable while trends were [11].

In this chapter, rather than writing another review on the use of CCE in patients with shock, we prefer to illustrate and briefly discuss four typical frequently encountered ICU situations, where CCE is very useful for treatment adjustment: (i) detection of fluid responsiveness (ii and iii), detection of RV failure in ARDS patients and its consequence, and (iv) septic cardiomyopathy involving the left ventricle. While these cases are illustrated with TEE, similar information may be obtained using TTE except for SVC but with a greater operator dependency.

Clinical Vignette 1: Detection of Fluid Responsiveness (Fig. 18.1)

A 35-year-old man was admitted to the ICU after drug poisoning and aspiration. He was initially intubated and ventilated in zero PEEP without hemodynamic instability. The systolic arterial pressure was 90 mmHg and the serum lactate level non-elevated. The initial evaluation reported a PPV of 9% with mild decrease in RV stroke volume during tidal ventilation and respiratory variation of the SVC. After applying a PEEP (required by severe hypoxemia), the cardiac index (CI) dropped, as well as the blood pressure, and the PPV increased. TEE evaluation demonstrated a complete collapse of SVC at inspiration with a huge decrease in RV stroke volume. After fluid expansion, CI increased, and SVC collapse disappeared, as well as the respiratory variation of RV stroke volume leading to hemodynamic improvement.

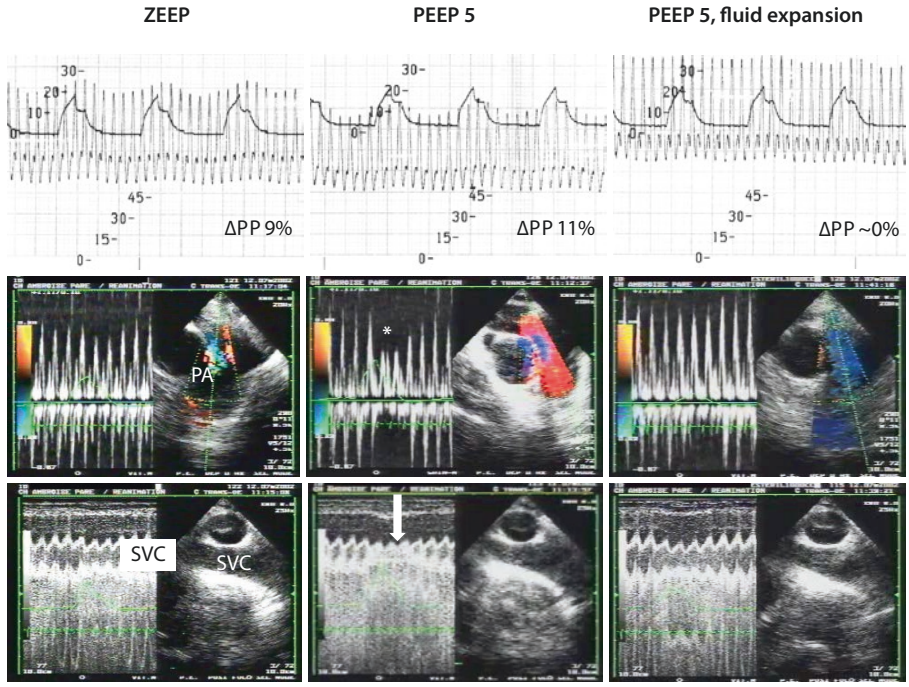

Fig. 18.1 SVC collapses (arrow) and decreases in RV stroke (asterisk) during tidal ventilation using PEEP 5 cmH_2O compared to zero PEEP (ZEEP). These findings disappeared after fluid expansion. CI cardiac index, PEEP positive expiratory pressure, ΔPP respiratory variations of pulse pressure, SVC superior vena cava, PA pulmonary artery

Take-Home Messages

This case illustrates different important points for hemodynamic management with echo.

- The need for fluids may change according to the respiratory settings. Echo evaluation has then to be done with regard to the mechanical ventilation settings, and a reassessment is required as soon as these settings are modified.
- Pulsed-wave Doppler into the main pulmonary artery allows recording the respiratory changes of RV stroke volume. When significant, it gives the intensivist the hemodynamic information that there is some "bad" interaction between the right ventricle and the ventilator, which is mediated either by a lack of enough fluid content into the thorax (preload effect) or by a RV systolic overload (afterload effect; see also Vignette 2) [8]. Such a cyclic decrease in RV stroke volume is the cause of the observed PPV and may be corrected by fluid expansion in this clinical case.
- TEE may be used before and after fluid expansion, when decided, to look for respiratory variations of SVC and RV stroke volume, as well as the efficacy of such a fluid challenge (increased CI).
- SVC respiratory variations are the most specific parameter of fluid responsiveness as recently reported in a multicenter study prospectively including 540 unselected patients with shock [12]. This parameter requires a TEE approach.

Clinical Vignette 2: Detection of RV Failure I (Fig. 18.2)

A 55-year-old man was admitted to the ICU for septic shock related to severe pneumonia. He rapidly required to be intubated and ventilated with a lung protective approach. At the time of TEE evaluation, PaO_2/FiO_2 was 110 mmHg and $PaCO_2$ 55 mmHg. The patient was in shock with a low blood pressure and a high lactate level (5 mmol/L). Significant PPV were observed. TEE study was performed and reported RV failure with a pattern of severe acute cor pulmonale (ACP) with a huge RV dilatation. Fluid expansion was inefficient and even deteriorated the patient with an increase in PPV and an enlargement of the RV. Norepinephrine was then started, allowing to increase blood pressure, to correct PPV, and to slightly decrease the RV size.

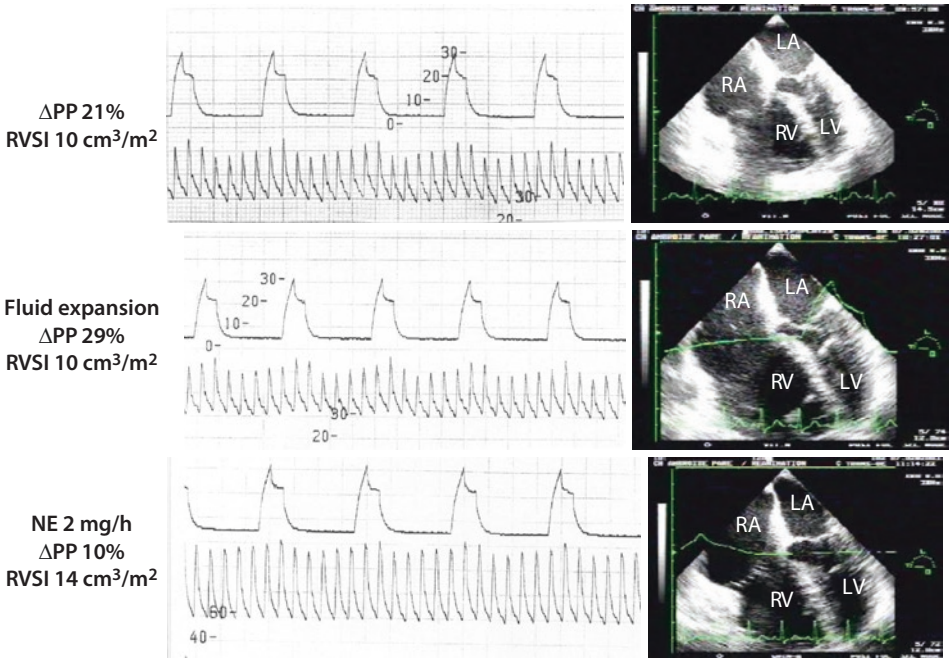

Fig. 18.2 Significant respiratory variations of pulse pressure (ΔPP) are observed in the first panel (top) as well as an acute cor pulmonale pattern with right ventricle dilatation. After fluid expansion (second panel, medium), hemodynamic worsened with regard to an increase of ΔPP and an enlargement of the right ventricle. After norepinephrine infusion (third panel, bottom), ΔPP was corrected and the right ventricle size decreased. RVSI right ventricle stroke index, NE norepinephrine, LA left atrium, LV left ventricle, RA right atrium, RV right ventricle

Take-Home Messages

This case illustrates different important points for hemodynamic management with echo.

- In this patient, PPV was due to RV failure and the related respiratory variations in RV stroke volume (not reported here). TEE allowed the intensivist to understand the cause of such shock with significant PPV.
- Fluid expansion does not permit in this situation any hemodynamic improvement and even may induce deterioration. Based on TEE evaluation, it is useless. It is usually recommended not to infuse fluids when the right ventricle is

severely dilated [13]. A clinical study done in patients with massive pulmonary embolism has reported that the higher the RV size the lower the increase in CO induced after fluid expansion [14].

- Norepinephrine is a powerful therapy to improve RV function. It increases blood pressure and then RV coronary blood flow by stopping the vicious circle of functional RV ischemia. At small or moderate dose, its potential vasoconstriction of the pulmonary circulation is very limited.

Clinical Vignette 3: Detection of RV Failure II (Fig. 18.3)

A 41-year-old man was admitted to the ICU for acute respiratory failure due to pneumonia. He was quickly intubated and ventilated. He developed an ARDS. Few hours after intubation, he developed a circulatory failure with a systolic arterial pressure (SAP) of 90 mmHg, a heart rate of 128 bpm, and an elevated serum lactate level. At the time of TEE examination, the plateau pressure and driving pressure were 33 cmH_2O and 28 cmH_2O, respectively. Blood gas analysis revealed a PaO_2/FiO_2 ratio of 100 and a $PaCO_2$ of 67 mmHg. TEE showed an enlargement of the right ventricle associated with a paradoxical septal motion, named *acute cor pulmonale* (ACP). Based on the echo findings, tidal volume was slightly decreased to limit plateau and driving pressures. In the same time, instrumental dead space was removed in order to control hypercapnia. Hemodynamics very rapidly improved (SAP 123 mmHg, heart rate 90 bmp) as the RV size decreased. The paradoxical septal motion did not completely disappear but was less pronounced.

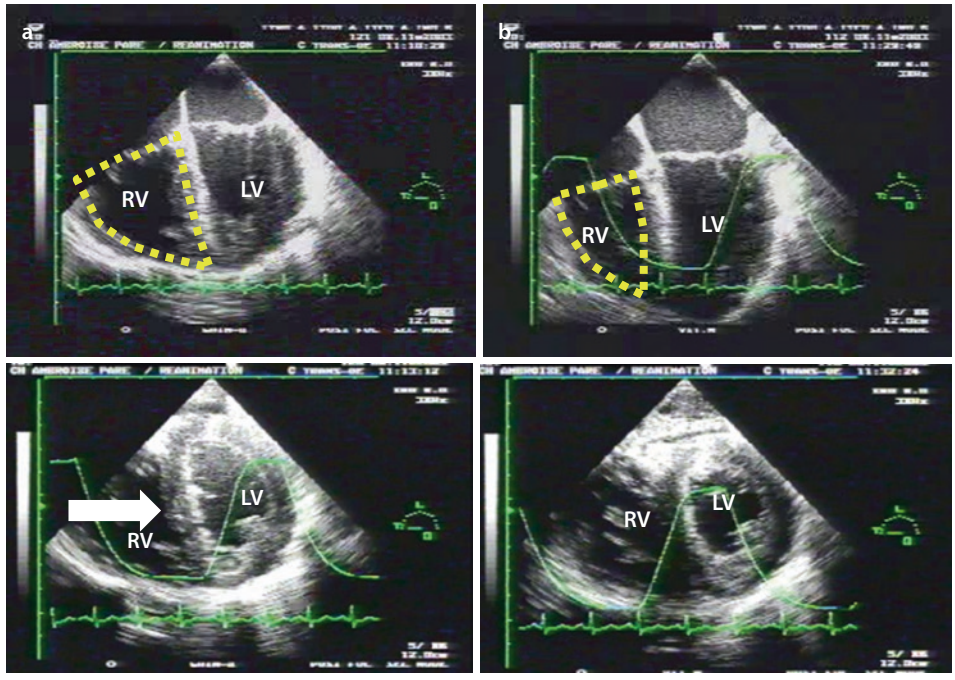

Fig. 18.3 Panel **a**: Enlargement of the right ventricle on a transverse mid-esophageal view (top) with paradoxical septal motion on a transgastric short-axis view (arrow, bottom). Panel **b**: After adaptation of respiratory settings (see the manuscript), the right ventricular size decreased, and paradoxical septal motion was less pronounced. LV left ventricle, RV right ventricle

Take-Home Messages

This case illustrates different important points for hemodynamic management with echo.

- RV failure, named ACP, is frequently encountered in ARDS treated with protective ventilation. A 22% incidence has been reported in 752 patients [15]. This means that a systematic detection has to be done by echocardiography, at least during the first 3 days following mechanical ventilation, especially in the case of circulatory failure. TEE has been reported to be more sensitive than TTE for detection [16]. This is generally true that TEE is more efficient than TTE in patients with high PEEP, fluid overload, and chest tubes [17].
- ACP may lead to hemodynamic compromise [18] and then must be corrected.
- We have reported that four risk factors are associated with RV failure, pneumonia as the cause of ARDS, driving pressure $\geq$ 18 cmH_2O, PaO_2/FiO_2 < 150, and $PaCO_2 \geq$ 48 mmHg [15]. The incidence of ACP increases with the number of risk factors. Thus, managing hemodynamics using CCE in such patients also means to adapt the respiratory strategy to the RV function.

Clinical Vignette 4: Septic Cardiomyopathy (Fig. 18.4)

A 66-year-old woman was admitted to the ICU for a septic shock related to urinary tract infection. She was intubated and mechanically ventilated. After fluid optimization, she was still in shock with a low blood pressure (SAP 75 mmHg, base deficit 19 mmol/L). Despite the absence of ARDS, TEE demonstrated RV failure with an ACP pattern. RV function as well as hemodynamics was corrected by infusion of high-dose norepinephrine and continuous veno-venous hemofiltration (see also Vignette 3). A few hours later, a worsening of hemodynamics occurred with new lactic acidosis. TEE now demonstrated severe LV systolic dysfunction. Dobutamine was then infused at small dose, allowing increase in LV ejection fraction, correction of acidosis, and hemodynamic stabilization.

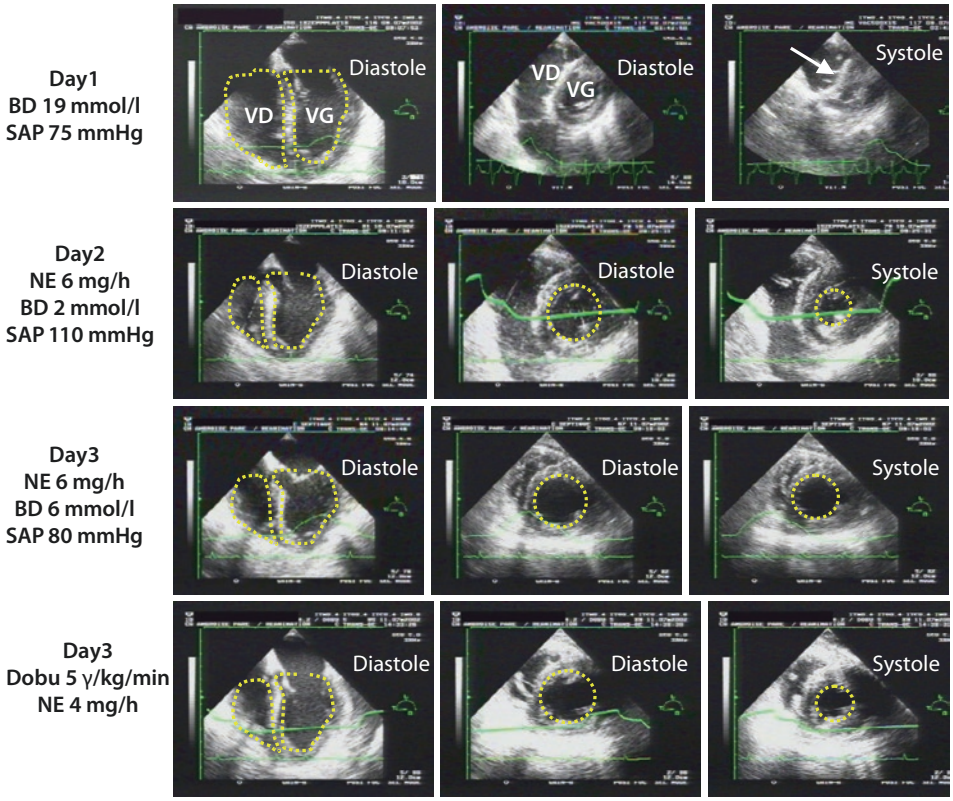

Fig. 18.4 Left column: Transverse mid-esophageal view; middle column, transgastric short-axis view in diastole; right column, transgastric short-axis view in systole. Right ventricular failure and acute cor pulmonale pattern were present at day 1 (top). After norepinephrine infusion, RV function normalized at day 2 but was followed by secondary worsening related to LV systolic dysfunction (day 3). Dobutamine infusion restored LV systolic function (bottom). BD base deficit, SAP systolic arterial pressure, RV right ventricle, LV left ventricle, NE norepinephrine, Dobu dobutamine. Arrow marks the paradoxical septal motion. Dotted yellow lines mark RV and LV endocardial border

Take-Home Messages

This case illustrates different important points for hemodynamic management with echo.

- Septic cardiomyopathy may injure the right and the left side.
- The most efficient way to detect such a complication is to use CCE. In particular, S_cVO_2 has been reported to be normal in the case of severe LV systolic dysfunction with low cardiac index in septic shock patients [19].
- ACP pattern may be observed in the absence of ARDS, especially when sepsis and profound acidosis, which impair RV systolic function, are associated with positive pressure ventilation which increases RV afterload.
- Different hemodynamic profiles may occur at different time during the evolution of a septic shock. This requires frequent reassessment of cardiac function by CCE.
- Infusion of small dose of dobutamine, when appropriate (poor organ perfusion, low LV ejection fraction, optimization of fluid resuscitation), is useful to improve hemodynamics despite no evidence of decreased ICU mortality in this setting has been published so far.

Conclusion

CCE is an amazing device for monitoring hemodynamics in the most complicated situations as septic shock and ARDS. It may allow to independently diagnose the need for more fluids, for norepinephrine or dobutamine infusion, or for adjustment of the mechanical ventilation settings. Since CCE is never blindly performed, intensivists must remind that CCE is a help to improve patients' management and not a goal for itself. In other words, intensivists should not treat an "abnormal" echo picture but have to interpret echo studies in the light of the clinical situation. Since CCE is a discontinuous hemodynamic monitoring device, it always has to be associated with a continuous monitoring of invasive blood pressure, as well as serial dosage of serum lactate or base deficit, at least in the most severe patients. In the future, development of cheap esophageal echo probe that could be left in place into the patient is desirable [20].

Take-Home Messages

- CCE is key to manage patients with circulatory failure.
- TEE is probably more suitable than TTE in ventilated patients for hemodynamic monitoring, as it is less operator dependent.
- Echo evaluation may be very simply based on four parameters: SVC respiratory variation, RV size, LV systolic function, and movement of the interventricular septum.

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