Critical care echocardiography is one of the most useful monitors for critically ill patients (1-4). Cardiac function and hemodynamic could be assessed non-invasively using this technique at the bedside and provide information which help clinicians to have a better management of intensive care unit (ICU) patients with hemodynamical compromise. 2D echocardiography, pulsed and continuous wave Doppler, colour Doppler, tissue Doppler imaging (TDI), speckle tracking and 3D imaging are the main techniques which improve the assessment of the cardiac function. Both transthoracic echocardiography (TTE) and transesophageal echocardiography (TEE) routes are used in ICU patients. TTE is sometimes limited due to the poor echogenicity of patients with chronic obstructive pulmonary disease (COPD), obesity or with high positive end-expiratory pressure (PEEP). As well presence of tapes on the chest after cardiac surgery may prevent to obtain good images to solve the clinical problem. Then TEE could be performed to overcome these limitations. But, many improvements as harmonic imaging, digital acquisition improved the performance of TTE. Then, TTE should be considered first in patient with unexplained shock or with respiratory failure. TTE is very useful when clinical signs are not enough to solve the clinical problem and then goal-directed echocardiography should be done. In ICU patients TTE is particularly useful because clinical situations are
complexes and for instance septic shock could be associated with acute respiratory distress syndrome (ARDS) and then a comprehensive echocardiography should be done. More, TTE should be considered not only as an imaging technique but as a monitor which may help the clinician to follow hemodynamic changes and to decide either to give fluid or to start dobutamine or to increase noradrenalin infusion in patients which shock.

**Assessment of systolic function and cardiac output**

Left ventricular (LV) systolic function is a critical point to analyse in ICU patients with hemodynamic compromise to well analyse the pathophysiology of patient in shock or in respiratory failure. Echocardiography is considered as the first tool to assess this function. LV systolic function depends on preload, afterload, contractility and heart rate. Mainly, this systolic evaluation is done in ICU patients by assessing myocardial global and segmental contraction. Global assessment of LV includes determination of ejection fraction (EF) and cardiac output (5,6).

**EF**

LV performance may be quantified by assessing EF (Figure 1). Shortening fraction is a surrogate parameter of EF and is obtained by using M-mode echocardiography from a parasternal long-axis view measuring left ventricular systolic dysfunction (LVSD) and left ventricular end-diastolic diameter (LVEDD) (Figure 1). Shortening fraction (SF) can be calculated as follow: \( SF(\%) = \frac{\text{LVEDD} - \text{LVESD}}{\text{LVEDD}} \times 100 \) (normal rage 25–45%) (5). This measurement reflects EF only in case of homogeneous contraction of the LV (Figure 1).

Using TEE or TTE systolic LV function can also be quantitatively assessed by fractional area change (FAC) as follow at the level of papillary muscles in a short axis view of the LV: \( \text{FAC(\%)} = \frac{\text{LVEDA} - \text{LVSA}}{\text{LVEDA}} \times 100 \) with LVEDA end diastolic area and LVSA end systolic area of LV (normal value 36–64 %) (7,8).

LV stroke volume (LVSV) and LV end-diastolic volume (LVEDV) may be assessed using Simpson method using either apical 4-chamber view alone or combining this view with apical 2-chamber view (Figure 2) and EF can be calculated as following \( \text{EF} = \frac{\text{LVEDV} - \text{LVSV}}{\text{LVEDV}} \) (normal value 55–75%) (7). Global systolic function can also be estimated visually especially when endocardial definition is insufficient for to Simpson method. With 2D echocardiography a reasonable correlation with measured quantitatively by echocardiography EF (Simpson) is demonstrated particularly when LVEF is visually estimated using intervals of 5% to 10% (9). Three dimensional (3D) reconstructions that use data from multiple tomographic images but do not seems accurate in ICU patients.

All these measurements need an adequate endocardial definition and accurate identification of the endocardial borders. Unfortunately, in the critical care setting, endocardial border definition may potentially be suboptimal because of technically limited TTE and poor imaging quality (1,10,11). Harmonic technique improved the visualisation of the endocardium and is widely used (12-14).
and in difficult cases TEE can be useful (1,10,11).

EF depends on both preload and afterload. The EF may look normal in septic shock patients before starting noradrenalin infusion. Later the infusion of noradrenalin will increase LV afterload and may unmask a LV systolic dysfunction. Then afterload should be interpreted together with the LV afterload (15).

**Longitudinal strain and speckle tracking**

It was demonstrated that cardiac dysfunction starts with an impairment of longitudinal strain despite the EF remains normal for a long period of time. Then it became usual to assess longitudinal strain using the speckle tracking technique (Figure 3). This technique permits to follow the distance between two speckles during systole. The initial distance is called Lo and the final L and then strain is calculated as follow (L−Lo)/Lo. During the systole the normal value is negative −21.1±2.4% (16). This technique is not available on all echocardiograph. Only the most recent and performant echocardiograph will provide the possibility to measure online the strain and speckle tracking.
Cardiac output (Qc)

Qc is calculated as follows: \( Qc = SV \times HR \) where SV = CSAao × VTlao (SV is stroke volume, HR heart rate, CSAao left ventricular outflow tract (LVOT) cross sectional area, VTlao velocity time integral of LVOT) (Figure 4) (17). CSA is derived from the LVOT diameter measured from parasternal long axis view and VTlao measured on aortic blood flow recorded from apical 5-chamber view using pulsed Doppler. TTE and TEE approach could be used but small errors in diameter measurement become large errors in cross sectional area calculations because of the quadratic relationship between these variables [CSAao = \((2 \times 3.14 \times LVOT^2)/4\)]. Diameter and VTI measurements need to be made at the same anatomic site, with an average of 3 measurements. Because LVOT size do not change any change of SV could be tracked by VTlao change. Pulmonary or aortic orifice, using TTE or TEE (17-19). This method was extensively validated against thermodilution in cardiologic field and in ICUs (17,20,21). Stroke volume may also be calculated as the difference of LV volume in diastole minus LV volume in systole (using the Simpson method) but this approach seems to be less accurate than previous one (22).

\[ Qc = \frac{\pi D^2}{4} \times VTlao \times HR \]

\( Qc \) = cardiac output
\( D \) = aortic annulus diameter
\( VTlao \) = aortic velocity time integral
\( HR \) = heart rate

Figure 4 Qc measurement.

dP/dt on mitral regurgitation

We demonstrated that all volunteers, in whom we performed TTE, a small mitral regurgitation was present (23). Because mitral regurgitation velocity changes during systole is related to the change of intra ventricular pressure, dP/dt could be easily assessed this flow recorded using continuous wave Doppler (Figure 5). By measuring the duration time (dt) between the velocity of 1 m/s and the velocity of 3 m/s (dP of 32 mmHg) on the mitral regurgitation envelop it becomes easy to diagnose any LV systolic dysfunction (normal ranges 800–1,200). This approach was well validated (24,25).

Mitral annular plane systolic excursion (MAPSE) and longitudinal wall fractional shortening (LWFS)

Systolic LV function can also be assessed by MAPSE measurement (26-29). MAPSE should be measured using M-mode echocardiography with the M-mode cursor aligned parallel to the LV walls. It corresponds to mitral annular displacement distance towards the apex and a reduced MAPSE thereby reflects impairment of the longitudinal LV contraction. The normal value of MAPSE ranges between 12 and 15 mm. A value <8 mm is associated with LV EF dysfunction (<50%) with a 98% sensitivity and 82% specificity (26). It is important to keep in mind that the correlation between MAPSE and EF is accurate in case of normal or dilated LV and should be interpreted with caution in case of hypertrophic LV. Interestingly, MAPSE
can be easily recorded even in patients with a poor acoustic window and for untrained echocardiographer. Bergenzaun et al. have recently described the value of MAPSE in ICU patients and showed that it reflects LV systolic and diastolic function and reduced MAPSE was independently associated with 28-day mortality (27). More recently, in a retrospective study, LWFS an M-mode index based on MAPSE, demonstrated a very good correlation with left ventricular longitudinal strain (LVLS) and therefore LV function, in intensive care patients. Interestingly, LWFS requires a simple M-mode measurement, available in all machines and reachable after minimal training. Its reproducibility and its accuracy make it a potential useful index in clinical use (28).

**TDI**

TDI is used to assess global systolic LV function. Sample volume is placed at the level of mitral annulus recording velocities during systole and diastole. Systolic myocardial velocity (Sm) is considered normal above 9 cm/s. Nagueh et al. reported that Sm had a good correlation with LV EF (30). Others demonstrated a good correlation with peak positive dP/dt (31).

**Ventricular maximal elastance**

The slope of the end-systolic pressure-volume relation, measured during progressively altered cardiac loading conditions, is still considered as the golden standard method for the assessment of LV contractility, independent of preload and afterload (32). This method could not be used easily at the bedside and should be considered only during clinical or experimental research.

**Assessment of asynchrony (33-36)**

Contraction asynchrony could be assessed using speckle tracking and could be useful in patients with cardiac dysfunction. This is not used in daily cardiac evaluation in ICU patients at the bedside, assessed during an echocardiographic examination with limited potential application.

**Assessment of diastolic function and pulmonary arterial occlusive pressure (37-40)**

Diastolic function is hard to assess in ICU patients because all parameters used to assess diastolic function could be impaired by hemodynamical dysfunction independently to the diastolic dysfunction. Mitral flow recorded using pulsed Doppler with the measurement of early (E) and late (A) velocities and the E/A ratio, together with mitral annulus early diastolic velocity E’ and the E/E’ ratio, size of left atrium and maximal velocity of tricuspid regurgitation were proposed in an algorithm to assess diastolic function and LV filling pressure (37). This algorithm was never validated in ICU patients. Ratio of E’ to propagation velocity (Vp) recorded using M-mode colour was proposed to assess LV filling pressure but this parameter is hard to assess in ICU patients and is not used.

**Clinical situations**

LV function should be assessed in all patients with hemodynamic compromise as shock and respiratory failure.

**Septic shock**

In septic shock LV dysfunction was demonstrated to be presented as high as 65% of cases but is not associated with increased mortality (41). Despite this meta-analysis recent cluster analysis of 300 patients with septic shock has shown that the cluster including patients with LV systolic dysfunction had higher mortality (33%) than another cluster (42). This systolic dysfunction could occur very early during the septic shock as well as after 48 or 72 hours (43). This dysfunction associates decreased EF and low cardiac output. Usually LV filling pressures are normal and the size of the left ventricle is normal. Actually, few studies...
demonstrated that left ventricle could be slightly dilated (but remains in the normal ranges) and this is usually associated with better prognosis than patients in which LV size was normal or ever reduced. This dysfunction is transient and disappears after few days and systolic function return to normal (43). Dobutamin infusion is usually started when tissue hypoxemia is associated with LV systolic dysfunction and a positive effect seems to be associated with a better prognosis than no effect (44). Diastolic dysfunction could be associated with LV systolic dysfunction or could be present without systolic dysfunction (45). Diastolic dysfunction is associated with poor prognosis (45). LV strain is impaired in many patients with normal systolic function in septic shock patients and is as well associated with poor prognosis (46).

**Cardiogenic shock**

Echocardiography is the main tool to diagnose the cause and to manage patients with cardiogenic shock. LV function is highly useful as well as the evaluation of LV filling pressures (Figure 6). With clinical signs, echocardiography analyses the hemodynamic consequences of the administration of catecholamines (including vasoconstrictive and/or inotropic drugs) on LVEF and CO. Also, echocardiography will help to decide to start hemodynamic mechanical assistance (ECMO) and when to wean this mechanical assistance.

**LV obstruction and shock**

In 22% of patients with septic shock Chauvet et al. demonstrated LV obstruction (47). This obstruction was due mainly to hypovolemia and vasoplegia which induced a decreased size of LV and hyperkinesia which are the precipitating factors. This obstruction was reversed by either stopping Dobutamine infusion or correcting hypovolemia and sometime starting beta blockers (Figure 7) (47). This obstruction could occur when precipitating factors are or not associated with anatomic substratum as LV hypertrophy (48).
Pulmonary oedema and ARDS

Echocardiography seems to be the most useful tool in case of pulmonary oedema to distinguish cardiogenic pulmonary oedema and acute lung injury or ARDS. PAOP could be assessed as previously stated in this article and in case of pulmonary oedema echocardiography may diagnose the cause (49).

Conclusions

Echocardiography should be the first line used method in ICU patients with hemodynamic compromise. LV function together with RV function and fluid responsiveness permits to assess the pathophysiology of shock or respiratory failure, to diagnose the cause and to monitor the patient over the time.

Acknowledgments

None.

Footnote

Conflicts of Interest: The authors have no conflicts of interest to declare.

Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

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doi: 10.21037/jeccm.2019.07.05