CURRENT OPINION

Less or more hemodynamic monitoring in critically ill patients

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Purpose of review
Hemodynamic investigations are required in patients with shock to identify the type of shock, to select the most appropriate treatments and to assess the patient's response to the selected therapy. We discuss how to select the most appropriate hemodynamic monitoring techniques in patients with shock as well as the future of hemodynamic monitoring.

Recent findings
Over the last decades, the hemodynamic monitoring techniques have evolved from intermittent toward continuous and real-time measurements and from invasive toward less-invasive approaches. In patients with shock, current guidelines recommend the echocardiography as the preferred modality for the initial hemodynamic evaluation. In patients with shock nonresponsive to initial therapy and/or in the most complex patients, it is recommended to monitor the cardiac output and to use advanced hemodynamic monitoring techniques. They also provide other useful variables that are useful for managing the most complex cases. Uncalibrated and noninvasive cardiac output monitors are not reliable enough in the intensive care setting.

Summary
The use of echocardiography should be initially encouraged in patients with shock to identify the type of shock and to select the most appropriate therapy. The use of more invasive hemodynamic monitoring techniques should be discussed on an individualized basis.

Keywords
cardiac output, hemodynamic monitoring, intensive care unit

INTRODUCTION

Although crucial, the physical examination is often not sufficient in patients with shock to enable clinicians to identify the main hemodynamic abnormalities involved and to select the best therapies [1,2]. Thus, hemodynamic monitoring is recommended to clearly and reliably determine the type of shock, to select the most appropriate treatment and to assess the patient's response to therapies [3]. Over the past decades, the hemodynamic monitoring techniques have evolved from intermittent toward continuous and real-time measurements, from invasive toward less-invasive approaches [4,5▪▪] and also differ in terms of number and nature of the provided hemodynamic variables [6▪▪]. Invasive monitoring of arterial blood pressure (ABP) is the first-line hemodynamic monitoring used in most patients with shock [3]. When further hemodynamic monitoring is needed, clinicians must use techniques that provide measurements of the cardiac output (CO). In addition to CO measurement, which is far from being enough to adequately manage the most complex patients, the advanced hemodynamic monitoring techniques provide other helpful hemodynamic variables. In this article, we discuss the relative place of the available hemodynamic monitoring techniques in patients with shock. We also discuss the future of hemodynamic monitoring.

THE PLACE OF THE HEMODYNAMIC MONITORING IN PATIENTS WITH SHOCK

The choice of the appropriate hemodynamic monitoring technique may differ depending on the phase

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KEY POINTS

- Over the last decades, hemodynamic monitoring techniques have evolved toward less-invasiveness as well as continuous and real-time measurements.
- Echocardiography is currently the first-line modality for hemodynamic evaluation in patients with shock and should be performed early to assess cardiac structure and function.
- It is recommended to monitor cardiac output and to use advanced hemodynamic monitoring only in patients with shock nonresponsive to initial therapy and/or in the most complex patients.
- The pulmonary artery catheter is recommended in patients with refractory shock associated with a right ventricular dysfunction. Transpulmonary thermodilution devices are recommended in patients with severe shock associated with acute respiratory distress syndrome. Less invasive and noninvasive cardiac output monitors are not reliable enough in the intensive care settings.
- The future of hemodynamic monitoring should be a minimally invasive multimodal monitoring including macrocirculation and microcirculation variables as well as metabolic variables and resulting to a personalized hemodynamic monitoring and management.

of shock, the complexity of the hemodynamic status and the response to initial therapy (Fig. 1). The main strengths and weaknesses of the main available hemodynamic monitoring techniques are summarized in Table 1.

INITIAL EVALUATION OF SHOCK STATES

In patients with shock, it is recommended to first perform a careful clinical examination [5■■]. Clinical signs such as mottling and increased capillary refill time are good markers of peripheral hypoperfusion and, at the initial phase of shock, are good indicators of low cardiac output. A low arterial pulse pressure (PP) suggests that the stroke volume is low, and a low diastolic arterial pressure (DAP) suggest that the vascular tone is low, especially in cases of tachycardia.

It is also recommended at the initial phase of shock to insert a central venous catheter and an indwelling arterial catheter, as well as to perform an echocardiography to assess the cardiac structure and function as early as possible [3].

From the central venous catheter, important hemodynamic variables such as the central venous pressure (CVP), the central venous oxygen saturation ($ScvO_2$) and the central venous carbon dioxide pressure ($PcvCO_2$) can be obtained. Although CVP has no value for predicting fluid responsiveness, its knowledge is important to estimate the organ perfusion pressure, which is assumed to be reflected better by the difference between mean arterial pressure (MAP) and CVP rather than by the sole MAP, especially in cases of profound hypotension and high CVP. In addition, a high CVP might be a good indicator of right ventricular dysfunction, which needs to be confirmed by echocardiography. The $ScvO_2$ is an acceptable surrogate of mixed venous blood oxygen saturation (SvO_2), which reflects the balance between oxygen consumption and oxygen delivery. A low $ScvO_2$ is an indicator of insufficient oxygen delivery with regards to oxygen consumption. In the case of shock, a low $ScvO_2$ spurs clinicians either to increase oxygen delivery or to decrease oxygen demand. If $ScvO_2$ is in the normal range, while the patient is in shock, it denotes alteration of oxygen extraction. In this case, it is ideal to obtain $PcvCO_2$, which, in combination with arterial carbon dioxide pressure ($PaCO_2$) provides the PCO_2 gap value ($PcvO_2–PaCO_2$), a good indicator of the adequacy of cardiac output with regards to the global metabolic requirements. In the case of low PCO_2 gap (<6 mmHg), there is no expectation of benefits through increase in cardiac output, whereas in the case of higher PCO_2 gap (>6 mmHg), increase in CO should be considered.

The arterial catheter not only provides arterial blood gases, but also allows an accurate measurement of the ABP with all its components: systolic ABP, DAP, PP and MAP, which all have a physiological meaning (see above). The arterial catheter also provides calculation of pulse pressure variation (PPV), which is a predictor of fluid responsiveness in mechanically ventilated under conditions of applicability [7■]. PPV has been constantly demonstrated to be reliable during ventilation with a tidal volume of at least 8 ml/kg in patients without spontaneous breathing activity and cardiac arrhythmias [7■].

Echocardiography can provide important information about cardiac function. However, it is more a technique of hemodynamic evaluation than hemodynamic monitoring. To overcome this limitation, miniaturized transesophageal echocardiography probes, which can be left inserted for a prolonged time without relevant side effects have been developed and could be thus useful for hemodynamic management of mechanically ventilated patients with shock [8]. Nevertheless, this technique remains very expansive and provides only a limited ultrasound assessment.

The main advantages of the echocardiography are its noninvasiveness and its ability to assess both cardiac structure and function [3]. From the measurement of the velocity–time integral (VTI) of the

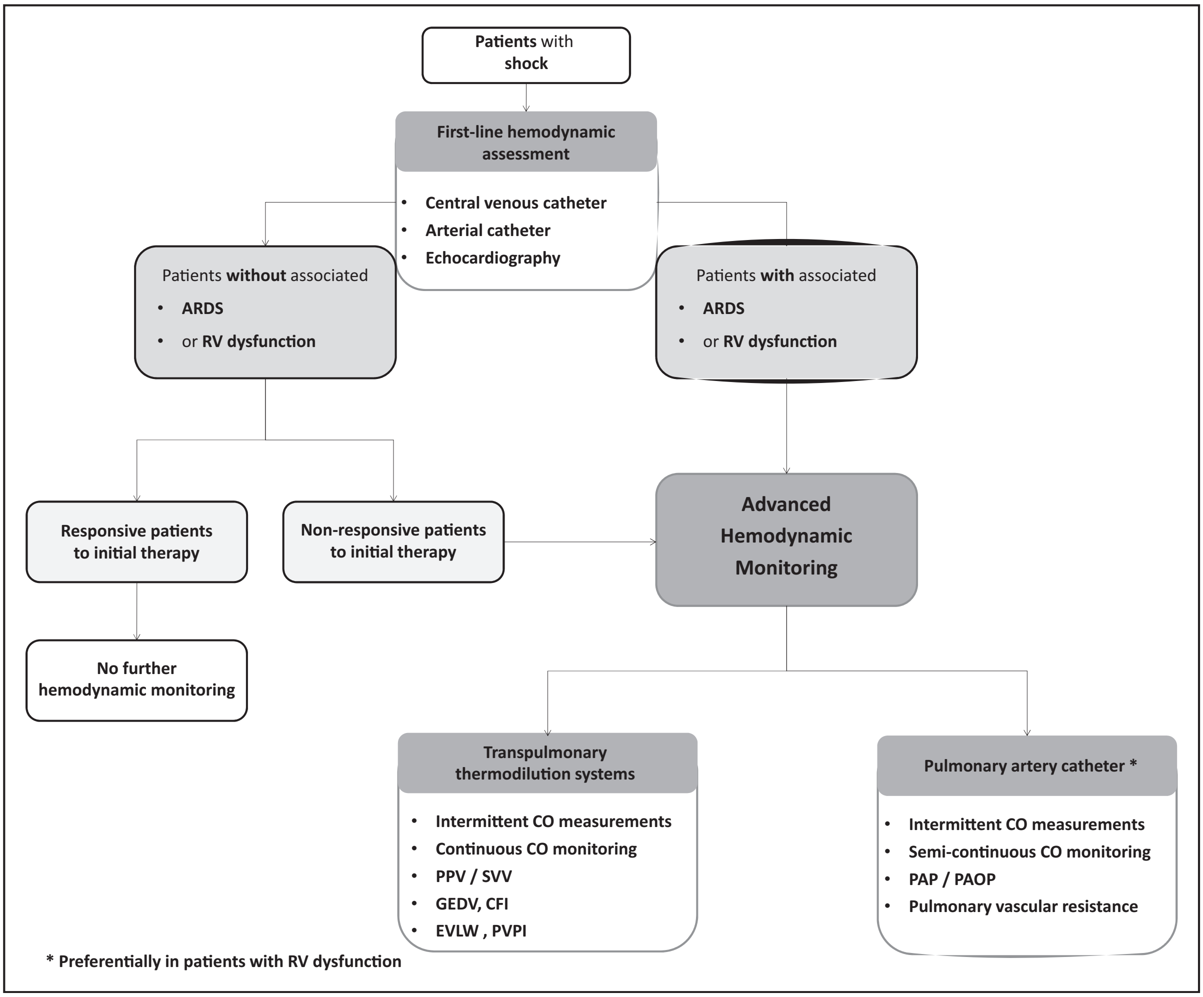

FIGURE 1. Algorithmic approach to decide which hemodynamic monitoring to use in patients with shock. ARDS, acute respiratory distress syndrome; CFI, cardiac function index; CO, cardiac output; EVLW, extravascular lung water; GEDV, global end-diastolic volume; PAOP, pulmonary artery occlusion pressure; PAP, pulmonary artery pressure, PPV, pulse pressure variation; PVPI, pulmonary vascular permeability index; RV, right ventricular; SVV, stroke volume variation.

flow in the left ventricular outflow tract, the measurement of the right ventricular size, the search for pericardial effusion and the search for respiratory variations in vena cava diameter, intensivists can quickly confirm and/or refine the type of shock. Moreover, the changes in CO induced by therapeutic tests of fluid responsiveness or by fluid administration can be reliably estimated by the changes in

Table 1. Summary of strengths and weaknesses of the main available hemodynamic monitoring devices

	Invasiveness	Reliability in ICU patients	Ease of set-up	Ability to monitor real-time CO measurement	Ability to provide other variables than CO
Pulmonary artery catheter	+++	+++	-	-	+++
Transpulmonary thermodilution systems	+++	+++	+	+++	+++
Uncalibrated arterial pulse contour analysis	++	+/−	++	+++	+
Noninvasive arterial pulse contour analysis	0	+/−	+++	+++	+
Esophageal Doppler	+	++	+	+++	++
Bioreactance	0	+/−	+++	+++	-

CO, cardiac ouptut.

VTI [9▪], as the area of the left ventricular outflow tract remains unchanged over a short time.

Nevertheless, echocardiography has limitations. First, it is an operator-dependent technique. It requires training before being skilled enough to deal with complex cardiac diseases. However, the period of training is limited for acquiring basic skills in critical care transthoracic echocardiography [10]. Second, the precision of the technique must be taken into account, especially when one assesses the response of CO during dynamic tests of fluid responsiveness [9▪].

WHEN TO USE ADVANCED HEMODYNAMIC MONITORING TECHNOLOGIES?

After collecting all the information from clinical examination, CVP, ABP and echocardiography, it is possible in most cases to make a therapeutic decision and select the most appropriate hemodynamic therapy. If the response of the patient is positive and shock is resolving, there is no need to add any other monitoring device. If the response is insufficient, it is recommended to obtain more information by using an advanced hemodynamic monitoring technique [3,5▪▪]. It is also recommended to use advanced hemodynamic monitoring earlier when acute respiratory distress syndrome (ARDS) is associated with shock state because in this situation, fluid management is trickier than in situations where there is no severe ARDS. The two hemodynamic monitoring technologies, which are considered advanced are the pulmonary artery catheter (PAC) and the transpulmonary thermodilution (TPD) systems.

Pulmonary artery catheter

The use of PAC has fallen out of favor for two decades because of the difficulty to measure and interpret the hemodynamic variables as well as the absence of demonstration of benefit of its use in critically ill patients [3,5▪▪,11,12]. Nevertheless, it has been recently suggested that PAC might still have a key role for the hemodynamic monitoring of critically ill patients [13▪▪]. Currently, PAC is recommended in patients with refractory shock associated with right ventricular dysfunction [3,5▪▪] and/or with ARDS [3,14▪▪]. Its advantage is to measure the pulmonary artery pressure and to provide an estimation of pulmonary vascular resistance, which might be useful in these settings.

PAC also provides other potentially useful hemodynamic variables, such as right atrial pressure, pulmonary artery occlusion pressure and SvO_2, which can be continuously monitored. It must be stressed that PAC only provides either intermittent or semi-continuous CO measurements and cannot reliably track short-term changes in CO [3].

Transpulmonary thermodilution devices

The use of TPD is recommended in patients with severe shock, especially in the case of ARDS [3]. This technique measures CO in an intermittent way, but TPD devices also provide a real-time measurement of CO through pressure waveform analysis (PWA) after initial calibration. The PWA also continuously provides PPV and/or stroke volume variation (SVV), two dynamic markers of preload responsiveness [7▪]. Interestingly, the CO measurement is accurate and precise, even in patients with high blood flow renal replacement therapy or in patients under therapeutic hypothermia [15▪▪]. The main limitation of this technique is the potential drift with time of the PWA, which requires frequent recalibration [3,16].

The mathematical analysis of the thermodilution curve provides other hemodynamic variables. The global end-diastolic volume (GEDV) is a marker of cardiac preload. The cardiac function index (CFI) and the global ejection fraction (GEF) are markers of cardiac systolic function. The extravascular lung water (EVLW) is a quantitative measure of pulmonary edema and the pulmonary vascular permeability index (PVPI), a marker of the lung capillary leak.

Thus, such devices are particularly appropriate for guiding fluid management of patients with concomitant acute circulatory and respiratory failures as they help clinicians assess the benefit/risk ratio of fluid administration. The benefit can be evaluated by preload responsiveness indices that these devices provide (PPV, SVV, PWA derived-CO response to passive leg raising or end-expiratory occlusion test). It must be stressed that the low tidal volume ventilation does not preclude the use of PPV in such patients. Myatra *et al.* [17▪] have recently described that an increase in the absolute value of PPV at least 3.5% induced by a transient increase in tidal volume from 6 to 8 ml/kg for 1 min could reliably predict fluid responsiveness. The denominator of the benefit/risk ratio can be evaluated by the values of EVLW and PVPI, two independent predictors of mortality in patients with ARDS [18,19], which can serve as safety parameters during fluid administration [15▪▪,19].

The recommendation of using advanced hemodynamic monitoring should apply only to the subgroup of patients with shock who do not respond to the initial treatment and/or with an associated ARDS [3,5▪▪]. A recent multicenter study including 1789 patients, confirms that, in Europe currently, advanced hemodynamic monitoring is far from being overused [20]. In the global population of patients, mechanical ventilation was used in 50% of patients and catecholamines in 40% of patients [20]. Overall, cardiac output monitoring (mainly PAC and TPD) was used in only 12% of patients [20].

WHAT IS THE PLACE OF THE OTHER CURRENTLY COMMERCIALIZED HEMODYNAMIC MONITORING TOOLS?

Uncalibrated minimally or noninvasive pressure waveform analysis devices

These devices also provide a continuous and real-time CO measurement as well as, for most of them, a continuous and automatic display of SVV and PPV. Their reliability in critically ill patients is worse than that of the calibrated devices, especially in cases of sepsis, with changes in vascular tone [6■■]. This explains why they are not recommended in the ICU settings [3,5■■]. Nevertheless, in patients with contraindication to TPD devices, invasive uncalibrated PWA devices requiring a radial artery catheter could be used to assess the short-term CO response to passive leg raising or fluid administration [21,22].

Esophageal Doppler

In addition to the CO measurement, this technique provides other potentially useful hemodynamic variables, in particular the mean acceleration and the peak of velocity of the systolic aortic blood flow, which can assess changes in cardiac systolic function [23]. Finally, the aortic blood flow variations can reliably predict fluid responsiveness in mechanically ventilated patients [24]. However, the reliability of this technique is affected by the movements of the Doppler probe into the esophagus, such that the technique is considered more suitable in the operating room than in the ICU where patients are less-sedated [4]. Therefore, the esophageal Doppler is predominantly reserved for the perioperative setting, with a very limited place in the ICU [3,5■■].

Bioreactance

Bioreactance-based systems derive CO from phase shift in voltage over the cardiac cycle of an electrical current crossing the thorax. Indeed, pulsatile changes in intrathoracic blood volume induce changes in the electrical conductivity of the thorax. These systems use skin surface electrodes placed on the patient′′s chest and neck that apply a low-amplitude, high-frequency electrical current, which traverses the thorax. Compared with a recent study [25], the reliability of the currently available bioreactance device has been greatly enhanced by the reduction in the period over which it averages CO [26]. Although the bioreactance-based system is dedicated to the operating room setting, it might be interesting to use in the prehospital phase or in the emergency room, or in the ICU when no other hemodynamic monitoring device is in place yet.

THE FUTURE OF HEMODYNAMIC MONITORING

In the area of digital health, the devices of the future should combine the following four characteristics: to be noninvasive, to be ergonomic and easy to use, to be wireless and wearable and to integrate smart software and algorithms [27,28■].

First of all, it is necessary to improve the reliability of the techniques to allow clinicians to noninvasively monitor the ABP. Today, techniques such as the volume clamp method or the radial artery applanation tonometry, are not accurate enough to be applicable in patients with shock [29]. This is why, continuous measurements of CO derived from the ABP waveform analysis obtained from these methods, are not sufficiently reliable [30–32] and cannot be currently recommended in critically ill patients [5■■]. New-generation sensors able to provide wireless and noninvasive high-fidelity pressure curves are emerging. From such ABP waveforms, it might be conceivable in the future to noninvasively and reliably monitor CO or assess the preload responsiveness (PPV, SVV, PWA-derived CO response to dynamic tests of fluid responsiveness). Nevertheless, invasive arterial catheterization is most often necessary for other reasons such as blood gas sampling, thus totally noninvasive PWA-derived CO monitoring should be reserved for the operating room rather than the ICU.

The future hemodynamic monitoring should also integrate the monitoring of regional perfusion and microcirculation. Indeed, alterations in the microcirculation as well as dissociation between the macrocirculation and the microcirculation occur in patients with shock, in those with septic shock [33]. Therefore, monitoring the microcirculation might be of interest to better understand the mechanisms causing shock, to better select and adjust systemic therapies and to ensure that improvement of the macrocirculation really results in improvement of the microcirculation, according to the principle of hemodynamic coherence [34]. Currently, the only microcirculatory bed, which can be investigated at the bedside, is the sublingual microcirculation, thanks to dedicated hand-held vital microscopes. In this regard, a consensus article about the assessment of the sublingual microcirculation in the critically ill patients has been recently published [35■■]. Nevertheless, the microcirculation analysis has currently two main limitations. First, the alteration of the sublingual microcirculation during shock may not be fully representative of the alteration of the other territories. Second, analyzing the microcirculation is still cumbersome and time-consuming [36]. Moreover, it is still not possible to obtain a complete assessment of the microcirculation in real-time, even if it has been shown that there was a good agreement between real-time visual assessment and off-line analysis [35■■].

Finally, the devices of the future should also include metabolic monitoring, allowing blood gases and electrolytes measurements without any blood sample [27].

Thus, using a multimodal approach, the future devices should not only reliably and less invasively monitor hemodynamics, but also help clinicians to offer the most appropriate therapy and to predict the potential adverse events. This then may contribute to a personalized hemodynamic monitoring and management approach [37].

CONCLUSION

Over the past years, hemodynamic monitoring techniques have continuously evolved toward less invasiveness and real-time measurements of different variables. In patients with shock, echocardiography is currently the first-line evaluation modality, whereas advanced hemodynamic monitoring is recommended for patients who do not respond to initial therapy and/or for the most complex patients. In the future, a minimally invasive multimodal monitoring approach integrating macrocirculatory, microcirculatory and metabolic variables will probably allow a more personalized management of critically ill patients with shock.

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Conflicts of interest

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REFERENCES AND RECOMMENDED READING

Papers of particular interest, published within the annual period of review, have been highlighted as:

■ of special interest
■■ of outstanding interest

1. Saugel B, Ringmaier S, Holzapfel K, *et al.* Physical examination, central venous pressure, and chest radiography for the prediction of transpulmonary thermodilution-derived hemodynamic parameters in critically ill patients: a prospective trial. J Crit Care 2011; 26:402–410.
2. Perel A, Saugel B, Teboul JL, *et al.* The effects of advanced monitoring on hemodynamic management in critically ill patients: a pre and post questionnaire study. J Clin Monit Comput 2016; 30:511–518.
3. Cecconi M, De Backer D, Antonelli M, *et al.* Consensus on circulatory shock and hemodynamic monitoring. Task force of the European Society of Intensive Care Medicine. Intensive Care Med 2014; 40:1795–1815.
4. Hamzaoui O, Monnet X, Teboul JL. Evolving concepts of hemodynamic monitoring for critically ill patients. Indian J Crit Care Med 2015; 19: 220–226.
5. ■■ Teboul JL, Saugel B, Cecconi M, *et al.* Less invasive hemodynamic monitoring in critically ill patients. Intensive Care Med 2016; 42:1350–1359.

This article is the most recent report of an expert panel concerning the hemodynamic monitoring in critically ill patients. The experts review the less invasive and the noninvasive available hemodynamic techniques. They also suggest that these techniques are not reliable enough in the intensive care settings.

6. ■■ Jozwiak M, Monnet X, Teboul JL. Pressure waveform analysis. Anesth Analg 2017; 126:1930–1933.

This review summarizes the characteristics of the monitoring devices using the pressure waveform analysis. Their relative place in the perioperative and intensive care settings is also discussed. The uncalibrated systems are more suitable for the perioperative context whereas the calibrated devices are reserved for the most complex critically ill patients.

7. ■ Monnet X, Marik P, Teboul JL. Prediction of fluid responsiveness: an update. Ann Intensive Care 2016; 6:111.

This review is a recent update concerning the prediction of fluid responsiveness. It summarizes the physiological background of the heart–lungs interactions and highlights the strengths and the pitfalls of the different available tests for predicting fluid responsiveness.

8. Vignon P, Merz TM, Vieillard-Baron A. Ten reasons for performing hemodynamic monitoring using transesophageal echocardiography. Intensive Care Med 2017; 43:1048–1051.
9. ■ Jozwiak M, Depret F, Teboul JL, *et al.* Predicting fluid responsiveness in critically ill patients by using combined end-expiratory and end-inspiratory occlusions with echocardiography. Crit Care Med 2017; 45: e1131–e1138.

This is one of the most recent publications studying the ability of transthoracic echocardiography to reliably predict fluid responsiveness by using the respiratory holds technique. It is interesting to note that combining end-expiratory and end-inspiratory occlusions is more compatible with the precision of echocardiography.

10. Jozwiak M, Monnet X, Cinotti R, *et al.* Prospective assessment of a score for assessing basic critical-care transthoracic echocardiography skills in ventilated critically ill patients. Ann Intensive Care 2014; 4:12.
11. Marik PE. Obituary: pulmonary artery catheter 1970 to 2013. Ann Intensive Care 2013; 3:38.
12. Simmons J, Ventetuolo CE. Cardiopulmonary monitoring of shock. Curr Opin Crit Care 2017; 23:223–231.
13. ■■ De Backer D, Vincent JL. The pulmonary artery catheter: is it still alive? Curr Opin Crit Care 2018; 24:204–208.

This review summarizes how to adequately acquire and interpret the measurements obtained with the pulmonary artery catheter. This review also discusses the current role of the pulmonary artery catheter for the hemodynamic monitoring of critically ill patients.

14. ■■ Vieillard-Baron A, Matthay M, Teboul JL, *et al.* Experts' opinion on management of hemodynamics in ARDS patients: focus on the effects of mechanical ventilation. Intensive Care Med 2016; 42:739–749.

This article is the most recent report of an expert panel concerning the management of hemodynamics in patients with acute respiratory syndrome. The experts recommend to use a pulmonary artery catheter or transpulmonary thermodilution, both providing useful hemodynamic variables for the hemodynamic management of such patients, in addition to the cardiac output measurement.

15. ■■ Monnet X, Teboul JL. Transpulmonary thermodilution: advantages and limits. Crit Care 2017; 21:147.

This review highlights the advantages and the limits of the transpulmonary thermodilution. It also summarizes the relative place of transpulmonary thermodilution in the hemodynamic management of surgical and ICU patients.

16. Hamzaoui O, Monnet X, Richard C, *et al.* Effects of changes in vascular tone on the agreement between pulse contour and transpulmonary thermodilution cardiac output measurements within an up to 6-h calibration-free period. Crit Care Med 2008; 36:434–440.

17. Myatra SN, Prabu NR, Divatia JV, *et al.* The changes in pulse pressure
■ variation or stroke volume variation after a 'tidal volume challenge' reliably predict fluid responsiveness during low tidal volume ventilation. Crit Care Med 2017; 45:415–421.

This study shows that an increase in pulse pressure variation (PPV) or stroke volume variation (SVV) induced by a transient increase in tidal volume from 6 to 8 ml/kg for 1 min could reliably predict fluid responsiveness. Thus, a low tidal volume ventilation should not preclude the use of PPV/SVV to predict fluid responsiveness in critically ill patients.

18. Jozwiak M, Silva S, Persichini R, *et al.* Extravascular lung water is an independent prognostic factor in patients with acute respiratory distress syndrome. Crit Care Med 2013; 41:472–480.

19. Jozwiak M, Teboul JL, Monnet X. Extravascular lung water in critical care: recent advances and clinical applications. Ann Intensive Care 2015; 5:38.

20. Funcke S, Sander M, Goepfert MS, *et al.,* ICU-CardioMan Investigators. Practice of hemodynamic monitoring and management in German, Austrian, and Swiss intensive care units: the multicenter cross-sectional ICU-CardioMan Study. Ann Intensive Care 2016; 6:49.

21. Monnet X, Vaquer S, Anguel N, *et al.* Comparison of pulse contour analysis by Pulsioflex and Vigileo to measure and track changes of cardiac output in critically ill patients. Br J Anaesth 2015; 114:235–243.

22. Biais M, de Courson H, Lanchon R, *et al.* Mini-fluid challenge of 100 ml of crystalloid predicts fluid responsiveness in the operating room. Anesthesiology 2017; 127:450–456.

23. Monnet X, Robert JM, Jozwiak M, *et al.* Assessment of changes in left ventricular systolic function with oesophageal Doppler. Br J Anaesth 2013; 111:743–749.

24. Monnet X, Rienzo M, Osman D, *et al.* Esophageal Doppler monitoring predicts fluid responsiveness in critically ill ventilated patients. Intensive Care Med 2005; 31:1195–1201.

25. Kupersztych-Hagege E, Teboul JL, Artigas A, *et al.* Bioreactance is not reliable for estimating cardiac output and the effects of passive leg raising in critically ill patients. Br J Anaesth 2013; 111:961–966.

26. Galarza L, Mercado P, Teboul JL, *et al.* Estimating the rapid haemodynamic effects of passive leg raising in critically ill patients using bioreactance. Br J Anaesth 2018. (in press).

27. Michard F. Hemodynamic monitoring in the era of digital health. Ann Intensive Care 2016; 6:15.

28. Michard F, Pinsky MR, Vincent JL. Intensive care medicine in 2050: NEWS for
■ hemodynamic monitoring. Intensive Care Med 2017; 43:440–442.

This article describes the future of the hemodynamic monitoring and the technical characteristics required for the future devices of monitoring.

29. Michard F, Sessler DI, Saugel B. Noninvasive arterial pressure monitoring revisited. Intensive Care Med 2018. [Epub ahead of print]

30. Monnet X, Picard F, Lidzborski E, *et al.* The estimation of cardiac output by the Nexfin device is of poor reliability for tracking the effects of a fluid challenge. Crit Care 2012; 16:R212.

31. Taton O, Fagnoul D, De Backer D, Vincent JL. Evaluation of cardiac output in intensive care using a noninvasive arterial pulse contour technique (Nexfin((R))) compared with echocardiography. Anaesthesia 2013; 68:917–923.

32. Wagner JY, Langemann M, Schon G, *et al.* Autocalibrating pulse contour analysis based on radial artery applanation tonometry for continuous noninvasive cardiac output monitoring in intensive care unit patients after major gastrointestinal surgery–a prospective method comparison study. Anaesth Intensive Care 2016; 44:340–345.

33. Hernandez G, Teboul JL. Is the macrocirculation really dissociated from the microcirculation in septic shock? Intensive Care Med 2016; 42:1621–1624.

34. Ince C. Hemodynamic coherence and the rationale for monitoring the microcirculation. Crit Care 2015; 19(Suppl 3):S8.

35. Ince C, Boerma EC, Cecconi M, *et al.*, Cardiovascular Dynamics Section of
■■ the ESICM. Second consensus on the assessment of sublingual microcirculation in critically ill patients: results from a task force of the European Society of Intensive Care Medicine. Intensive Care Med 2018; 44:281–299.

This is the most recent consensus from the European Society of Intensive Care Medicine about the assessment of the sublingual microcirculation at the bedside in critically ill patients. This consensus provides recommendations not only regarding the acquisition and the interpretation of microcirculatory images but also the future perspectives of the microcirculation analysis.

36. Monnet X, Saugel B. Could resuscitation be based on microcirculation data? We are not sure! Intensive Care Med 2018; doi: 10.1007/s00134-018-5180-2. [Epub ahead of print]

37. Saugel B, Vincent JL, Wagner JY. Personalized hemodynamic management. Curr Opin Crit Care 2017; 23:334–341.