# Dynamic monitoring tools for patients admitted to the emergency department with circulatory failure: narrative review with panel-based recommendations

Ivor S. Douglas[a], Mohammed H. Elwan[b,c,d], Marta Najarro[e] and Stefano Romagnoli[f,g]

**Intravenous fluid therapy is commonly administered in the emergency department (ED). Despite the deleterious potential of over- and under-resuscitation, professional society guidelines continue to recommend administering a fixed volume of fluid in initial resuscitation. Predicting whether a specific patient will respond to fluid therapy remains one of the most important, but challenging questions that ED clinicians face in clinical practice. Surrogate parameters (i.e. blood pressure and heart rate), are widely used in usual care to estimate changes in stroke volume (SV). Due to their inadequacy in estimating SV, noninvasive techniques (e.g. bioreactance, echocardiography, noninvasive finger cuff technology), have been proposed as a more accurate and readily deployable method for assessing flow and preload responsiveness. Dynamic monitoring systems based on cardiac preload challenge and assessment of SV, by using noninvasive and continuous methods, provide more accurate, feasible, efficient, and reasonably accurate strategy for prediction of fluid responsiveness than static measurements. In this article, we aimed to analyze the different methods currently available for dynamic monitoring of preload responsiveness. *European Journal of Emergency Medicine* 31: 98–107 Copyright © 2024 The Author(s). Published by Wolters Kluwer Health, Inc.**

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[a]Denver Health Medical Center, University of Colorado School of Medicine, Denver Colorado, USA, [b]Emergency Department, Kettering General Hospital, Kettering, UK, [c]Department of Cardiovascular Sciences, University of Leicester, Leicester, UK, [d]Department of Emergency Medicine, Alexandria University, Alexandria, Egypt, [e]Emergency Department, Ramón y Cajal University Hospital, Madrid, Spain, [f]Health Science Department, Section of Anesthesia and Critical Care, University of Florence, Florence, Italy and [g]Department of Anesthesia and Critical Care, Azienda Ospedaliero-Universitaria Careggi, Florence, Italy

Correspondence to Ivor S. Douglas, MD, Denver Health Medical Center, University of Colorado School of Medicine, 601 Broadway, MC 4000, Denver, CO 80204, USA
Tel: +1 303 436 6000; e-mail: idouglas@dhha.org

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## Introduction

Intravenous fluid administration is one of the most common therapeutic interventions performed in the emergency department (ED) [1].

However, it has been reported that over- and under-fluid resuscitation may be deleterious for the patient since it has been associated with increased morbidity, length of hospital stay, and mortality rates following a classic ‘U-shape’ fluid status vs. outcomes (Fig. 1) [2–4].

In daily practice, fluid management interventions align with the Frank–Starling curve [a relationship between the preload/stroke volume (SV)]. Based on the Frank–Starling law, as preload increases, left ventricle SV increases until the optimal preload is achieved [5]. However, SV assessment is infrequently performed and unreliable, therefore surrogate parameters [e.g. blood pressure (BP), heart rate] are generally used to estimate the changes to SV, which have obvious downsides (Fig. 2) [5].

Professional society guidelines continue to recommend a fixed volume of fluid in initial resuscitation (e.g. at least 30 mL/kg) in sepsis and septic shock according to the Surviving Sepsis Guidelines 2021 [6].

Preload responsiveness has been defined as an increase in SV by 10–15% after a transient perturbation in preload. Several methods of assessing preload responsiveness are currently available for use in the ED. They included the administration of a fluid bolus challenge (250–500 mL) or less frequently, a mini-fluid challenge (i.e. 100 mL of balanced crystalloids) [7,8] or the passive leg raising (PLR) test [6,9] (Table 1).

There is evidence suggesting that only half of the hemodynamically unstable patients improve hemodynamics after fluid administration [9]. The identification of those patients who may increase SV after fluid administration (i.e. fluid responders) is crucial for preventing adverse events and helps to administer exactly the amount of fluid that each patient needs [10].

Current evidence, indeed, suggests that goal-directed therapy guided by fluid responsiveness-dynamics was associated with shorter ICU length of stay, shorter hospital length of stay, reduced mortality and duration of mechanical ventilation [10].

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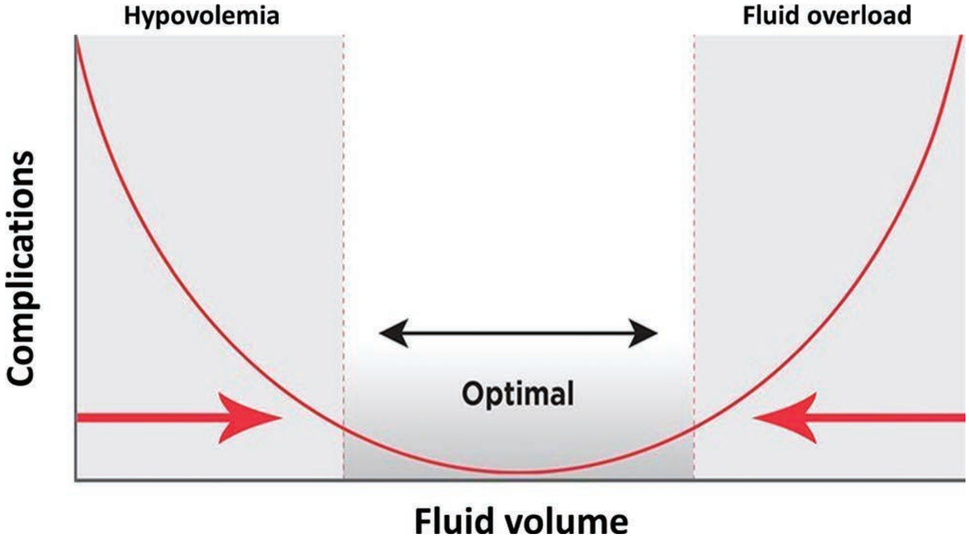
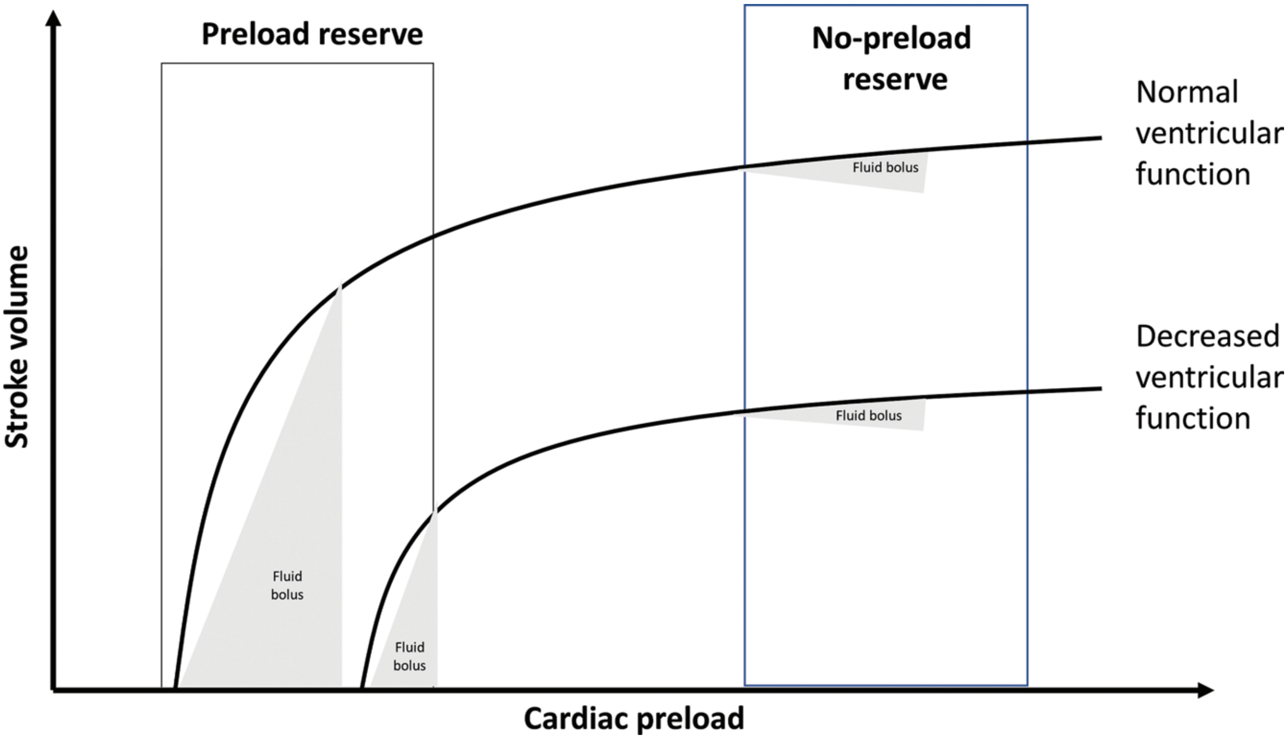
Fig. 1



Relationship between resuscitation volume and patient outcomes. There is probably a U-shape relationship between them, with increased mortality and incidence of adverse events in under- and over-resuscitation. Adapted from Evans *et al.* [9] with permission.

Fig. 2



Frank–Starling curve.

Taken together, these findings highlight the need for an evidence-based approach for evaluating hemodynamic monitoring protocols, coupled with optimized patient care algorithms that will improve patient-centered outcomes.

## Objectives

The purposes of the current manuscript are to:

1. Analyze the different tools currently available for performing dynamic assessments to ascertain a patient's

**Table 1 Functional hemodynamic monitoring parameters**

| Parameter | Formula | Threshold value |
|---|---|---|
| PPV | $PP_{max}-PP_{min}/PP_{mean} \times 100$ | +12% |
| SVV | $SV_{max}-SV_{min}/SV_{mean} \times 100$ | +12% |
| IVCd variation | $D_{max}-D_{min}/D_{mean} \times 100$ | +12% |
| SVCd variation | $D_{max}-D_{min}/D_{mean} \times 100$ | +36% |
| PLR | CO (or SV) measurement/variation | +10% |
| EEOT | CO (or SV) measurement/variation | +5% |
| FC (500 mL) | CO (or SV) measurement/variation | +15% |

CO, cardiac output; D, diameter; EEOT, end-expiratory occlusion test; FC, fluid challenge; IVCd, inferior vena cava diameter; PLR, passive leg raising; PP, pulse pressure; PPV, pulse pressure variation; SV, stroke volume; SVCd, superior vena cava diameter; SVV, stroke volume variation.
Adapted from Brienza *et al.* [51] with permission.

preload responsiveness and for managing individualized fluid management in the ED.

2. Provide ED clinicians with a reference framework extracted from the available data and the panel's clinical experience.

## Methods

This was a narrative review, in which panel-based recommendations were provided.

On 24 November 2022, an international group of four specialists in emergency and critical care medicine from Italy, Spain, UK and the USA of North America, working in collaboration, convened to discuss the role and relevance of dynamic assessments and monitoring tools in the ED from a clinical perspective.

A literature search was conducted to review the state of the art of dynamic monitoring of preload responsiveness in patients with circulatory failure admitted to the ED. It was performed in PubMed (www.pubmed.gov) for English, French, Spanish, Portuguese and Italian language articles published up to the present was performed using the terms 'Dynamic assessment' OR 'Dynamic monitoring' OR 'Fluid responsiveness' OR 'Preload responsiveness' OR 'Fluid Challenge' OR 'Stroke volume' OR 'Central venous pressure' OR 'Passive leg raising' AND 'Fluid therapy' OR 'Fluid management'.

An initial document was drafted as a result of these meetings, and it was reviewed by the panel members. Feedback from the panel was taken into consideration until the greatest level of consensus was achieved and the final text was validated. During the structured consensus-based decision-making process, panel members voted on the draft statements and recommendations.

## Findings

### Fluid management in the emergency department

With regards to fluid management, the ED physician faces two key questions: (1) Whether or not to start a fluid administration (timing to start) (2) How much fluid does it take to optimize hemodynamics?

#### *Whether or not to start a fluid administration (timing to start)*

There is evidence supporting that patients showing symptoms or signs of tissue hypoperfusion and appearing to be fluid responders (i.e. patients with increase in SV/CO after fluid load) should receive fluid administration as a component of the initial resuscitation approach [11].

#### *How to perform fluid management?*

The primary question to be addressed is whether a fluid bolus is *indicated* and has a measurable effect on achieving circulatory effectiveness (i.e. the patient is a fluid responder). Aya *et al.* [12], reported that the doses of fluids used for a fluid challenge modify the proportions of responders in postoperative patients. A dose of 4 mL/kg reliably detects responders and nonresponders.

However, different standardized protocols have failed to provide better outcomes [13–15], which clearly indicates the need to establish customized fluid management protocols centered on the patients' needs.

Regarding the optimal approach for fluid loading, the panel recommends:

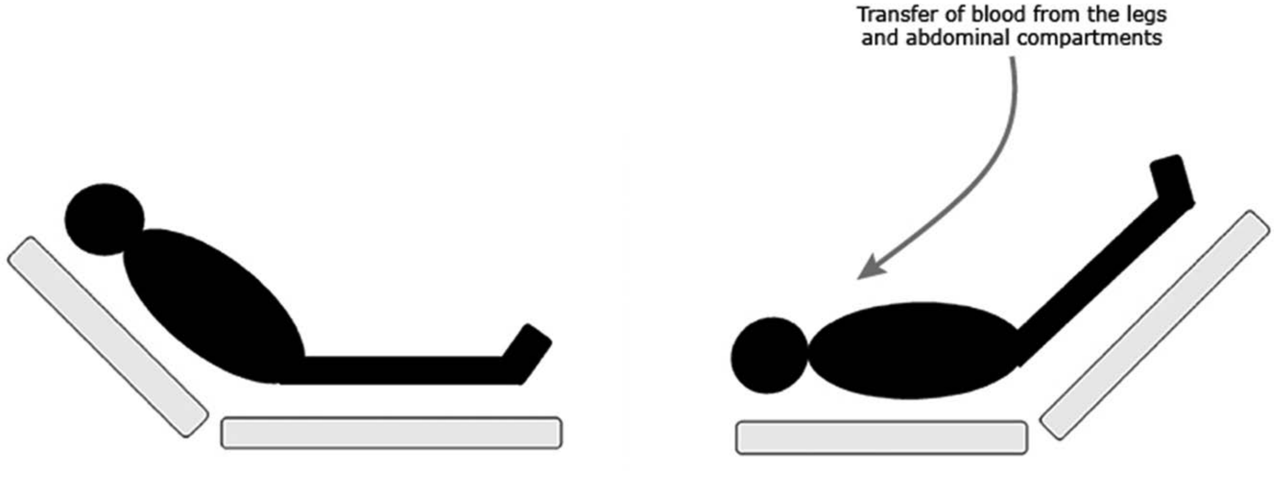
- Once signs and symptoms of hypoperfusion are detected [10], initiate monitoring of CO with a validated technique [e.g. echocardiography, minimally invasive CO monitoring systems based on pulse wave analysis (PWA), noninvasive bioreactance technology].
- Repeat a measurement of CO after administration of each standardized controlled fluid challenge (at least 4 mL/kg infused over less than 30 min) [12] or use a continuous CO monitoring device.

#### *Passive leg raising*

Cardiac preload can be augment, not only by the IV administration of fluids, but also by an internal translocation of venous preload volume. PLR test (Fig. 3) is a recommended strategy of preload responsiveness exploration by the Surviving Sepsis Guidelines 2021 [6] and the European Society of Intensive Care Medicine [16].

The elegant simplicity of this test rests in the premise that the lower limbs contain about 350 mL of venous blood volume, and that raising both legs to 45° will result in an 'autotransfusion' of venous blood into the central veins. The inherent benefit is that this volume perturbation is naturally 'individualized' to the individual patient's body mass and height and the intervention is completely reversible [17]. This test has the strong advantage of being reliable in conditions in which indices of preload responsiveness, based on the respiratory variations of SV or pulse pressure (i.e. SV variation and pulse pressure variation), such as spontaneous breathing, arrhythmias, low tidal volume ventilation, right ventricular dysfunction, and low lung compliance cannot be used [17]. Moreover, PLR can be repeated regularly for

**Fig. 3**



Passive leg raising.

**Table 2 Limitations of dynamic variables**

| Clinical scenario | False positive | False negative |
|---|---|---|
| HR/RR < 3.6 | | X |
| Arrhythmias | X | X |
| TV < 8 mL/kg (IBW) | | X |
| Abdominal hypertension (or pneumoperitoneum) | X | |
| Open thorax | | X |
| Spontaneous ventilation | X | X |

HR, heart rate; IBW, ideal body weight; RR, respiratory rate; TV, tidal volume. Adapted from Brienza *et al.* [51] with permission.

continuous reassessment for preload responsiveness and in case of negative test, the patient is repositioned and no harming fluids have been administered limiting the risk of fluid overload, venous congestion and tissue edema.

The panel suggests that, considering of the heterogeneity of ED patient populations (both in terms of pathologies and comorbidities), dynamic measures for fluid responsiveness assessment, are preferred over static approaches for assessing the volume responsiveness of patients requiring hemodynamic management. Among the available tests, PLR is a highly sensitive and easy method for the identification of fluid responders [13,17]. Limitations of dynamic measures are presented in Table 2.

## Methods for assessing preload responsiveness in the emergency department

As aforementioned, preload responsiveness has been defined as an increase in SV by 10–15% after a transient perturbation in preload. Whereas, fluid tolerance may be defined as ‘the degree to which a patient can tolerate administration of fluids without causation of organ dysfunction’ [18].

A spectrum of methods is currently available for assessing preload responsiveness with varying performance characteristics and utility in the ED.

Historically, optimization of fluid management has been based on the assessment of vital signs (e.g. BP, heart rate), laboratory tests (e.g. serum lactate level, mixed/central venous oxygen saturation), physical examination (e.g. skin mottling, neurological status, capillary refill time) and static assessments of cardiac preload, such as central venous pressure (CVP) and pulmonary capillary wedge pressure [19,20] (Table 3).

Surrogates of perfusion indicators: BP, CVP, inferior vena cava (IVC) diameter.

## Clinical parameters

ED physicians have commonly used systolic or mean BP measurements as a surrogate of blood flow changes [1]. However, shock may exist with BP within the normal range or even higher (increase in vasomotor tone), so focusing a fluid management strategy on normalizing these parameters may not be appropriate [21].

According to the recommendations of the European Society of Intensive Care Medicine, during shock resuscitation target BP should be individualized. Additionally, they recommend initially targeting a MAP of ≥65 mmHg [16]. However, no discrete guidance is provided regarding individualization except for body weight.

## Static assessments of cardiac preload

The CVP can be measured using a central venous catheter advanced via the internal jugular or subclavian vein and placed in the superior vena cava near the right atrium or by a central catheter introduced peripherally. Placing a central catheter is a time-consuming maneuver that may delay timely resuscitation. A normal CVP reading is between 8 and 12 mmHg (although in spontaneous ventilation even 0–2 mmHg can be considered normal). Importantly, CVP is related to the right atrial

**Table 3 Overview of the different methods for assessing fluid responsiveness**

| | Methods |
|---|---|
| Clinical assessment of tissue perfusion | Mental status<br>Urine output<br>Skin perfusion:<br>Capillary refill time<br>Mottling score |
| Classical assessment of fluid status | Arterial pressure<br>Central venous pressure<br>Heart rate<br>Lactate concentration<br>Mixed venous oxygen saturation<br>Pulmonary capillary wedge pressure/ pulmonary artery occlusion pressure<br>Flow time corrected (?) |
| Dynamic Fluid responsiveness assessment in the presence of mechanical ventilation (heart-lung interaction) | • Pulse pressure variation[a]<br>• Stroke volume variation[a]<br>• End-expiratory occlusion test<br>• Pleth variability index |
| Dynamic Fluid responsiveness assessment not requiring mechanical ventilation | • Passive leg-raising test<br>• Mini-fluid challenge |

[a] No spontaneous breathing, Vt ≥8 mL/kg, Crs ≥30 mL/cm$H_2O$, HR/RR >3.6.
Adapted from Cecconi *et al.* [16]; Desai and Garry [19]; and Monnet *et al.* [20].

pressure and therefore depicts the filling pressure of the right side of the heart, representing a marker of eventual preload responsiveness. However, CVP measurement has many limitations, especially in the ED. Therefore, CVP has consistently failed to predict preload responsiveness [22].

### Ultrasounds

Dynamic change in the diameter of the IVC, measured with ultrasound (US), is a technique that has received tremendous recent attention for its potential ability to aid in preload quantification [23].

There are important limitations to measuring IVC diameter, collapsibility and distensibility accurately, since they are affected by the segment of the vein considered [23].

Moreover, even assuming perfect accuracy and reproducibility in measurements, several common clinical scenarios will confound the relationship between IVC variability and preload responsiveness [23]. In addition, cardiac factors, most importantly right ventricular dysfunction, can also confound the results; such patients typically have a chronically dilated IVC which renders interpretation difficult [23]. Moreover, USs do not allow real-time continuous monitoring [23], and the collapsibility and diameter thresholds have not been validated in critically ill patients [24].

### *Measurement of blood flow*

Blood flow (SV and/or CO) can be estimated through several validated techniques that, according to technologies and principles of measurement, can be divided into invasive [e.g. thermodilution via pulmonary artery catheter, calibrated (via central venous catheter thermodilution calibration principle) PWA techniques], minimally invasive (e.g. PWA with invasive BP with internal calibration or uncalibrated) and noninvasive (e.g. bioreactance, echocardiography, noninvasive finger cuff technology) techniques. Elwan *et al.* [25] reported that baseline SV and CO were better at predicting the response to fluid resuscitation than traditional markers. While dynamic assessment is the recommended approach, it appears that a qualitative understanding of whether the SV/CO is high or low could provide additional useful information for ED care. Monitoring CO with a pulmonary artery catheter has been used as a reference method for years [26]. Currently, less invasive monitoring techniques have gained popularity.

They included transpulmonary thermodilution, which is easier to implement than pulmonary artery catheters; however, the measurements might be less accurate [27].

### Transpulmonary thermodilution

Transpulmonary thermodilution allows measurement of intrathoracic blood volumes, extravascular lung water and CO. Transpulmonary thermodilution technique–based devices have emerged as an interesting monitoring approach that allows for the assessment of cardiac output in two different ways, namely by using the Stewart–Hamilton principle and by pulse contour analysis of the arterial curve sampled [27,28]. However, thermodilution requires regular recalibration, the global end-diastolic volume does not distinguish between the left and the right ventricle, and global ejection fraction overestimates left ventricle systolic function in the case of ventricular dilation [27,28].

### Arterial waveform analysis

The methods based on arterial waveform analysis (invasive and minimally invasive), both pulse pressure analysis and pulse power analysis, estimate SV from the arterial pressure waveform [29]. Since all the arterial waveform methods critically depend on an ideal arterial pressure tracing, conditions that distort the arterial waveform, regardless of its nature, will result in inaccuracies [30]. Moreover, depending on the algorithm used and the calibration method, devices made by different manufacturers have different precision or trending abilities [30].

### Transesophageal echocardiography

Esophageal Doppler monitoring is a minimally invasive tool for continuously measuring SV. It measures the blood flow in the descending aorta by using a Doppler transducer probe into the distal esophagus [26]. There is a noninvasive method based on this principle. Transthoracic Doppler echocardiography estimates the CO. It assumes that the actual SV at the level of left ventricle outflow is then estimated by assuming that the descending aorta receives 70% of the total CO [29]. However, both methods are not free of limitations. They measure blood flow in the descendent aorta and extrapolate that into left ventricle outflow [29], the cross-sectional area of the aorta is not fixed [29], are relatively operator-dependent with an inter- and intra-observer variability of 10–12% [31], and finally, the probe position needs to be very accurate and misalignment of more than 20° can lead to misinterpretations [31].

### Plethysmography-based technologies

Plethysmography-based technologies are not blood flow estimation methods, but rather dynamic indicators of preload responsiveness. Plethysmography-based technologies assume that respiratory variation in pulse oximeter waveforms reflects blood volume status in mechanically ventilated patients [32]. It has been reported that respiratory variations in the pulse oximeter plethysmography waveform amplitude have been able to predict preload responsiveness in ICU [32]. However, this cannot be easily measured either at the bedside or ED and, in addition, cannot be continuously monitored [32]. The pleth variability index (PVI) is a dynamic and noninvasive parameter for automated and continuous calculation of the respiratory variations in the pulse oximeter waveform amplitude [33]. Although its capacity for monitoring preload responsiveness has been suggested, additional studies are necessary to help clarify its utility in different scenarios [32,34].

### Bioelectrical impedance

Bioelectrical impedance analysis measures the resistance value caused by a difference in electric conductivity (impedance), which, in theory, allows bioimpedance to assess body composition status [35]. It has been published that bioimpedance was a feasible method for assessing volume status [35] and that may predict PLR responders [36]. However, there are some doubts about how this measurement should be used in emergency care [37].

### Bioreactance

Bioreactance has emerged as a noninvasive method to assess cardiac performance.

Bioreactance is a noninvasive technique used for real-time dynamic monitoring of SV and CO. It uses a pair of skin surface electrodes placed on the patient's thorax that apply a low-amplitude, high-frequency electrical current which traverses the thorax [38,39] (Fig. 4). The assumptions underpinning the bioreactance approach is that fluctuations in blood volume during the cardiac cycle induce changes in the electrical conductivity of the chest [38,39]. These fluctuations are recorded by the electrodes located on the skin surface, with a time delay called a phase shift, which allows the estimation of the SV. The underlying scientific rationale is that the higher the cardiac SV, the more significant these phase shifts become [38,39] (Fig. 4).

The accuracy, precision, responsiveness and reliability of a noninvasive bioreactance CO monitoring (NICOM) system for detecting changes in CO was determined in a total of 65 888 pairs of samples from 110 patients [40]. According to the results of this study, CO measured by NICOM had the most often acceptable accuracy, precision, and responsiveness in a wide range of circulatory situations [40]. Moreover, in patients with pulmonary hypertension, the NICOM system accurately and reliably measured CO at rest and after the vasodilator challenge [41].

NICOM system has been demonstrated to be an accurate method for dynamic monitoring of preload responsiveness in hemodynamically unstable ICU patients and healthy volunteers after PLR and fluid challenges, with almost 100% concordance with carotid flow assessment [42,43]. Additionally, the NICOM system was able to predict preload responsiveness accurately from changes in CO during PLR [44].

Guided by bioreactance, initial fluid resuscitation in septic patients was associated with a lower fluid balance and better clinical outcomes [45].

Table 4 summarizes the main parameters used for assessing preload responsiveness.

Table 5 shows the operative performance of different indices predictors of fluid responsiveness.

The panel concludes that:

- Dynamic monitoring of preload responsiveness using noninvasive cardiac output monitoring may inform fluid optimization in the ED [19,46].

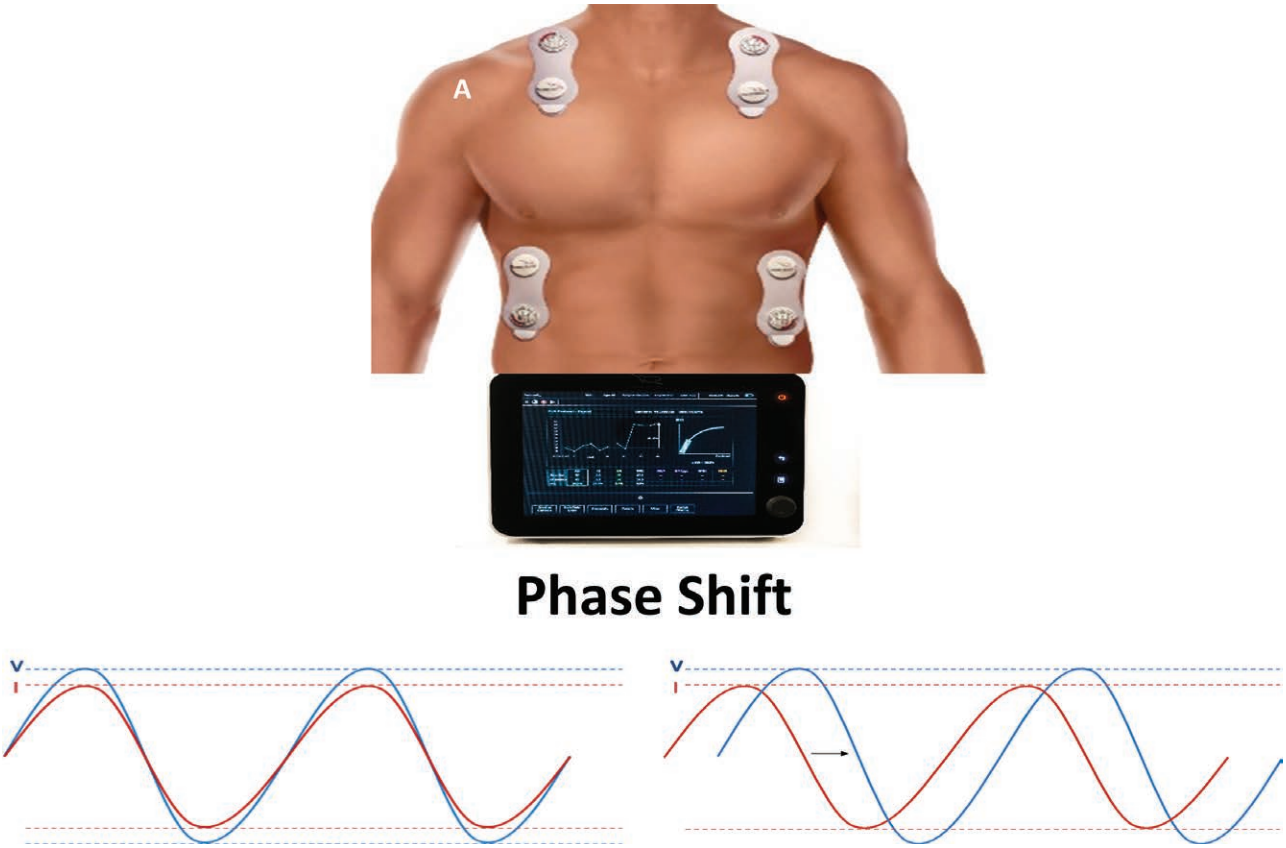
## Discussion

Knowing whether a specific patient will respond to fluid therapy remains one of the most important, but challenging questions that ED physicians face in daily practice.

Dynamic monitoring of fluid management has been developed in an attempt to provide a customized therapy focused on the patient's needs [47].

The results of the FRESH (fluid responsiveness evaluation in sepsis-associated hypotension) study, a randomized unblinded clinical trial designed to answer questions surrounding the benefits of dynamic measure-guided fluid resuscitation, demonstrated that dynamic monitoring for fluid management responsiveness resulted in a significantly lower volume of fluid as compared to standard care [48]. Additionally, there was a significant reduction in the need for renal replacement therapy or invasive mechanical ventilation in the patients who underwent fluid management guided by dynamic monitoring [48]. Based on the FRESH study, in shock patients who underwent fluid management, dynamic monitoring may improve outcomes.

**Fig. 4**



The noninvasive bioreactance cardiac output monitoring (NICOM) system (Starling, Baxter Inc. Deerfield, USA). Four noninvasive sensor pads are applied to the thorax, creating a 'box' around the heart. A high-frequency current is passed between the two outer electrodes, and the resulting voltages are recorded between the two inner electrodes. The relative phase shift and rate of change of phase between these signals are determined and used in the calculations of stroke volume (SV).

The spectrum of invasive, minimally invasive and noninvasive methods currently available for dynamic monitoring of preload responsiveness may not all be appropriate for implementation in a usual care manner in the ED. The unique patient characteristics and throughput of a busy ED, suggest that the method of choice would preferably be noninvasive, accurate, precise, operator-independent, easy to use and preferably inexpensive [26].

Assessment of CO and, even more importantly, changes in CO can be extremely useful when assessing circulatory function [19,46]. Transpulmonary thermodilution technique is still recognized as gold standard for evaluating and determination of the CO in ICU [27,28]. However, it is not free of drawbacks (i.e. it requires the placement of a central venous catheter to perform the measurement, needs dedicated materials and requires regular recalibration due to changes in vascular impedance) [27,28]. Therefore, this method has been suggested in patients undergoing complex surgery (e.g. liver transplantation, esophagectomy and cardiac surgery) or critically ill patients admitted to ICU with circulatory shock [49].

Noninvasive CO monitoring methods are emerging in the ED and in the prehospital environment [50]. Currently available technologies for monitoring preload responsiveness in the ED include ultrasonography, pulse oximeter plethysmography waveform analysis and variability (e.g. PVI) and bioreactance [50].

Regarding US technology, although it has been used in the ICU for assessing CO, continuous echocardiographic monitoring of CO remains largely debated [29,31].

Dynamic monitoring based on cardiac preload challenge and assessment of SV, by using noninvasive and continuous methods like bioreactance, is much more accurate than static measurements [25,26,38–40]. Bioreactance is a noninvasive method that provides continuous CO measurements [38–40]. It has been suggested that an SV-guided fluid resuscitation, via noninvasive bioreactance monitoring, in patients with severe sepsis and septic shock was associated with

**Table 4 Overview of the different parameters for assessing fluid responsiveness**

| Method | Physiology or rationale | Limitations |
|---|---|---|
| Static parameters | | |
| Clinical signs | • Resolution of clinical features of shock, in response to a fluid bolus (e.g. reduction of skin mottling, improved capillary refill time, increase of urine output) | • Only poor capillary refill was found to correlate to fluid responsiveness<br>• Significant inter-observer variability<br>• In critical care, classical signs may be obscured by an orgy of pathology<br>• Clinical changes could change slowly |
| CVP | • A hypovolemic patient is expected to have a low CVP<br>• That patient's CVP might increase in response to fluid challenge (depending on cardio-circulatory function)<br>• If the patient remains relatively hypovolemic, the change in CVP should be relatively small<br>• A patient who is 'well filled' should have a clear increase in their CVP | • CVP is not a parameter of fluid responsiveness<br>• Apart from RV preload and cardiac function, the CVP is influenced by numerous other pathophysiological variables, including RV compliance, intrathoracic pressures, tricuspid valve competence and where in the CVP waveform the measurement is taken |
| PAWP | • PAWP measurement should represent LA pressure<br>• LA pressure should represent LVEDP<br>• LVEDP should be a close surrogate for LV preload<br>• Thus, a hemodynamically unstable patient with low PAWP should be challenged with more fluid | • PAWP is confused by many situations in which the PAWP is not equal to LV end-diastolic pressure:<br>• It is higher than LVEDP when there is mitral stenosis or regurgitation, left-to-right shunt, COPD, positive pressure ventilation, atrial myxoma, pulmonary venous hypertension or simply poor catheter placement<br>• It is lower than the LVEDP when there is LV failure, high PEEP, a poorly compliant LV (e.g. in HOCM) or whenever there is aortic regurgitation |
| Dynamic parameters | | |
| SVV and PPV | • The lower on the Frank–Starling Curve patients' heart is working, the more the stroke volume increases after fluid loading<br>• Decrease in preload due to mechanical inspiration results in a decrease in ventricular wall stretch<br>• This results in a decrease in stroke volume<br>• Thus, patients who have decreased filling are going to have more difference between their inspiration and expiration stroke volumes | Tests based on cardiopulmonary interactions can only be used in intubated and ventilated patients and become invalid in the following situations:<br>• Spontaneously breathing patient<br>• Cardiac arrhythmias<br>• Tidal volume $<8$ mL/kg<br>• Compliance of the respiratory system $<30$ mL/cm$H_2O$<br>• Intra-abdominal hypertension<br>• HR/RR $<3.6$ |
| Tidal volume challenge | • In ventilated patients with a tidal volume of 6 mL/kg, the tidal volume temporary increase to 8 mL/kg indicates preload responsiveness if PPV increases | • Can only be used in intubated and ventilated patients and has the same limitations as those for PPV and SVV |
| End-expiratory occlusion test (EEOT) | • End-expiratory pause of 15 s followed by an increase in CO in the event of preload responsiveness<br>• Can be used in ventilated patients even in case of arrhythmia, whatever the tidal volume and the positive end-expiratory pressure level | • Can only be used in intubated and ventilated patients<br>• The patient must tolerate this rather long breathing interruption |
| Passive leg raising test (autotransfusion) | • To raise both your legs up to 45° keeping the thorax parallel to the ground will result in an 'autotransfusion' of venous blood into the central veins<br>• This represents a reversible fluid challenge<br>• This method of testing fluid responsiveness is well-validated | • You need a patient with both legs intact<br>• You rely on an intact pelvis, so this excludes a lot of messy trauma patients (in whom it would be very useful)<br>• It cannot be done if you have a balloon pump in situ, or postangiography (because you need to lie flat) - and thus a lot of low-cardiac-output cardiogenic shock patients are excluded<br>• It cannot be done if you are even slightly concerned about increased intracranial pressure |

COPD, chronic obstructive pulmonary disease; CVP, central venous pressure; HOCM, hypertrophic obstructive cardiomyopathy; LA, left atrial; LV, left ventricle; LVEDO, Left ventricle end-diastolic pressure; PAWP, pulmonary artery wedge pressure; PEEP, positive end-expiratory pressure; RA, right atrial; RV, right ventricle; SVV, stroke volume variation.

Adapted from Desai and Garry [19] and Shi *et al.* [46].

**Table 5 Operative performance of dynamic indices of fluid responsiveness**

| Test | Threshold | Sensitivity (95% CI) | Specificity (95% CI) | AUROC |
|---|---|---|---|---|
| Mini-fluid challenge | 1 | 0.84 (0.76–0.90) | 0.76 (0.68–0.83) | 0.84 |
| | 5% | 0.82 (0.76–0.88) | 0.83 (0.77–0.89) | 0.91 |
| PLR | 10% | 0.85 (0.81–0.88) | 0.91 (0.88–0.93) | 0.95 |
| | 13% | 0.83 (0.61–0.94) | 0.80 (0.68–0.88) | 0.84 |
| EEOT | 5% | 0.86 (0.74–0.94) | 0.91 (0.85–0.95) | 0.96 |
| | 5% | 0.82 (0.73–0.89) | 0.89 (0.82–0.94) | 0.92 |
| PPV | 10% | 0.74 (0.66–0.81) | 0.77 (0.70–0.83) | 0.82 |
| SVV | 12% | 0.83 (0.75–0.88) | 0.85 (0.78–0.90) | 0.90 |
| Tidal volume challenge | 3% | 0.9 (0.76–0.97) | 0.87 (0.31–0.99) | 0.92 |
| SPV | 7.5% | 0.92 (NA) | 0.87 (NA) | 0.91–0.93 |
| SPV ($\Delta$down)[a] | $>5$ mmHg | 0.86 (NA) | 0.86 (NA) | 0.92 |
| $\Delta$IVC | 16% | 0.77 (0.65–0.86) | 0.87 (0.70–0.95) | 0.86 |

AUROC, area under de receiver operating curve; CI, confidence interval; EEOT, end-expiratory occlusion test; IVC, inferior vena cava respiratory variability; PLR, passive leg raising; PPV, pulse pressure variation; SPV, systolic pressure variation; SVV, stroke volume variation.

[a] Absolute systolic pressure lowering.

Adapted from Weigl *et al.* [26] and Alvarado Sánchez *et al.* [27].

**Table 6 Overview of the main advantages and disadvantages of cardiac output monitors**

| Method | Advantages | Disadvantages |
|---|---|---|
| PAC | Measure CVP<br>Intermittent and continuous<br>SVR can be obtained | Pulmonary infarction<br>Rupture of pulmonary artery<br>Arrhythmias<br>Need right heart catheterization |
| Esophageal Doppler | Less invasive<br>Simple to use | Needs intubated patient<br>Only measure descending aortic flow<br>Not good in AR |
| Echocardiography | Provides detailed cardiac information<br>Estimate preload | Needs additional training<br>Inability to image patient |
| Bioimpedance | Continuous<br>Difficult to set up | Numerous mathematical assumptions<br>Signal stability fails after 24 h |
| Bioreactance | Noninvasive<br>Continuous<br>Sensors can be placed anywhere in thorax and back | Numerous mathematical assumptions<br>Signal stability fails after 24 h |
| Flick's principle | Easy set up<br>Provides additional ventilatory parameters | Not suitable for unstable patient<br>Shunt can affect CO estimation |
| Pulse wave analysis methods | Advantages | Disadvantages |
| PICCO | Intermittent and continuous<br>Measures GEDV/EVLW<br>Estimate preload | Need a central venous access |
| LIDCO | Intermittent and continuous<br>SVR can be obtained | Cannot be used if patient is on lithium or NDM<br>Need frequent blood drawing<br>Does not estimate preload |
| Flo-Trac | SVR can be obtained<br>Measure PPV/SVV<br>Many validation studies | Not reliable in very high CO state<br>Perform poorly with tachyarrhythmia<br>Valvular pathology prevents accurate reading of CO |

AR, aortic regurgitation; CO, cardiac output; CVP, central venous pressure; EVLW, extravascular lung water; GEDV, global end-diastolic volume; NDM, nondepolarizing muscle relaxant; PAC, pulmonary artery catheter; PPV, pulse pressure variation; SVR, systemic vascular resistance; SVV, stroke volume variation.
Adapted from Weigl *et al.* [26]; Alvarado Sánchez *et al.* [27]; Kobe *et al.* [29]; and Laher *et al.* [50].

reduced fluid balance and improved secondary outcomes [45].

Table 6 summarizes the main advantages and disadvantages of the CO monitors.

## Conclusions

Noninvasive monitoring has evolved in the past few years, seeing the appearance of promising new devices.

Different noninvasive methods are currently available for dynamic monitoring of preload responsiveness. According to the current evidence and the authors experience, noninvasive methods that assess accurately real-time dynamic monitoring of SV and CO, may be considered as the method of choice for dynamic monitoring in the ED.

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### Conflicts of interest

There are no conflicts of interest.

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