Fluid Responsiveness Monitoring In Surgical and Critically Ill Patients

Clinical Impact of Goal-Directed Therapy

Special REPORT

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Needs Statement

Volume expansion is recognized as critically important in optimizing patient status during surgery or in intensive care settings, and the ability to predict fluid responsiveness represents a major clinical challenge. Goal-directed perioperative fluid management using dynamic indicators of fluid responsiveness such as stroke volume has been shown to decrease postoperative morbidity and hospital stay. However, inappropriate volume expansion is associated with increased mortality, and the challenges of balancing fluid minimization with avoidance of fluid overload are formidable. There remains a clinical need for noninvasive functional hemodynamic monitoring that can predict fluid responsiveness across hospital settings.

Learning Objectives

At the completion of this activity, participants should be better prepared to:

1. Devise an inventory of clinical challenges that are associated with fluid resuscitation and management of surgical and critically ill patients.
2. Delineate available fluid responsiveness monitoring methods and relative benefits and limitations associated with the use of each.
3. Appraise recent evidence supporting a clinical rationale for using fluid responsiveness monitoring as part of goal-directed fluid management in various acute care settings.
4. Compare the cost-effectiveness of available methods of monitoring fluid responsiveness, particularly in settings of surgery or intensive care.

Goal

The goal of this educational activity is to provide anesthesiologists, surgeons, and critical care specialists with information on the clinical rationale and recent evidence supporting optimal fluid monitoring and management as part of goal-directed fluid management.

Accreditation Statement

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Financial Disclosures

Maxime Cannesson, MD, PhD: Edwards Lifesciences, Masimo Corporation (product consultation).

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Disclosure of Unlabeled Use

This educational activity contains discussion of some devices that have been studied but not FDA-approved for fluid responsiveness monitoring. This discussion is noted within the text. Please refer to official prescribing information for all products for discussion of approved indications, contraindications, and warnings.

Estimated Time of Completion

This activity should take approximately 60 minutes to complete.

Method of Participation

There are no fees for participating and receiving credit for this activity. The participant should, in order, read the objectives and monograph and answer the multiple-choice post-test. Participation is available online at CMEZone.com (availability may be delayed from original print date). Enter the project number SR1047 in the keyword field to access this activity directly. Or, complete the answer sheet with registration and evaluation on page 8 and mail to: AKH Inc., PO Box 2187, Orange Park, FL 32067-2187; or fax to (904) 215-0534. Statements of participation will be mailed/e-mailed approximately 6 to 8 weeks after receipt of mailed or faxed submissions. A score of at least 70% is required to complete this program successfully. One retake is allowed. The corrected answer sheet will be provided for comparison with course information. Credit is available through September 30, 2011.

Disclaimer

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Introduction

Volume expansion is a common and important therapeutic effort in surgical and critical care settings,[1] with an overall goal of optimizing patient status during procedures and avoiding the adverse outcomes associated with either too little fluid or fluid overload.[2] When volume expansion augments cardiac preload and successfully increases *cardiac output* (CO), the volume of blood pumped by the heart per minute, and *stroke volume*, the volume of blood pumped from one ventricle of the heart with each beat, it can enhance outcomes.[2] Optimization of fluid use, guided by individual patient variables, may provide the best results. Although the term *fluid administration* often is used in this context, it can be confusing because it describes both volume expansion and hydration. This review mainly focuses on *volume expansion* for the purpose of preload and CO increase, and therefore uses that term.

Tailoring volume expansion is a challenge, because predicting fluid responsiveness—defined as a significant increase in CO after volume expansion—involves many uncertainties.[1] For example, only 40% to 72% of critically ill patients exhibit significantly increased CO in response to volume expansion.[3] In addition, prevailing fluid therapy is not evidence-based in many cases.[4] Randomized trials are few, evidence-based guidelines have been slow to develop,[5] and perceived wisdom has a strong influence on practices.[4] These include fluid minimization or restriction, which may avoid excessive intravascular volume[6] but may induce hypovolemia.[7] Should hypovolemia occur, the results may include hypotension, inadequate tissue perfusion, organ dysfunction, and increased postoperative morbidity and mortality.[8,9] A more liberal approach to fluid replacement runs the risk of hypervolemia,[2] which can lead to postoperative weight gain (5-10 kg), increased morbidity and mortality, cardiopulmonary complications, interstitial edema, and longer length of stay (LOS) in the intensive care unit (ICU).[2,6]

An alternative approach supported by a growing body of evidence is goal-directed fluid management, which uses flow-related hemodynamic parameters to predict response to volume expansion and is employed in conjunction with the administration of fluids and vasopressors to reach specific therapeutic end points.[10,11] This strategy allows for individualized therapy[10,12] and is associated with improved outcomes in perioperative and ICU settings (Figure 1).[10,12,13] Fluid responsiveness monitoring methods, each with specific advantages and disadvantages, are available for goal-directed therapy.

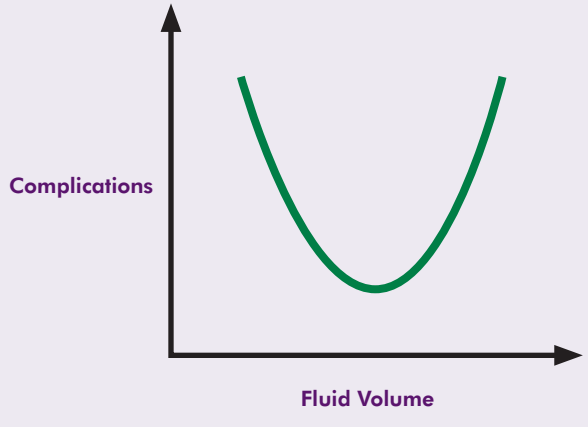

Figure 1. Association between perioperative complication rate and fluid management.

Hypovolemia (left of U-curve) and hypervolemia (right) are associated with several complications (eg, cardiac, renal, pulmonary, infectious). Goal-directed fluid management associated with optimal CO correlates with the lowest rate of perioperative complications.

CO, cardiac output

Fluid optimization concepts have changed dramatically during the past 10 years. In a recent review, Chappell et al describe a rational approach for fluid management during anesthesia.[14] The authors emphasize several important concepts, including the importance of using the right kind of fluid in appropriate amounts at the right time to improve patient outcomes.[14] They also caution against comparing the patient outcome effects of 2 drug classes with different indications (crystalloids and colloids). According to Chappell et al, a discussion of this topic should focus on crystalloids *and* colloids rather than crystalloids *versus* colloids. The goal of perioperative fluid optimization is the same as that of the cardiovascular system under normal conditions: adequate blood flow in vital organs and traumatized tissues, to avoid compromising the former and enable effective wound healing in the latter.[14] In clinical practice, rational substitution therapy incorporating crystalloids and iso-oncotic colloids in balanced preparations replaces perioperative fluid losses according to physiologic background: Crystalloids serve to replace extracellular losses, and colloids are used when cardiac preload needs to be restored, to optimize CO. The current trend is to restrict crystalloid administration and to optimize CO using colloids.

Principles of Fluid Responsiveness Monitoring

The primary question that fluid responsiveness monitoring seeks to answer is whether the patient's CO will increase after volume expansion.[15] For this to occur, the patient must have *preload dependence*—defined as the ability of the heart to increase stroke volume in response to an increase in preload. Predicting preload dependence involves consideration of several parameters[16] related to the Frank-Starling relationship, which describes the intrinsic ability of the heart to adapt to increasing volumes of inflowing blood (Figure 2).[15]

Evidence of accuracy, reproducibility, validation in clinical practice, and safety is important in selecting a fluid monitoring method.[10,15] For example, some clinicians use intraoperative urine output as a guide, but the relationship between urine output and volume expansion in this setting is unclear.[17,18] Others prefer to use a volume challenge, in which a small volume of fluid is administered and hemodynamic responses (including CO) are monitored; however, since approximately half of patients are not volume-responsive, this approach may be inefficient and potentially dangerous.[19,20] Moreover, this approach requires accurate CO monitoring devices. Interestingly, despite several studies showing that CO optimization can improve patient outcomes, clinical acceptance of this approach is not widespread.

Another criterion for distinguishing among fluid responsiveness monitoring methods is cost-effectiveness.[20,21] However, the cost–benefit differences are difficult to evaluate because of the limited number of outcomes studies.[10] More comparative, randomized trials are needed to evaluate the relative cost-effectiveness of monitoring methods,[10,22] but recent studies suggest that goal-directed therapy and CO optimization may have a positive effect on patient outcomes for as many as 15 years after surgery.[23]

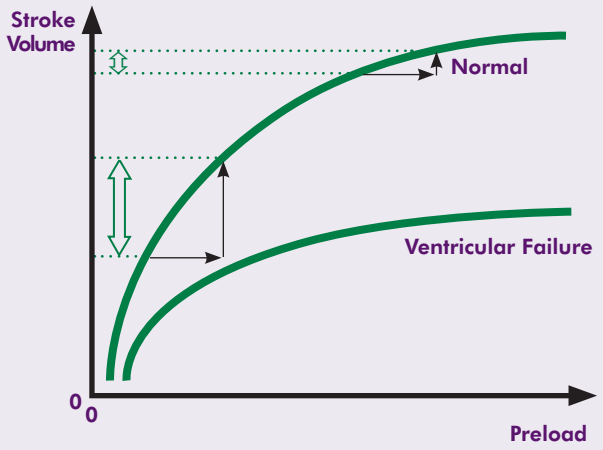

Figure 2. Frank-Starling relationship between ventricular preload and ventricular stroke volume.[15]

The first portion of this relationship is called the steep portion, and the second is called the plateau. If the heart is working on the steep portion (low preload), then an increase in preload, induced by volume expansion, will induce a significant increase in stroke volume. Here the heart is said to be preload-dependent. If the heart is working on the plateau (elevated preload), then an increase in preload, induced by volume expansion, will not induce a significant increase in stroke volume. Here the heart is said to be preload-independent. The Frank-Starling relationship depends on preload and stroke volume as well as ventricular function, and the curve is flattened when ventricular function is impaired. Consequently, for a given preload value, it is not possible to predict the effects of an increase in preload on stroke volume.

Table. Selected Methods for Monitoring Dynamic Parameters of Preload Dependence[2,3,15,21,29,30]

Method	Advantages	Limitations
Noninvasive		
PVI (part of Masimo Rainbow SET platform; Masimo Corp.)	Multimodal monitoring (eg, hemoglobin, oxygen content) No calibration Real-time and continuous information Ease of use Clinical validation	Vasomotor tone No artifact detection Proprietary algorithm
Minimally Invasive		
SVV (FloTrac/ Vigileo; Edwards Lifesciences LLC)	Multimodal monitoring (eg, CO, vascular resistances) No calibration Clinical validation	Requires specific material No artifact detection Divergent data regarding CO determination Proprietary algorithm
ΔPP	Considered gold standard for accuracy Clinical validation	Subject to confounding effects
Invasive		
SVV, ΔPP (PiCCO Plus; Pulsion Medical Systems AG)	Clinical validation SVV Pulse pressure variations Multimodal monitoring (eg, CO, vascular resistances)	Requires specific material Calibration No artifact detection Proprietary algorithm

CO, cardiac output; **ΔPP,** respiratory variations in arterial pulse pressure; **PVI,** pleth variability index; **SVV,** stroke volume variation

Adapted from reference 15.

Finally, the ideal monitor for goal-directed therapy should be noninvasive and easy to use.[10,15] Even so, hemodynamic monitoring devices will improve outcomes only if paired with treatment that itself improves outcomes.[21]

Fluid Responsiveness Monitoring Parameters

Hemodynamic parameters that can predict fluid responsiveness can be grouped generally as static or dynamic indicators. Classically, static indicators are parameters of ventricular preload such as central venous pressure (CVP), pulmonary capillary wedge pressure (PCWP), or left ventricular end-diastolic volume or area (LVEDA) obtained using transesophageal echocardiography (TEE). All of these parameters have been shown to be of minimal value as predictors of fluid responsiveness.[3,15,24,25] For example, data from PCWP, which estimates LVEDA, may be misleading because several variables affect ventricular compliance, such as myocardial ischemia, vasopressor use, afterload reduction, and ventricular interaction.[26] Similarly, CVP has been found to be a poor predictor of fluid responsiveness; in a systematic review, the likelihood that CVP could predict fluid responsiveness accurately was only 56%.[27] Safety also may be an issue with some modalities: CVP, for example, carries the concern of central line infection.[28] Moreover, echocardiographic parameters such as LVEDA are inaccurate predictors of fluid responsiveness and require technical skills and training. This does not mean that such parameters should not be monitored in the anesthesiology or ICU practice, but rather that they should not be used to assess fluid responsiveness.

Today, dynamic indicators have been shown to be the best and most consistent predictors of fluid responsiveness (Table).[2,3,15,21,29,30] These parameters rely on cardiopulmonary interactions, the respiratory-induced variations in left ventricular (LV) stroke volume or its surrogates, induced by positive pressure ventilation.[15,24]

Dynamic parameters of fluid responsiveness have limitations—particularly that they must be used in mechanically ventilated patients under general anesthesia.[15] Because tidal volume (V_t) affects their predictive value, these dynamic indicators generally must be used with a V_t no less than 8 mL/kg of ideal body weight with a positive end-expiratory pressure (PEEP) between 0 and 5 cmH_2O,

although the pleth variability index (PVI) has been used with V_t less than 8 mL/kg and PEEP greater than 5 cmH_2O. Other limitations related to cardiopulmonary interactions, such as intrathoracic pressure and the general requirement that the patient be in sinus rhythm, are common to all dynamic parameters. In addition, some limitations are specific to the particular parameters.

The passive leg-raising maneuver can be used to predict fluid responsiveness in both spontaneously breathing[31] and mechanically ventilated patients, even in the presence of arrhythmia.[32] Patients who experience an increase in stroke volume, CO, or cardiac index (CI) with this maneuver are more likely to respond to volume expansion.[31-33] CI is calculated as CO divided by body surface area.[34] Because CI variations induced by a passive leg raising are higher in responders than in nonresponders, CI is a useful tool for monitoring fluid responsiveness in the ICU setting.[35] Most studies focusing on the ability of passive leg raising to predict fluid responsiveness in the ICU used esophageal Doppler for the measurement of CI. Other devices, such as transpulmonary thermodilution (PiCCO) or uncalibrated pulse contour analysis, have been proposed with acceptable results.

Dynamic indices of fluid responsiveness relying on cardiopulmonary interactions include respiratory variations in systolic arterial pressure (SPV), respiratory variations in arterial pulse pressure (ΔPP or PPV; pulse pressure is the difference between systolic pressure and diastolic pressure), stroke volume variation (SVV), and respiratory variations in pulse oximetry plethysmographic waveform amplitude (ΔPOP or PVI). Of these, ΔPOP and PVI are the only noninvasive parameters.

Respiratory Variations in Arterial Pulse Pressure

ΔPP is obtained from the arterial pressure waveform, and ΔPP monitoring requires an arterial line. Despite its relative invasiveness, ΔPP has been considered the gold standard for monitoring fluid responsiveness,[30] and more than 30 studies have demonstrated the ability of SPV or ΔPP to predict fluid responsiveness in mechanically ventilated patients under general anesthesia (Figure 3).[3,15,21,36-39] In a trial of 40 mechanically ventilated patients with acute circulatory failure related to sepsis, ΔPP predicted fluid responsiveness accurately.[37] A ΔPP value of 13% allowed discrimination between responders and nonresponders with a sensitivity of 94% and a specificity of 96%, and ΔPP was a more reliable indicator of fluid responsiveness than SPV. High respiratory variations indicate preload dependence, whereas low respiratory variations indicate preload independence.[15]

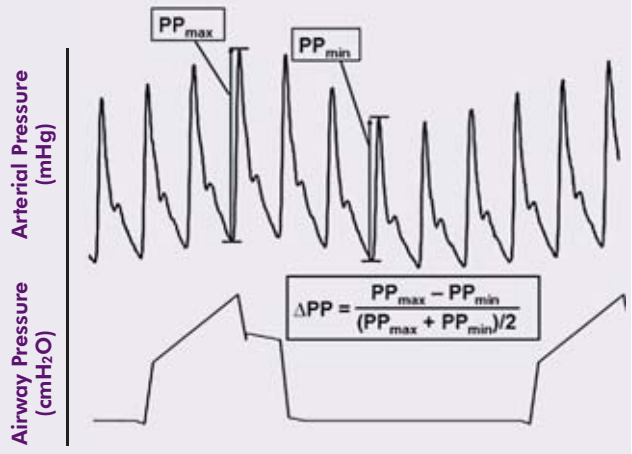

Figure 3. Arterial pressure waveform and airway pressure waveform recordings explaining how pulse pressure variations are calculated.[15]

PP_{max}, maximal pulse pressure during a single respiratory cycle; **PP_{min}**, minimal pulse pressure during a single respiratory cycle; **ΔPP**, respiratory variations in arterial pulse pressure

However, in a recent study (N=15), ΔPP was not shown to be a reliable predictor of fluid responsiveness in the setting of orthotopic liver transplantation.[40] The authors noted that the reasons for the negative results remain unclear. Contributing factors may have included methodological issues, the intraoperative setting, underlying cirrhotic cardiomyopathy, the characteristic low systemic vascular resistance of cirrhotic patients, and a lack of protocol standardization to allow comparative studies.[40,41]

Aboy's algorithm for estimating ΔPP continuously from the arterial pressure waveform alone has been published and is available on Philips Intellivue MP70 monitors.[42,43] Auler's algorithm can be used with standard bedside monitors for the automatic calculation and real-time monitoring of ΔPP.[44]

Stroke Volume Variation

SVV has been shown to be a valid measure of fluid responsiveness.[45,46] Different technologies are available for measuring SVV.[24] An estimate of both SVV and PPV is displayed in real time by PiCCO Plus system (Pulsion Medical Systems AG), a device designed to monitor CO continuously based on transpulmonary thermodilution and arterial pulse contour analysis.[45,47] The pulse contour method measures SVV through a femoral catheter (transcardiopulmonary thermodilution).[48,49]

Another device that measures SVV, the FloTrac/Vigileo system (Edwards Lifesciences LLC), requires standard arterial access and is considered minimally invasive and easy to use.[50] In a randomized controlled trial (RCT) of patients who had undergone elective cardiac surgery (N=40), SVVs assessed using the FloTrac/Vigileo and the PiCCO Plus systems performed similarly in predicting fluid responsiveness.[48] Today, many investigations have demonstrated the ability of this algorithm to predict fluid responsiveness in the operating room.[25,31,51,52] However, in a study of 20 patients undergoing major abdominal surgery, SVV obtained by arterial pulse contour analysis using the FloTrac/Vigileo system did not prove to be a reliable predictor of fluid responsiveness in "real-world" conditions.[53] Questions have been raised about this study, including the limits of the use of SVV in certain patient groups, the fact that esophageal Doppler was used to measure CO, and the fact that SVV was not compared with the gold standard (ΔPP).[41]

Other Invasive and Semi-Invasive Methods

The respiratory SPV and its negative component, Δdown, measured with the aid of an arterial catheter, can be used to guide fluid therapy.[54,55] However, several studies have found SPV and Δdown to be less effective in predicting hemodynamic response to fluid expansion than ΔPP.[37,56] Pestel's algorithm automatically calculates SPV and ΔPP.[15,57]

Respiratory changes in inferior vena cava diameter and superior vena cava diameter predict fluid responsiveness[58-60] and rely on indices derived from TEE.[24,61] Respiratory variations in LV stroke

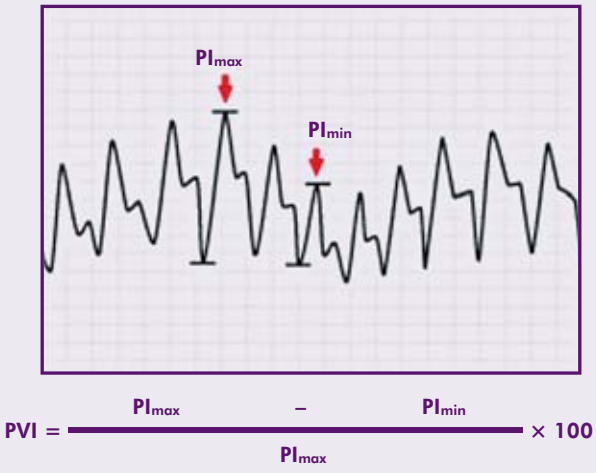

Figure 4. Calculating PVI[70]

PI: the ratio of nonpulsatile to pulsatile blood flow through the peripheral capillary bed. PVI: an automatic measure of dynamic change in PI that occurs during the respiratory cycle.

PI, perfusion index; **PVI,** pleth variability index

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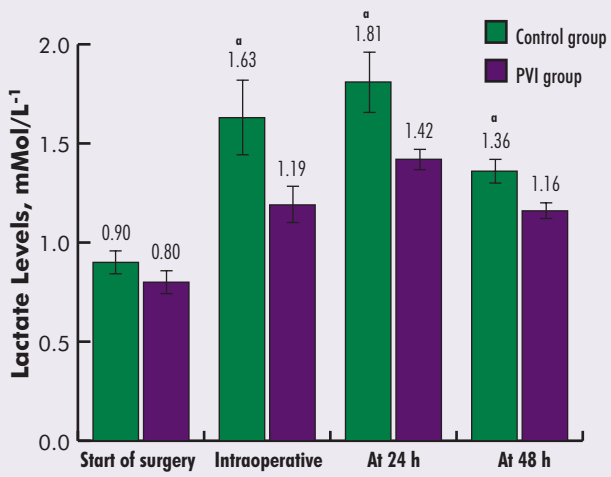

Figure 5. Lactate levels during and after surgery.[73]

Intraoperative: maximum intraoperative value. Data presented as mean ± SEM.

[a] $P<0.05$.

PVI, pleth variability index; **SEM,** standard error of mean

area (ΔSA) and respiratory changes in peak velocity of aortic blood flow (ΔVpeak) also can be measured with TEE and can predict fluid responsiveness.[33] Limitations include operator-dependence and technical difficulty.[62] Using an esophageal probe, TEE is considered semi-invasive.[33] It is limited by a small risk for pharyngeal or esophageal perforation.[63]

Respiratory variation in aortic blood flow, measured with an esophageal Doppler monitoring device, also has been shown to predict fluid responsiveness.[64] Esophageal Doppler monitoring uses a smaller esophageal probe than TEE, and therefore is less invasive; it also requires less training to operate and is less expensive.[63] Esophageal Doppler technology has the disadvantages of limited accuracy, frequent dislocation of the ultrasound probe, and poor toleration in awake patients.[50]

Noninvasive Methods

Attached noninvasively to a finger,[62] the pulse oximeter probe uses photoelectric plethysmography to detect changes in blood volume at the site of measurement.[35] ΔPOP is related strongly to ΔPP,[65] sensitive to changes in preload,[66] and an accurate predictor of fluid responsiveness in mechanically ventilated patients.[34,35,39,65,67,68]

Pulse oximeter technology is noninvasive,[24] and when joined with an appropriate preoptimization resuscitation protocol, ΔPOP may be a cost-effective means of reducing anesthesia stress and decreasing mortality, morbidity, and surgical costs.[21] ΔPOP has been shown to be an accurate predictor of fluid responsiveness in various surgical and acute care settings, including cardiac surgery,[34,68] major hepatic surgery,[39] and sepsis,[67] and in patients who are hypotensive.[35] For example, Natalini and colleagues compared ΔPP with ΔPOP in 22 mechanically ventilated hypotensive patients and found that fluid responsiveness was predicted similarly by the 2 methods.[35] However, until the development of PVI (Masimo Corp.; see below), ΔPOP calculation required sophisticated tools that were not readily available,[24] so ΔPOP could not be measured easily at the bedside or monitored continuously, and therefore, could not be optimized.[62]

Pleth Variability Index

PVI is a clinical algorithm that allows for noninvasive, automated, continuous calculation of ΔPOP using a pulse oximeter in mechanically ventilated patients during general anesthesia.[24,62,69] PVI is a measure of the dynamic change in perfusion index (PI)—the ratio of nonpulsatile to pulsatile blood flow through the peripheral capillary bed—occurring during a complete respiratory cycle (Figure 4).[24,70] There is a significant relationship between PVI and ΔPOP (r=0.92; $P<0.05$),[24] and PVI, as validated against ΔPP, has the ability to predict fluid responsiveness with good sensitivity and specificity: PVI greater than 14% before volume expansion discriminated between responders and nonresponders with 81% sensitivity and 100% specificity.[62] A study comparing PVI with SVV confirmed that PVI is an accurate predictor of fluid responsiveness.[71] In this study, baseline SVV correlated significantly with changes in stroke volume index ($P<0.001$), as did baseline PVI ($P<0.004$). The difference between the area under the receiver operating characteristic curve for SVV (0.993) and PVI (0.973) was not significant.

PVI may play a role in optimizing hemodynamic status in patients undergoing major abdominal surgery.[72,73] In an RCT, patients scheduled for major abdominal surgery (N=82) were randomized into 2 groups; a group monitored for PVI and a control group receiving standard care. The primary outcome measure, perioperative lactate level, was significantly lower in the PVI group ($P<0.05$) (Figure 5), and peri- and postoperative volume infused were lower in the PVI group. It was concluded that PVI improved perioperative fluid management in abdominal surgery. In another study, PVI predicted fluid responsiveness in patients with septic shock: A threshold PVI value of 20 identified patients with ΔPP greater than 15% with a sensitivity of 84% and specificity of 90%.[74]

In addition, PVI may predict the hemodynamic effects of PEEP in ventilated and sedated patients following coronary artery bypass grafting.[69] Among such patients with normal lung function and receiving no inotropes or vasoactive drugs, PVI predicted the hemodynamic effects of 10 cmH_2O of PEEP when V_t was no less than 8 mL/kg. Thus, PVI may help the clinician optimize respiratory uptake in oxygen and its delivery to tissues.

That said, PVI also has limitations. Like other dynamic parameters, it does not predict fluid responsiveness as accurately in spontaneously breathing patients as in mechanically ventilated ones.[24,62] It also appears unable to distinguish between respiration-induced changes in PI and changes induced by other phenomena, such as nociceptive stimulation.[24] Finally, acute changes in vasomotor tone may influence PVI.[75]

The Evidence for Goal-Directed Therapy

Growing evidence indicates that goal-directed therapy using appropriate fluid monitoring methods, such as ΔPP and PVI, is effective in optimizing patient outcomes.[15] For example, in an RCT (N=33), monitoring and minimizing ΔPP by volume loading during high-risk surgery improved postoperative outcome and decreased hospital LOS.[38] The median duration of postoperative hospital LOS was lower in the intervention group than the control group (7 vs 17 days; $P<0.01$), as were the number of postoperative complications per patient (1.4±2.1 vs 3.9±2.8; $P<0.05$) and the median duration of mechanical ventilation (1 vs 5 days; $P<0.05$) and LOS in the ICU (3 vs 9 days; $P<0.01$).

Similarly, in an RCT with 60 high-risk patients undergoing major abdominal surgery, a goal-directed hemodynamic optimization protocol using the FloTrac/Vigileo device was associated with a shorter median LOS: 15 days for the goal-directed group versus 19 days for the control group receiving a standard management protocol ($P=0.006$).[50] The goal-directed group also had a reduced incidence of perioperative complications (20%) relative to the control group (50%; $P=0.03$). In another study (N=120), high-risk patients undergoing major abdominal surgery whose fluid management was guided by SVV had fewer complications than those receiving routine intraoperative care ($P=0.0066$).[76]

Several studies support the clinical benefit of esophageal Doppler monitoring, such as an RCT in 128 patients undergoing colorectal resection and randomized to either esophageal Doppler-guided fluid management or CVP-based intraoperative fluid management.[77] The trial demonstrated that esophageal Doppler-guided fluid management was associated with a 1.5-day median reduction in postoperative hospital LOS ($P<0.05$), with significantly faster time to resumption of full diet ($P<0.001$), significantly fewer gastrointestinal complications ($P<0.001$), and less overall morbidity ($P=0.05$).

In 2007, the literature regarding the influence of goal-directed therapy on postoperative outcomes was reviewed.[10] The authors concluded that individualized goal-directed therapy in the perioperative period improved gut function and reduced postoperative nausea and vomiting, morbidity, and hospital LOS. A 15-year follow-up study of high-risk surgical patients (N=106) found that short-term goal-directed therapy in the perioperative period may improve long-term outcomes, in part due to the ability of such therapy to reduce the number of perioperative complications.[23]

PVI has a demonstrated ability to discriminate fluid responders from nonresponders and a capacity to predict hypotension during induction of anesthesia, which may be useful in identifying patients at high risk for developing severe hypotension during anesthesia induction.[62,78] More study is needed to follow up on existing research on goal-directed therapy and confirm the clinical value of available fluid responsiveness monitoring methods.

Conclusion

Volume expansion in surgical and critical care settings is vital and challenging. The clinician must avoid both hypovolemia and hypervolemia, individualizing fluid therapy to take account of the patient's fluid responsiveness. Goal-directed fluid management, guided by fluid responsiveness monitoring, can improve patient outcomes. Dynamic fluid responsiveness monitoring methods—such as ΔPP, PVI, and SVV—are preferable to static methods such as CVP and PCWP. Each dynamic method has its benefits and limitations. PVI allows for noninvasive, automated, continuous calculation of ΔPOP and can predict fluid responsiveness with good sensitivity and specificity in a variety of surgical and critical care settings. PVI has the potential to help goal-directed fluid management become more widely practiced, to the benefit of patients.

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Post-Test

1. **Fluid management can enhance outcomes when volume expansion _____.**
   a. decreases cardiac preload, cardiac output (CO), and stroke volume
   b. augments cardiac preload and increases CO and stroke volume
   c. augments cardiac preload and decreases CO and stroke volume
   d. maintains unchanged cardiac preload, CO, and stroke volume

2. **Which of the following is a risk associated with hypervolemia or hypovolemia?**
   a. Increased length of hospital stay
   b. Postoperative weight gain
   c. Interstitial edema
   d. All of the above

3. **Goal-directed fluid management _____.**
   a. uses flow-related hemodynamic parameters to predict response to volume expansion
   b. is the same as fluid minimization
   c. typically optimizes CO using crystalloids and restricts colloid administration
   d. assumes that all patients have preload dependence

4. **Static indicators _____.**
   a. do not include central venous pressure
   b. include respiratory variations in systolic arterial pressure
   c. are preferable to dynamic indicators as predictors of fluid responsiveness
   d. have been shown to have minimal value as predictors of fluid responsiveness

5. **Dynamic parameters of fluid responsiveness _____.**
   a. do not rely on cardiopulmonary interactions
   b. have not been shown to be the best predictors of fluid responsiveness
   c. must be used in mechanically ventilated patients under general anesthesia
   d. include pulmonary capillary wedge pressure

6. **Respiratory variations in arterial pulse pressure (ΔPP), a dynamic parameter, _____.**
   a. are the same parameter as respiratory variations in systolic arterial pressure
   b. are measured noninvasively from the skin surface
   c. have been shown to have a sensitivity of 60% and a specificity of 80%
   d. are obtained from the arterial pressure waveform

7. **The FloTrac Vigileo system _____.**
   a. measures stroke volume variation (SVV) through a central venous catheter
   b. requires standard arterial access
   c. does not measure SVV
   d. has not been shown in a study to perform similarly to the PiCCO Plus system in predicting fluid responsiveness

8. **Respiratory variations in pulse oximetry plethysmographic waveform amplitude (ΔPOP) _____.**
   a. have a strong relation to ΔPP
   b. are sensitive to changes in preload
   c. accurately predict fluid responsiveness in mechanically ventilated patients
   d. all of the above

9. **The pleth variability index (PVI) _____.**
   a. is noninvasive and accurately predicts fluid responsiveness
   b. requires an arterial line
   c. uses a small esophageal probe
   d. predicts fluid responsiveness as accurately in spontaneously breathing patients as in mechanically ventilated ones

10. **According to a 15-year follow-up study of high-risk surgical patients, short-term goal-directed therapy in the perioperative period _____.**
    a. resulted in similar long-term outcomes to the use of conventional therapy
    b. may improve long-term outcomes
    c. would have been more effective in the postoperative than the perioperative period
    d. increased long-term morbidity

Answer Sheet and Evaluation Form

Fluid Responsiveness Monitoring in Surgical And Critically Ill Patients

Clinical Impact of Goal-Directed Therapy

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Evaluation Questions

Please answer the following questions by circling the appropriate rating.
4 = Strongly Agree 3 = Agree 2 = Disagree 1 = Strongly Disagree

1. After participating in this activity, I am better prepared to:

a. Devise an inventory of clinical challenges that are associated with fluid resuscitation and management of surgical and critically ill patients.	4	3	2	1
b. Delineate available fluid responsiveness monitoring methods and relative benefits and limitations associated with the use of each.	4	3	2	1
c. Appraise recent evidence supporting a clinical rationale for using fluid responsiveness monitoring as part of goal-directed fluid management in various acute care settings.	4	3	2	1
d. Compare the cost-effectiveness of available methods of monitoring fluid responsiveness, particularly in settings of surgery or intensive care.	4	3	2	1
2. The activity met my educational needs.	4	3	2	1
3. The faculty were knowledgeable and effective in the presentation of content.	4	3	2	1
4. The teaching method and educational materials were effective.	4	3	2	1
5. The learning activities were effective and incorporated active learning methods.	4	3	2	1
6. The post-test accurately assessed learning.	4	3	2	1

7. The content was objective, current, scientifically based, and free of commercial bias.
❑ Yes ❑ No (please explain): _____

Post-Test Answer Section

Please circle the correct answer for each question. (A score of at least 70% is required to receive credit.)

1.	**a**	**b**	**c**	**d**
2.	**a**	**b**	**c**	**d**
3.	**a**	**b**	**c**	**d**
4.	**a**	**b**	**c**	**d**
5.	**a**	**b**	**c**	**d**
6.	**a**	**b**	**c**	**d**
7.	**a**	**b**	**c**	**d**
8.	**a**	**b**	**c**	**d**
9.	**a**	**b**	**c**	**d**
10.	**a**	**b**	**c**	**d**

8. Based on information presented in this activity, I will:
❑ do nothing, as the content was not convincing.
❑ seek additional information on this topic.
❑ change my practice.
❑ do nothing, as current practice reflects the program's recommendations.

9. The most important concept learned during this activity that may effect a change in patient care is: _____

10. What issue(s) related to the therapeutic area discussed in this activity, or other topics, would you like addressed in future continuing education?

11. Additional comments: _____