Guiding Fluid Management In the Surgical Setting

Part 1

Case Study

A 49-Year-Old Man Is Referred for a Right Nephrectomy Under General Anesthesia

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Part 2

Case Study 1

A 60-Year-Old Man Admitted for Radical Cystectomy and Ileal Conduit

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Case Study 2

A 73-Year-Old Man Scheduled for Spinal Decompression With Instrumentation

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Introduction

The assessment of intravascular volume status and optimization of hemodynamics remains an important clinical challenge. This is particularly true in the intraoperative and critical care settings, 1 where rapid and dynamic changes in hemodynamic parameters can be caused by anesthetics, blood loss, impaired cardiac contractility, and changes in systemic vascular resistance (SVR) and autonomic nervous system outflow. 2

A key determinant of successful hemodynamic optimization is the ability to characterize where left ventricular cardiac mechanics lie on the Frank-Starling curve—whether relative hypovolemia is present and whether administration of fluids will result in preload-dependent increase in cardiac output (CO)—thereby increasing blood flow and oxygen delivery. 3 Often, the clinician’s inability to accurately and proactively assess this parameter leads to misuse of fluids, inotropes, or pressors, resulting in worse outcomes during surgery that persist into the postoperative period. For example, the use of fluid administration in a patient whose cardiac mechanics are at the upper end of the Frank-Starling curve actually can impede forward CO as well as lead to pulmonary edema, resulting in impaired oxygenation and poor outcomes. 4 In this manner, empiric fluid management strategy has the potential of prolonging mechanical ventilation and hospital length of stay (LOS), and causing worse overall outcomes. 5-7

The concept of goal-directed hemodynamic management, which relies on evidence-based interventions guided by continuous monitoring of key hemodynamic parameters, has evolved as a response to the poor outcomes seen with empiric volume management. Clinical evidence shows that goal-directed hemodynamic optimization of high-risk patients, initiated in the operating room (OR) and continued in the intensive care unit (ICU), not only improves short-term outcomes, but also increases long-term survival. 5,4 In fact, one recent meta-analysis of 29 studies concluded that a preemptive strategy of hemodynamic monitoring and intervention significantly reduces surgical morbidity and mortality. 5

Despite the demonstrated value of goal-directed hemodynamic management, the American Society of Anesthesiologists guidelines do not offer definitive recommendations regarding the optimal parameters on which to guide evidence-based interventions. 5 This review will briefly discuss the limitations associated with traditional methods used to assess circulatory parameters, as well as an emerging and perhaps more sensitive and proactive strategy to assess hemodynamics for the optimization of CO and patient outcomes.

Traditional Strategies for Fluid Management

In the Perioperative Setting

The key question to ensure tissue perfusion and circulatory optimization is whether administration of fluids under specific situations would result in a clinically relevant increase in CO, thereby enhancing tissue perfusion and oxygen delivery. 1,2,10 Furthermore, a strategy that does not require an empiric fluid challenge in order to determine whether fluid administration would increase CO has the obvious benefit of precluding fluid administration and volume overload–induced complications in patients whose cardiac mechanics were proactively characterized as “fluid nonresponsive.” 5

Unfortunately, methods that have been used to assess fluid responsiveness over the past several decades have failed to reliably satisfy either of these standards. 1,2,10-13 The most rudimentary measure used for this purpose is the mean arterial pressure (MAP), but this value alone provides little useful information regarding actual blood flow or oxygen delivery. 2 Similarly, measurement of central venous pressure (CVP) via placement of a central venous catheter in combination with measured urine output are loose and highly indirect measures with a large degree of temporal lag that correlate very poorly with CO. 2,10 In fact, Marik and colleagues have shown that CVP has only about 50% predictability for fluid responsiveness. 14 This has led investigators to state that CVP should not be used in ICUs or ORs because of its lack of accuracy. 10,13

Placement of a pulmonary artery catheter (PAC) allows measurement of pulmonary artery occlusion pressure (PAOP) as well as estimation of CO and SVR through the thermodilution method. 2,10,15 However, PAC placement is not suitable for all patients, and high-profile studies suggest that placement of a PAC as part of a standardized protocol does not necessarily improve patient outcomes. 16,17 Additionally, placement of an intravascular catheter, whether for measurement of CVP or PAOP, is associated with various complications, including vascular trauma and bleeding, infection, air embolism, deep venous thrombosis, and arrhythmia. 18,20

In an effort to determine fluid responsiveness, intraoperative transesophageal echocardiography (TEE) also has been used to assess left ventricular function, but this technique is cumbersome and the value of the measured data is highly operator-dependent. 1,10
The medical history includes a history of smoking (1 pack per day for 30 years), alcohol use, and IV drug use now discontinued. The patient’s height is 1.83 m and weight is 63 kg. A preoperative echocardiograph (EKG) is normal; left ventricular ejection fraction is 45%. Additionally, the EKG shows mild pulmonary hypertension (systolic pulmonary artery pressure is 40 mm Hg) and moderate right ventricular dysfunction (right ventricle is slightly dilated).

The plan for anesthesia management consists of induction with IV etomidate and fentanyl and maintenance using inhaled sevoflurane and fentanyl boluses. Vascular access consists of a peripheral IV (16-gauge needle), a left subclavian central venous double-lumen catheter equipped with central venous oxygen saturation (ScvO₂) readings (PreSep central venous oximetry catheter, Edwards Lifesciences), and a left radial arterial line. Hemodynamic monitoring relies on central venous pressure, cardiac output (CO) monitoring (FloTrac Monitor, ScvO₂ monitoring, Edwards Lifesciences), and stroke volume variation (SVV). The goal of the hemodynamic management was to keep SVV below 13% and ScvO₂ above 75%, and to maximize CO.

Baseline crystalloids infusion is 5 mL/kg per hour. After 1 hour of surgery, the estimated blood loss is 800 mL (Figure 1). At this stage, it was decided to administer 500 mL of IV fluids (6% hydroxyethyl starch) because the SVV was significantly higher than 13% (18%) with a low CO and a low ScvO₂. At this point, we measured hemoglobin (Hb) and hematocrit.

Volume expansion induced a significant increase in CO (from 2.9 to 3.5 L/min; 21% increase) and a significant decrease in SVV (from 17% to 10%). At the same time, we observed an increase in ScvO₂ and in other hemodynamic parameters. Hb was measured at 7.9 g/dL, which led to the decision to transfuse 2 units of blood (Figure 2). Because SVV was in the “gray” or “inconclusive zone” (between 8% and 13% corresponding to SVV values for which fluid responsiveness prediction is unclear) and ScvO₂ and Hb were still low, it was logical at this point to give more fluid and to switch to blood because of the Hb value.

At this stage, Hb was measured at 10.7 g/dL. SVV was 8%, below the threshold for fluid administration. The only abnormally low parameter was ScvO₂ (66%), indicating that there was a mismatch between oxygen consumption and oxygen delivery. Because Hb and oxygen saturation were normal and because SVV suggested that the patient was now a nonresponder to volume expansion, it was decided to administer a small dose of dobutamine (5 mcg/kg per minute), thus increasing CO and ultimately oxygen delivery (Figure 3). Moreover, blood transfusion increased ScvO₂ but had very little impact on CO (only 5% increase).

At the end of surgery, the patient was extubated in the operating room. Dobutamine was discontinued 1 hour after surgery. The patient stayed overnight in the intensive care unit and was sent back to the ward on day 1. The postoperative course was uneventful.

Fluid management during surgery has a large impact on postoperative outcome. As can be seen in this case, fluid management and administration was based on a well-defined strategy aimed at optimizing CO and oxygen delivery. This management allowed better and more rational fluid administration and helped to tailor hemodynamic optimization based on the patient’s specific situation.

In the absence of this simple hemodynamic monitoring system, it is more likely that fluid administration would have been different and would have resulted in a different outcome. Moreover, once CO and SVV had been optimized, this monitoring system helped to introduce dobutamine in order to improve ScvO₂ (in this case Hb was already normalized).

Implementing simple protocols for fluid and hemodynamic optimization is easy and can help to improve patient outcomes. Moreover, they have the ability to standardize hemodynamic management and to decrease individual variation between anesthesiology providers.
As indicated above, the poor sensitivity of these methods for dynamic assessment of CO is further complicated by the fact that although they can sometimes identify when CO increases in response to fluid administration (which may therefore prompt consideration of additional fluid administration), they cannot reliably predict fluid responsiveness without an empiric fluid challenge.2,31

Several clinical situations in which physiologic SVV is altered interfere with the utility of this parameter to assess fluid responsiveness, as with other pulse pressure/pulse contour systems. These include open-chest procedures, use of low tidal volume mechanical ventilation, right ventricular failure, and arrhythmia.31,33 However, SV and CO are still valuable parameters.

Conclusion

Goal-directed perioperative hemodynamic and fluid management results in improved short- and long-term outcomes and can be easily achieved/integrated. Traditional measures, including MAP, CVP, PAOP, and even intraoperative TEE, have specific drawbacks that limit their use for the optimization of perioperative volume status.

By contrast, SVV can be used to predict whether CO will increase in response to a fluid challenge. The FloTrac system can easily and dynamically assess SVV through analysis of PPV via an arterial catheter and has been shown to result in improved outcomes when used to guide perioperative fluid management.

References

Part 2 of 2

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**Introduction**

Recently, Dr. Maxime Cannesson demonstrated the basic concept that morbidity is reduced when operative patients receive the correct amount of volume therapy (volume optimization)—as opposed to too much (volume maximization) or not enough (volume minimization).\(^1\) Several studies also have demonstrated that perioperative goal-directed volume therapy has been associated with significant reductions in the operative stress response and enhanced microcirculatory flow in various tissue beds.\(^2\) Studies using esophageal Doppler also have shown that morbidity and hospital length of stay (LOS) were reduced when volume therapy was individualized by placing each patient at the top of his or her individual Frank-Starling curve.\(^3,5\) Other studies have demonstrated that pre- and immediate postoptimization of the high-risk surgical patient also reduces morbidity,\(^6,7\) as well as short- and long-term (15-year) mortality.\(^8,9\)

**Arterial Pressure Variations and Volume Status Measurement**

The relationship between arterial pressure variations and volume status is easily quantified by the dynamic indices of volume responsiveness, including systolic pressure variation, pulse pressure variation, and stroke volume variation (SVV). These indices—defined only in patients who are mechanically ventilated with tidal volumes of 8 to 10 cc/kg and who have regular rhythms—are highly predictive of volume responsiveness. Traditional static measures such as central venous pressure, pulmonary artery occlusion pressures, and urine output are not predictive.\(^10-13\)

Numerous researchers have demonstrated the incredible sensitivity and specificity of both pulse pressure and SVV. Variations of 13% to 15% in either pulse pressure or stroke volume represent the dividing line between responders and nonresponders to volume therapy. Variations greater than 15% are associated with volume responsiveness; variations less than 13% are not responsive.\(^11-14\) It has been shown in mechanically ventilated operative patients that an SVV of 13% literally can divide operative patients into 2 groups: those who are likely and those who are unlikely to respond to a fluid challenge.\(^15\) The FloTrac system automatically provides measures of SVV every 20 seconds after connecting it to either a new or existing arterial catheter. Small-scale trials have demonstrated that the use of these dynamic indices in high-risk surgical patients decreases time on mechanical ventilation, time in the intensive care unit, and hospital LOS.\(^16\)
Case Study 1: A 60-Year-Old Man Admitted for Radical Cystectomy and Ileal Conduit

The patient's history includes tobacco use, gross hematuria, and a new diagnosis of high-grade diffuse transitional cell carcinoma of the bladder. The patient was admitted for radical cystectomy and ileal conduit. The patient reported no allergies and was not taking any medications. There was no significant anesthetic history. Upon admission, the patient's height was 179 cm, weight was 58.8 kg, blood pressure (BP) was 120/70 mm Hg, with a regular heart rhythm of 70 beats per minute. Respiratory rate of 14 breaths per minute with an oxygen saturation of 98% on room air was measured. The patient was afebrile and edentulous with a modified Mallapati Class I airway. The rest of the physical exam was unremarkable. The patient had an 18-g IV in the left forearm. The patient was brought to the operating room having been sedated with midazolam; standard monitors were applied followed by induction with lidocaine and propofol. Muscle relaxation was achieved with rocuronium, after which the patient was intubated. Mechanical ventilation was initiated with 8 cc/kg tidal volume at a rate of 10 breaths per minute. Maintenance was achieved with isoflurane in air and oxygen. A 20-g right radial arterial catheter was placed and connected to a FloTrac sensor. Dynamic response testing was performed to assure optimal damping. Three attempts with ultrasound guidance were made at obtaining central venous access for volume therapy, medication therapy, and central venous pressure (CVP) measurement, but attempts to pass a wire into the superior vena cava were unsuccessful. Two 14-g peripheral IV catheters then were placed for volume therapy as needed, and stroke volume variation (SVV) via the FloTrac system was considered as the primary preload dependence tool rather than measures of “volume status” via CVP. Surgery began at 7:47 AM. A baseline arterial blood gas at 9:26 AM demonstrated a base excess of 0.2 (Figure 1, point A, SVV 6-9).

Shortly after 9:30 AM, 3 prolonged periods of massive hemorrhage occurred, which can be seen by immediate and significant increases in SVV above 13% indicating significant periods of volume loss and preload dependence (Figure 1, points B, D, and F). Each of these periods was met with volume therapy including crystalloids, colloids, and blood products as indicated by point-of-care testing. The appropriate volume was rapidly given until the SVV returned to a point (<13%) at which the patient was likely no longer volume-responsive (Figure 1, points C, E, G, and H). During the period of resuscitation, there was a significant base deficit as expected. However, once the hemorrhage stopped and the patient was made volume-replete (ie, no longer volume-responsive [SVV < 13%]), the base deficit rapidly improved. Neither pressor nor bicarbonate therapy was administered. At 1:40 PM, the patient was admitted to the intensive care unit. He was intubated with no base deficit (base ≥ 1.5; Figure 2), stable BP and heart rate, and was extubated on postoperative day 1.

It was obvious that the patient needed volume resuscitation. Tools, such as the FloTrac sensor, generally inform clinicians of when additional fluid administration is no longer warranted. Thus, the patient’s resuscitation, although dramatic, ended without a base deficit (Figure 2). Cases such as this highlight the relationship between intraoperative volume optimization and the central role it plays in assuring the adequacy of perfusion.

Volume responsiveness as measured by SVV has not only been validated in the supine position, but also in the prone position, during neurosurgery, liver transplantation, cardiac surgery, and thoracic surgery. Additionally, when operative volume management is performed using SVV, not only do perfusion indicators such as lactate remain within normal limits, but morbidity and rehospitalization rates are decreased.

Recently, the FloTrac system was used to deliver goal-directed therapy in spontaneously ventilating patients undergoing elective total hip arthroplasty. Although volume responsiveness could not be assessed by SVV as these patients were spontaneously ventilating, volume therapy was administered until the stroke volume was optimized. Results from this pilot trial showed significant reductions in perioperative morbidity.

Pinsky described a fundamental truth about hemodynamic monitoring and patient outcomes in the following way: Hemodynamic monitoring devices do not improve outcome unless paired with treatment protocols that are known to improve outcomes. The use of SVV and
Case Study 2: A 73-Year-Old Man Scheduled for Spinal Decompression With Instrumentation

A 73-year-old man (weight, 80 kg; height, 182 cm) with symptomatic spinal stenosis was scheduled for a T12 to S1 decompression with instrumentation. Past surgical history included a total hip replacement at age 69 years and a 2-level lumbar laminectomy 4 years prior. His past medical history was notable for hypertension and coronary artery disease. At age 72, the patient had 2 drug-eluting stents placed (left anterior descending artery and circumflex). Preoperative medications included metoprolol extended release (25 mg twice daily), simvastatin (10 mg daily), clopidogrel (75 mg daily, discontinued 3 days prior), aspirin (325 mg daily), and olmesartan-hydrochlorothiazide (40 mg/12.5 mg daily). Additional preoperative evaluation included a transthoracic echo that demonstrated mild anterior wall hypokinesis and an ejection fraction of 40%.

General anesthesia was initiated with midazolam (2 mg), fentanyl (2 mcg/kg), propofol (2 mg/kg), and rocuronium (0.5 mg/kg), and then maintained with oxygen/air/sevoﬂurane (1/1/0.8) and a dexmedetomidine infusion (0.007 mcg/kg per minute). A radial arterial catheter with a FloTrac sensor was placed to provide continuous cardiac output (CO) and dynamic monitors of cardiac function. The PreSep oximetry catheter was placed for intra- and postoperative monitoring of central venous oxygen saturation (ScvO2).

Following induction, vital signs were recorded: heart rate 75, blood pressure (BP) 110/80 mm Hg, cardiac index (CI) 1.4 L/min/m², stroke volume index (SVI) 20 mL/m², stroke volume variation (SVV) 13%, and ScvO2 63% (Table). Despite normal heart rate and BP, newer supplemental monitors of cardiovascular function demonstrated the CI was well below the minimum target of 2.4 L/min/m². Extended periods of hypoperfusion may increase the incidence of perioperative complications. Therefore, the dynamic functional parameters, such as SVI and SVV, were used to guide and monitor interventions to improve the CO. As SVI was below the normal range (35-45 mL), and SVV was outside my target range of less than 12%, the patient was given a bolus of 500 mL of 6% hydroxyethyl starch 130/0.4 in 0.9% sodium chloride injection. The CI and ScvO2 both increased, but remained below the targets of 2.4 L/min/m² and 70%, respectively. Because the SVV and SVI were now within target ranges, additional fluid was less likely to improve the cardiac function. Thus, an infusion of dopamine (4 mcg/kg per minute) was initiated. The measured parameters improved and remained within their target ranges until the cumulative estimated blood loss (EBL) approached 900 mL, when the SVV began to increase and the ScvO2 began to decrease (Table). The suspected anemia was confirmed with a measured hematocrit of 25. The patient received 2 units of packed red blood cells with an improvement again in all measured hemodynamic parameters.

Following completion of the 7-hour procedure, the patient was extubated in the operating room. Continuous ScvO2 monitoring with the PreSep catheter was continued during the immediate postoperative period as a monitor of both global perfusion and tissue oxygen supply in this patient, who was at increased risk for continued postoperative blood loss. The patient was weaned off dopamine shortly after arrival in the surgical ICU. The surgical wound drains continued to fill slowly with an additional EBL of 500 mL over the first 6 hours, but the ScvO2 remained greater than 70%. No further blood transfusions were required. The patient was transferred to the ward the following morning as drainage slowly ceased.

The FloTrac sensor is useful as a guide for the perioperative management of patients with co-existing diseases and decreased margin for error. In this case, the PreSep oximetry catheter served as an early guide to the need for transfusion, and was then continued into the ICU for monitoring of a patient at risk for continued postoperative blood loss.

<table>
<thead>
<tr>
<th>Event</th>
<th>Heart Rate</th>
<th>Blood Pressure (mm Hg)</th>
<th>Cardiac Index (L/min/m²)</th>
<th>Stroke Volume Index (mL/m²)</th>
<th>Stroke Volume Variation</th>
<th>Central Venous Oxygen Saturation</th>
</tr>
</thead>
<tbody>
<tr>
<td>After induction</td>
<td>75</td>
<td>110/80</td>
<td>1.4</td>
<td>20</td>
<td>13%</td>
<td>63%</td>
</tr>
<tr>
<td>After fluids</td>
<td>60</td>
<td>125/80</td>
<td>2.1</td>
<td>35</td>
<td>8%</td>
<td>65%</td>
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<tr>
<td>After dopamine</td>
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<td>130/85</td>
<td>2.5</td>
<td>38</td>
<td>9%</td>
<td>70%</td>
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<tr>
<td>After estimated blood loss, 900 mL</td>
<td>70</td>
<td>120/75</td>
<td>2.4</td>
<td>34</td>
<td>14%</td>
<td>60%</td>
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<tr>
<td>After transfusion</td>
<td>65</td>
<td>130/80</td>
<td>2.6</td>
<td>40</td>
<td>8%</td>
<td>75%</td>
</tr>
</tbody>
</table>

Table. Vital Signs During Surgery

a monitoring tool such as the FloTrac system provides a practical and accurate method of individualizing and optimizing volume therapy and delivering goal-directed therapy to operative patients.

Conclusion

Intraoperative fluid management is a component of patient care with occasional differing priorities between clinicians. The placement of a pulmonary artery catheter has the potential to comprehensively characterize cardiovascular function and guide fluid administration, but carries with it risk and cost. The FloTrac sensor along with the PreSep oximetry catheter (see Case Study 2) provide information that may better characterize the cardiovascular physiology and guide patient management. The cardiac output (CO) derived from the arterial pressure waveform provides a continuous measurement of total blood flow. If CO is not adequate, the dynamic monitor of SVV provides a guide for potential therapeutic interventions. The cardiac index/CO and SVV...
measurements also provide clear demonstration of the patients who require inotropic support rather than additional fluids to optimize CO.

With the growing body of evidence that perioperative goal-directed fluid management decreases the incidence of complications, the Flo-Trac sensor and PreSep oximetry catheter provide the common language for clinicians to coordinate and optimize patient management in the perioperative setting.

References


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