AANA Journal Course

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Update for Nurse Anesthetists

Reexamining Traditional Intraoperative Fluid Administration: Evolving Views in the Age of Goal-Directed Therapy

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Intraoperative volume administration has long been a topic of debate in the field of anesthesia. Only recently, however, has the conversation shifted to a discussion of appropriate intraoperative volume. A thorough review of the literature explores the history of today's widely accepted fluid administration equation and discusses possible explanations and consequences of iatrogenically induced hypervolemia. Current studies exploring various volume administration techniques are reviewed, as are emerging technologies available to help guide anesthesia providers with intraoperative fluid management.

Keywords: Fluid management, fluid restriction, goal-directed volume administration, hypervolemia.

Objectives

At the completion of this course, the reader should be able to:

1. Describe current fluid recommendations and their origin.
2. Address the physiologic causes and complications associated with hypervolemia.
3. Differentiate between standard, restrictive, and goal-directed fluid administration.
4. Discuss evidence-based literature available regarding intraoperative fluid therapy.
5. Discuss potential tools and/or modifications of fluid administration in anesthesia practice.

Introduction

In the perioperative setting, much debate has centered on crystalloid vs colloid therapy and appropriate indications for each. However, it is only recently that the question of the total volume of fluid administered began to be systematically investigated. Historically, fluid equations quoted in highly regarded anesthesia texts, such as *Miller's Anesthesia*,[1] have advocated for liberal fluid administration incorporating replacement of fluid volume deficits due to *nil per os* (npo)—nothing by mouth—hourly maintenance, estimated blood loss, urine output replacement, and third-space losses. The goal of such volume administration is avoiding hypovolemia, thus preventing end-organ damage. Recent studies, however, have called into question the appropriateness of large-volume fluid administration and have begun to reveal consequences associated with traditional practice. Such revelations have led to advances in technology allowing anesthesia providers to measure intraoperative volume status in real time as opposed to more traditional static methods (ie, urine output). Comparison of volume administration techniques allows for a critical analysis of historical practice as well as the potential benefits of emerging technology to aid in perioperative goal-directed therapy.

Traditional Intraoperative Volume Administration

• ***Maintenance Rate.*** To appreciate the implications of fluid therapy, one needs an understanding of the currently used fluid equation. Some anesthesia texts recommend the following calculation for intraoperative volume replacement[2]:

$$V1 = M + npo + EBL + TS$$

where V1 = Hourly Volume; M = Maintenance; npo =

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Fasting Deficit; EBL = Estimated Blood Loss; and TS = Third-Space Losses. This recommendation originated in the 1950s with the work of Holliday and Segar[3] regarding maintenance fluid requirements in the pediatric population. The authors advocated that hourly parenteral fluid administration be based on the caloric expenditure calculated by weight.[3] Their work produced the widely embraced "4-2-1 rule" for which maintenance rates are calculated (Table 1).

Body weight (kg)	Fluid requirement (mL/kg/h)
0-10	4
10-20	2
≥ 20	1

Table 1. Weight-Based Maintenance Fluid Requirements (From Holliday and Segar.[3])

• ***NPO Deficit.*** In 1975, Furman[4] published expanded recommendations that included replacement of a fasting deficit for surgical patients. Furman estimated that the fluid deficit could be calculated from Holliday's maintenance requirement multiplied by the hours since last oral intake. Such replacement has become standard practice, as most patients arrive in the operating room having been ordered npo since midnight. This practice occurs despite 1999 recommendations from the American Society of Anesthesiologists that a fast from clear liquids can be safely limited to 2 hours for elective procedures requiring anesthesia.[5]

• ***Estimated Blood Loss and Urine Output.*** Replacement of intraoperative blood loss and urine output is generally well agreed on. Debate surrounding this topic is most often centered on the use of crystalloid vs colloid solutions. A crystalloid solution is one is which inorganic ions and small organic molecules are dissolved in water.[6] The main solute can include glucose or sodium chloride to which calcium, lactate, and potassium may be added to more closely mimic human plasma osmolality. Current recommendations advocate the use of crystalloid solutions for hourly maintenance rate, replacement of urine output, intraoperative insensible losses, and replacement of intraoperative blood loss with a 3:1 ratio of crystalloid solution.[2]

Colloid solutions are made of large molecules or microscopic particles of one substance dissolved in another.[6] These particles do not settle and cannot be filtered. In the clinical arena, colloid solutions are divided between semisynthetic colloids (gelatins, dextrans, and hydroxyethyl starches) and naturally occurring plasma derivatives (albumin, fresh frozen plasma, and immunoglobin solutions). Coagulopathies can be a concern with the use of dextrans and hydroxyethyl starches because of hemodilution of clotting factors, platelet disaggregation, and an inhibitory effect on factor VIII.[6] Alterations in platelet function, thus increasing the potential for blood loss, are the basis for maximum dose recommendations of 1.5 to 2 g/kg for such solutions. Anaphylactic and anaphylactoid reactions have been reported with both the semisynthetic and naturally occurring colloid suspensions. The provider must be diligent when administering such solutions, to identify early signs of allergic reactions. Current recommendations for colloid use include replacement of intraoperative blood loss with a 1:1 ratio.[2]

• ***Third-Space Losses.*** Current practice regarding the so-called "third space" originated with the work of Shires et al[7] in 1961, who postulated a decrease in the functional extracellular compartment (plasma plus interstitial volume) during surgical trauma. Plasma volume, red blood cell mass, and extracellular fluid volume (ECFV) were measured before incision and 2 hours into the procedure. The control group consisted of 5 patients presenting for minor surgical procedures and an experimental group, which included 13 patients presenting for major, nonemergent surgery. All patients received general anesthesia. Each case was subjectively ranked by presumed degree of surgical tissue trauma.

By injecting known isotopes, followed by serial blood samples subsequent to a 20-minute equilibration time, Shires et al created volume of distribution curves. The authors observed a reduction in ECFV that exceeded blood loss in the experimental group. Shires and colleagues theorized that this shrinkage of ECFV in patients having major surgery was due to sequestration of fluid into a compartment no longer able to participate in the equilibration process. The authors correlated the degree of ECFV contraction with the level of tissue trauma, concluding that the larger the surgical procedure, the more significant the ECFV loss.[7] The "Doctrine of Shires" was born.

It is important to note that the fluid shift described by Shires et al is distinct from the movement of fluid to the interstitial compartment well known to anesthesia providers. In a healthy patient, a shift of fluid to the interstitium is returned to the circulation via the lymphatics, thus making it a functional part of circulation. Shires and coworkers theorized fluid shift was one in which the volume became nonfunctional. Critics of their work argue that the reported short measurement times and the inability to replicate the findings with various tracer substances make it a poor model for determining fluid administration. Inadequate equilibration times produced a falsely high concentration of tracer indicating an inaccurately low volume of distribution.[8] Subsequent studies with various tracer substances and/or longer equilibration times contradict the existence of a nonanatomic third space.[8,9] Despite its shortcomings, the work of Shires and colleagues has formed the basis of modern fluid therapy in the operating room, where infusion volumes of 6 to 8 mL/kg/h or greater are common for major surgical procedures to account for presumed third-space losses.[2]

Hemodynamic variable	Standard therapy	Restrictive therapy	Supplemental therapy	Goal-directed therapy
Maintenance therapy	4 mL/kg at 0-10 kg of body weight; 2 mL/kg at 10-20 kg; 1 mL/kg at ≥ 20 kg	90% of standard therapy	110% of standard therapy	Volume administration based on a specific endpoint
npo	Maintenance × fasting hours			
Estimated blood loss	1:1 Replacement with colloid solution; 3:1 replacement with crystalloid solution			
Third space	0-2 mL/kg for minimal tissue trauma (open herniorrhaphy); 2-4 mL/kg for moderate tissue trauma (open cholecystectomy); 4-8 mL/kg for severe tissue trauma (open bowel resection)			
Compensatory volume expansion	With neuraxial anesthesia: 10 mL/kg; without neuraxial anesthesia: 5-7 mL/kg			

Table 2. Comparison of Fluid Therapies: Standard, Restricted, Supplemental, and Goal-Directed
(From Morgan et al[2] and Rahbari et al.[20])

Effects of Hypervolemia

With current fluid administration practices rooted in research performed more than 50 years ago, it is not surprising that perioperative overhydration is common. Large fluid volume replacements were traditionally recommended, with the aim of preventing hypovolemia. Although the consequences of hypovolemia have been widely discussed, it is only recently that concerns for hypervolemia have begun to garner interest. With surgical patients gaining an average of 3 to 10 kg of weight following major procedures, new scrutiny is being placed on perioperative volume administration.[10]

Lowell et al[11] retrospectively examined 48 postsurgical patients admitted to the intensive care unit. They noted that patients whose weight gain was greater than 10% of their preoperative weight had mortality rates of 31.6% vs 10.3% in patients whose weight gain remained less than 10% of their preoperative status. Mortality rates rose with further weight increases.[11]

Subsequent work identified evidence of postoperative pulmonary edema when the volume administered exceeded 67 mL/kg/h, a volume frequently seen in practice.[12] Others extended this work by examining the physiologic effects of fluid administration in healthy volunteers by mimicking the perioperative setting through a preoperative fast followed by 40 mL/kg of lactated Ringer's solution given over 3 hours.[13] Following administration of the infusion, subjects demonstrated a significant decrease in their forced vital capacity and forced expiratory volume in 1 second that lasted 8 hours following bolus completion. A median weight gain of 0.85 kg was also noted 24 hours after completion of administration of the fluid bolus.[13]

It has long been accepted that gross tissue edema is associated with decreased oxygen tissue tension and impaired wound healing.[9] Such complications are often seen when large fluid volumes are administered and substantial fluid shifts occur. Chan et al[14] investigated how intestinal edema affects surgical anastomosis of the bowel. In their animal model, manipulation of the bowel increased tissue weight in the intestine by 5% to 10% from baseline at the site of anastomosis and 5 cm from the suture line. Edema increased by an additional 5% when an intravenous (IV) infusion of 5 mL/kg/h of crystalloid was initiated during the intraoperative period. This edema was still present at the site of anastomosis 5 days following the surgical procedure. This work emphasizes the consequences of iatrogenically induced hypervolemia. Although the potential for complications such as pulmonary edema and cardiac compromise is generally appreciated, other effects, such as prolonged ileus, decreased wound healing, and impaired coagulation, are now receiving noteworthy consideration.

Defining Fluid Treatment Regimens

Although *standard, supplemental,* and *restrictive* therapies are based on calculations performed by the anesthesia provider (Table 2), *goal-directed therapy* uses a specific endpoint, such as cardiac output (CO), to guide volume administration. Historically this was accomplished using thermodilution methods following central catheterization, but recent advancements in volume status measurement have produced less invasive options, including esophageal Doppler monitoring for continuous CO calculations.[15]

Comparing Fluid Administration Methods

In the last 2 decades, research comparing varying IV volumes and administration techniques has increased. In 2003, Brandstrup et al,[16] in a widely cited article, investigated a standard vs restricted fluid replacement regimen

Hemodynamic variable	Standard group	Restricted group
npo deficit	Replaced with 500 mL NS	Replaced with 500 mL 5% dextrose in water
EBL	EBL ≤ 500 mL: 1,000-1,500 mL NS EBL > 500: additional 6% hydroxyethyl starch EBL > 1,500 mL: Blood component therapy (earlier if clinically indicated)	Replaced with 6% hydroxyethyl starch milliliter for milliliter/Blood component therapy when EBL > 1,500 mL or when clinically indicated
Third-space losses	NS: 7 mL/kg for first hour; 5 mL/kg for hours 2 and 3; 3 mL/kg for remainder of surgery	No replacement given
Epidural preloading	500 mL 6% hydroxyethyl starch	No replacement given
Postoperative fluid therapy	1,000-2,000 mL crystalloid	1,000 mL 5% dextrose in water and 1:1 6% hydroxyethyl starch replacement of loss to drains
Total volume administered	5,388 mL (2,700-11,083 mL)	2,740 mL (1,100-8,050 mL)

Table 3. Comparison of Standard and Restricted Fluid Regimens
Abbreviations: NS, normal saline; EBL, estimated blood loss.
(From Brandstrup et al.[16])

for colorectal surgery. In an 8-hospital trial involving 141 patients, participants were randomly assigned to receive a restrictive or standard regimen. Differences in fluid protocols included epidural preloading and replacement of third-space losses in the standard treatment group. Fasting deficit was replaced with normal saline in the standard group vs 5% glucose in water in the restrictive group. Blood loss in the restrictive group was immediately replaced with 6% hydroxyethyl starch vs normal saline in the standard group for estimated blood loss of 1 to 500 mL. Estimated blood loss above 500 mL in the standard group received 6% hydroxyethyl starch. Both groups received blood component therapy when deemed clinically relevant. The postoperative fluid regimen for the restrictive group included 1,000 mL of 5% glucose on the day of surgery and blood loss to drains replaced with 6% hydroxyethyl starch. The standard regimen included 1,000 to 2,000 mL of crystalloid based on preexisting protocols on the postsurgical unit. The median volume administration on the day of surgery was 2,740 mL (range, 1,100-8,050 mL) for the restrictive group vs 5,388 mL (range, 2,700-11,083 mL) in the standard group ($P < .0005$; Table 3).

Patients in the restrictive group had a significantly lower incidence of cardiopulmonary complications ($P = .007$) and wound healing complications ($P = .04$). No adverse effects related to decreased volume administration were noted in the restrictive group. The authors concluded that restricted fluid therapy, aimed at maintaining preoperative weight status, decreased postoperative complications after colorectal surgery.[16]

Nisanevich et al[17] evaluated use of restricted fluid vs supplemental fluid administration in 156 patients with ASA status 1 to 3 who were undergoing nonemergent abdominal procedures. The supplemental-fluid group received an initial bolus of 10 mL/kg of lactated Ringer's solution followed by an infusion of 12 mL/kg/h. The restricted-fluid group received 4 mL/kg/h throughout the entire intraoperative period. A predetermined fluid algorithm guided hemodynamic resuscitation, urine output, and blood loss replacement for both groups. Postoperative fluid administration was guided by department protocol, typically 5% dextrose and 0.45% sodium chloride at a dosage of 1 to 1.5 mL/kg/h. The authors discovered that more patients in the restricted group required fluid boluses per protocol to maintain hemodynamics. However, even taking into consideration the fluid boluses, patients in the restricted group received significantly less fluid than did their counterparts in the supplemental group. Surgical complications ($P = .046$), weight gain ($P < .01$), and time to passage of flatus or feces ($P < .001$) were all significantly lower in the restricted group, as was time to discharge ($P = .01$).

Introducing the Esophageal Doppler Monitor

In an effort to avoid a fixed-volume approach to fluid administration, researchers began to investigate goal-directed therapy using EDM.[18] Based on the recommendations of 3 meta-analyses,[19-21] the Medicare and Medicaid systems have recommended the use of EDM in patients requiring close monitoring of intravascular volume status.[18]

The first of these analyses evaluated 5 randomized control trials assessing the use of EDM-based fluid administration vs conventional administration based exclusively on hemodynamic parameters.[21] All 5 of the studies included patients undergoing major abdominal surgery, and all were deemed to have met acceptable quality standards based on methods, randomization, allocation concealment, and blinding of investigators. Based on the results of the analysis, the authors concluded that fluid management guided by EDM resulted in fewer postoperative complications, decreased number of admissions to the intensive care unit, and shortened length of hospitalization. Complications tracked included those affecting the cardiovascular, respiratory, renal, and gastrointestinal systems.

The second meta-analysis included in the Medicare/

Medicaid recommendations for EDM use was published in 2008.[19] The analysis included 4 randomized control trials involving 393 patients and compared intraoperative fluid management guided by EDM vs routine care in patients undergoing nonemergent, major abdominal surgery. The authors concluded that use of EDM resulted in a significant decrease in postoperative complications and shorter hospitalization. Additionally, the authors noted that the quantities of fluid administered with EDM-guided therapy vs routine care did not vary significantly, indicating that improved postoperative outcomes may have resulted from the timing of volume administration. A lack of uniformity in inclusion criteria and study design prevented the authors from recommending routine use of EDM because of its cost.

A final analysis reviewed 288 patients in 3 trials comparing use of EDM with fluid administration guided by the anesthesia provider.[20] The authors discovered a statistically significant reduction in postoperative morbidity, although no difference in postoperative mortality was noted.

Included in all 3 meta-analyses used was the work of Gan et al.[15] The aim of this study was to determine whether plasma expansion guided by use of EDM decreased postoperative morbidity in patients presenting for major abdominal surgery. The study included 100 patients, ASA status 1 to 3, presenting for major nonemergent general, urologic, or gynecologic procedures who experienced an estimated blood loss greater than 500 mL.[15]

Before induction of anesthesia, all patients received a bolus (5 mL/kg) of lactated Ringer's solution followed by an infusion of 5 mL/kg/h. Following tracheal intubation, an EDM probe was inserted to the level of the midesophagus and blood flow signals were identified. An internal nomogram in EDM allowed for calculation of left ventricular stroke volume and systolic flow time. After correction for heart rate, the systolic flow time, or corrected flow time (FTc), can be an indicator of systemic vascular resistance and is susceptible to changes in left ventricular preload.

Following placement of the EDM probe, patients were randomly assigned to 1 of 2 groups. The protocol group followed a predetermined algorithm for fluid replacement based on calculations of stroke volume (SV) and FTc. Based on this protocol, boluses of 6% hydroxyethyl starch were administered when FTc was less than 0.35 seconds (normal range, 0.33-0.36 seconds). If the SV was maintained or increased following fluid administration, the bolus was repeated until no further increase in SV was noted. Boluses were withheld when FTc was longer than 0.40 seconds. With FTc values between 0.35 and 0.39 seconds, fluid boluses were administered as long as SV continued to increase by more than 10% of baseline. This process was initiated immediately following EDM placement and occurred every 15 minutes until maximum SV and goal FTc values had been reached. A 6% concentration of hydroxyethyl starch was used to a maximum dose of 20 mL/kg, at which point lactated Ringer's was substituted.

For patients randomly assigned to the control group, EDM was not visible to the anesthesia provider. Fluid administration was based on standard parameters, including decreased urine output, elevated heart rate, decreased blood pressure, or low central venous pressure. Both groups received blood products when clinically indicated.

Data analysis revealed that patients who had fluid administration guided by EDM saw a significant increase in SV, CO, and FTc compared with members of the control group. Use of EDM resulted in earlier oral intake, fewer patients with severe postoperative nausea and vomiting, and a shorter median length of stay. The authors concluded that improved perfusion of the gastric mucosa may have contributed to decreased nausea/vomiting, shorter time to oral intake, and ultimately a shorter hospitalization. Additional findings indicated that standard hemodynamic measurements, such as blood pressure, heart rate, and oxygen saturation, were not reliable indicators of mild hypovolemia.[15]

Identifying a "Responsive" Patient

In addition to EDM-directed therapy, additional methods to guide intraoperative volume administration are under review. The basis of goal-directed therapy is to optimize volume status, and ensure oxygen delivery, through well-defined parameters while avoiding fluid overload. Research has focused on identifying methods to accurately predict patients who will respond favorably to volume administration while simultaneously providing clinicians with real-time, valid information to guide fluid management.

Responsiveness is defined as a 10% increase in SV following administration of an IV fluid bolus.[22] Based on the Frank-Starling law, normovolemia is integral to achieving maximal SV. When an individual responds to a fluid bolus, the assumption is that an intravascular fluid deficit may exist. In an attempt to correct the deficit, volume administration is repeated until the increase in SV is less than 10%, indicating that normovolemia has been achieved. Such guidelines identify patients who require intravascular volume as opposed to vasopressors or inotropic therapy. Intraoperative use of EDM, in addition to other emerging technologies, can aid the anesthesia provider in identifying patients in whom an intravascular deficit exists, thus minimizing excess volume administration and its associated complications.

Available Invasive Technologies

Many attempts have been made to develop technology capable of predicting fluid responsiveness in the intraoperative setting. Unfortunately, not all options are as

accurate as once believed. The pulmonary artery catheter (PAC) has long been the mainstay of assessing intravascular volume status. Despite early promise of the device, research has identified major inconsistencies in patient outcomes with PAC-guided fluid therapy in addition to a high incidence of complications.[2,22]

Since the decline of the PAC, many less invasive alternatives to assess volume status have emerged. Arterial pulse waveforms can predict fluid responsiveness through both pulse contour and pulse power analysis. The pulse contour CO technique is based on transpulmonary thermodilution and therefore requires both central venous access and a femoral or axillary arterial line. Because of this level of invasiveness, its use has been limited.[22]

The lithium dilution CO monitor (LiDCO) uses 2 forms of software to predict fluid responsiveness through power pulse analysis.[23] Current models of the device require arterial monitoring, although future models reportedly aim to be noninvasive. Calibration of the device requires a small bolus of IV lithium (0.15-0.3 mmol) to calculate CO. Input of CO from an additional monitor is possible. The small dose of lithium required for calibration is not pharmacologically significant for most patients, although the lithium dilution CO is not recommended in patients whose weight is less than 40 kg, those in their first trimester of pregnancy, or anyone receiving lithium therapy.[23] Patients with severe peripheral arterial vasoconstriction, aortic regurgitation, or aortic balloons may not be candidates for lithium dilution CO monitoring because of interference with continuous waveform analysis. Injection of a small dose of IV lithium creates an arterial lithium concentration curve. The second software component of lithium dilution CO is then able to obtain continuous measurements of SV, stroke volume variation (SVV), and CO. Together, the 2 software technologies combine to produce a continuous display of systolic pressure variation, pulse pressure variation (PPV), and SVV, all of which are appropriate to aid in the diagnosis of hypovolemia.[22]

Other devices available to evaluate cardiac preload and volume status include transesophageal echocardiography (TEE) and thoracic impedance. Transesophageal echocardiography allows visualization of the heart chambers by esophageal placement of a Doppler probe. Such direct visualization allows for detection of volume deficits. Specialized training is necessary for proper placement and interpretation; therefore, its use in goal-directed therapy has been limited. Initial work evaluating thoracic impedance appears promising; however, no studies are available concerning its use in intraoperative fluid guidance.[22]

Noninvasive Technologies

Because of the complications and/or advanced training associated with invasive monitoring, researchers have begun to investigate noninvasive methods to predict fluid responsiveness. One promising technique is use of the plethysmographic variability in both the pulse oximetry and arterial waveform. This technology is a dynamic assessment of preload and can be calculated in 1 of 3 ways: (1) pressure based (PPV); (2) flow based (SVV); or (3) volume based (plethysmographic variability index, or PVI).[24] Typically, SVV and PPV are calculated using measurements obtained through an arterial catheter. When a patient is ventilated mechanically, changes in intrathoracic pressure induce changes in ventricular preload. This change is translated into variations in maximum and minimum values of the arterial and pulse oximetry waveform. When these differences are calculated at end-inspiration and end-expiration, a numeric value is derived that can help providers determine the patient's hydration status.

Although this technology is beneficial, its invasive nature is associated with complications and technical difficulties. Calculated respiratory variations in the pulse oximetry plethysmographic waveform have been shown to predict fluid responsiveness; however, this process is not easily done, and therefore its clinical application has been minimal.[25] Visual analysis of waveform variation has also been shown to be unreliable and can lead to overestimation of fluid needs. The introduction of PVI, which is automatically calculated from a pulse oximetry monitor, offers a noninvasive alternative to assess intravascular volume status.

In an attempt to demonstrate the efficacy of PVI, Cannesson and colleagues[25] investigated the use of the pulse oximetry probe (POP), perfusion index (PI), and PVI in accurately predicting a patient's response to an IV fluid bolus. The PI is a measurement of pulsatile vs nonpulsatile blood flow through the capillary bed. The PVI is a dynamic measurement of PI over the course of 1 respiratory cycle and is displayed as a percentage. A lower PVI value indicates less respiratory variation in PI and therefore a decreased likelihood to induce hemodynamic changes following volume administration.

In the study by Cannesson et al,[25] patients undergoing coronary artery bypass grafting received a radial arterial line, a central venous catheter, and a PAC after induction of general anesthesia. Following a period of hemodynamic stability, baseline data were obtained. The authors simultaneously assessed respiratory variations in arterial pressure calculated manually (ΔPP) and automatically (PPV) as well as respiratory variations in the POP calculated manually (ΔPOP) and automatically (PVI). Traditional volume status measurements were also made. (See Table 4 for all measured variables.) There was no surgical stimulation at this time. After baseline data were obtained, a 500-mL bolus of 6% hydroxyethyl starch was given and an additional set of hemodynamic variables was taken.

Patients were qualified as either "responders," those who had a 15% increase or greater in cardiac index following the bolus, or "nonresponders," those who saw

Abbreviation	Definition
ΔPOP	Pulse oximetry probe respiratory variation
PI	Perfusion index
ΔPP	Manual calculations of respiratory variations in arterial pressure
PPV	Automated calculations of respiratory variations in arterial pressure
SBP	Systemic blood pressure
HR	Heart rate
MAP	Mean arterial pressure
CVP	End-expiratory central venous pressure
PCWP	End-expiratory pulmonary capillary wedge pressure
SpO_2	Oxygen saturation
SVI	Stroke volume index
CI	Cardiac index
SVRI	Systemic vascular resistance index

Table 4. Measurements/Definitions of Volume Status
(From Cannesson et al.[25])

a less than 15% increase in cardiac index. The authors determined that responders had significant increases in traditional volume status measurements (cardiac index, MAP, CVP, and end-expiratory pulmonary capillary wedge pressure) following fluid bolus. Conversely, ΔPP, PPV, ΔPOP, and PVI all decreased (Table 5). A positive linear correlation existed between ΔPP and PPV at baseline and the change in cardiac index following fluid administration, indicating that the greater the variations in arterial pressure at baseline, the greater the increase in cardiac index following volume administration. The same was true for ΔPOP and PVI. Similar results were observed in an independent study.[26]

Cannesson's and Zimmerman's groups concluded, based on their results, that PVI is an accurate, noninvasive method for predicting fluid responsiveness in the mechanically ventilated patient. Accurate interpretation of PVI is reliant on a patient in normal sinus rhythm, mechanically ventilated at a tidal volume of at least 8 mL/kg, and a heart rate to respiratory rate ratio above 3.6.

The work by Cannesson et al was completed using the Radical-7 device (Masimo Corp). The monitor is marketed as a noninvasive tool that resembles a pulse oximeter. In addition to oxygen saturation as measured by pulse oximetry, the Radical-7 is capable of measuring PVI, total hemoglobin level, oxygen content, carboxyhemoglobin and methemoglobin levels, acoustic respiration rates, heart rate, and PI.

The goal of newer, noninvasive tools is to validly assess intravascular volume. The assumption with such technology is that adequate volume implies adequate CO. In contrast to measuring systemic volume status, near-infrared spectroscopy allows measurement of oxygenation at the level of the tissue. As changes in perfusion result

Outcome	Hemodynamic variables
Increased	CI, MAP, CVP, PCWP
Decreased	ΔPP, ΔPOP, PPV, PVI

Table 5. Outcomes of "Responders"
Abbreviations: CI, cardiac index; CVP, central venous pressure; MAP, mean arterial pressure; PCWP, pulmonary capillary wedge pressure; ΔPP, manual calculations of respiratory variations in arterial pressure; ΔPOP, pulse oximetry probe respiratory variation; PPV, automated calculations of respiratory variations in arterial pressure; PVI, plethysmography variability index.
(From Cannesson et al.[25])

from mild hypovolemia, changes in near-infrared spectroscopy readings would theoretically occur simultaneously. Current research in this domain using near-infrared spectroscopy has not been evaluated in goal-directed therapy, and therefore its use requires further study.[22]

Goal-Directed Therapy in the Prone Position

As previously discussed, the scientific foundation for PPV is centered on the circulatory changes associated with positive pressure ventilation.[24] Corrected flow time is based on forward blood flow relative to systemic vascular resistance.[15] Because many physiologic changes occur in both the cardiovascular and pulmonary systems in the prone position, researchers have investigated whether such tools are accurate in predicting fluid responsiveness in patients so positioned.

A study of 44 prone patients undergoing posterior lumbar spinal fusion measured PPV (PPVauto) from a radial arterial line as well as cardiac index, SVI, and FTc from an EDM.[27] Baseline measurements were obtained with the patient in the supine position, after which 6 mL/kg of 6% hydroxyethyl starch was administered. Five minutes following the infusion, an additional set of measurements was obtained. Patients were turned prone, and 15 minutes of hemodynamic stability was allowed before final measurements were taken. If necessary, an additional fluid bolus was given intraoperatively, which prompted obtainment of respiratory and hemodynamic variables.

With the patient in the supine position, the colloid bolus significantly increased SVI and decreased heart rate and PPVauto. In the prone position, there were significant increases in mean arterial pressure, SVI, cardiac index, and FTc and significant decreases in automatically measured pulse pressure following bolus administration. The greater the variation in pulse pressure at baseline, the greater the increase in SVI. Baseline FTc corresponded indirectly to SVI (Table 6). The authors concluded that both PPVauto and FTc were markers to accurately predict fluid responsiveness in the prone position.

Practical Implications

Recommendations guiding fluid administration for anesthesia providers have existed for more than 50 years.

Hemodynamic variable	Prone position	Supine position
Stroke volume index	↑	↑
Heart rate	↔	↓
Pulse pressure (automatic calculation)	↓	↓
Mean arterial pressure	↑	↔
Cardiac index	↑	↔
Corrected flow time	↑	↔

Table 6. Effects of Positioning after Fluid Loading on Hemodynamic Variables
Abbreviations: ↑, increased; ↔, unchanged; ↓, decreased. (From Yang et al.[27])

Unfortunately, much of the basis for these recommendations may be specious. Reexamination of traditional fluid equations is under way as current recommendations produce a high prevalence of postoperative hypervolemia.[9,12,13,17] No longer should the focus of volume administration center on avoiding hypovolemia, but rather maintenance of a euvolemic state. Technological advancements are emerging to better guide fluid management and aid providers in identifying patients who may benefit from fluid administration. Many of these new technologies aim to be minimally invasive and require little additional training for their use. Incorporation of such advancements into anesthesia practice holds the promise of optimizing fluid therapy.

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