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Marc Yacovone  
*University of New England*

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The Impact of Intraoperative Goal-Directed Fluid Therapy

Marc Yacovone

University of New England

Cheryl Nimmo, DNP, MSHSA, CRNA

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## The Impact of Intraoperative Goal-Directed Fluid Therapy

### **Abstract**

Anesthetists provide intra-operative fluid therapy by utilizing a variety of different methods. Deciding on the appropriate method is multifaceted, and the choice of method is a determinate of safe and effective outcomes. Camach-Navarro et al. (2015) determined that postoperative complications are linked to either giving too much or too little fluid. Unfortunately, the deleterious effects of improper fluid therapy are often overlooked.

Minor surgical procedures which result in little to no blood loss, often lead to positive outcomes using the fixed volume calculation approach to fluid therapy. However, when major surgical procedures are performed on sick patients a fluid management plan must be established. When fluid replacement is based on first applying fixed volume calculations, followed by assessing urine output or providing intraoperative loss replacement (restrictive therapy), improper volumes may result. Gutierrez, Moore, & Liu. (2013) found that empirical calculations do not factor in the specific procedure type and physiological effect on the patient. The lack of specificity demonstrates the limitations in fixed volume fluid calculations when managing major surgical procedures on sick patients. Surgeries that incorporate hemodynamic instability require careful fluid replacement volumes. Goal directed fluid therapy is deployed when improper fluid volumes may lead to serious negative patient outcomes.

Research shows that monitoring fluid responsiveness reduces the incidence of improper fluid volumes, and should be guided by goal-directed fluid therapy (Camach-Navarro et al., 2015).

Goal- directed fluid therapy is defined as administering intravenous fluids to achieve a desired goal (Trinooson & Gold, 2013). Fluid responsiveness is defined as an increase in stroke volume

or cardiac output upon fluid loading (Cherpanath, Geerts, Legrand, Schultz, & Groeneveld, 2013).

The importance of ongoing research in discovery of the best practice techniques involving fluid administration is necessary to provide outstanding patient care. Research and local practice standards offer a variety of fluid therapy methods. The question is which fluid therapy technique is best suited for specific surgeries and specific patient types. Current research is investigating the possible benefit of utilizing dynamic index monitoring of stroke volume variation as a guide to goal-directed fluid therapy.

### **Introduction**

Goal-directed fluid therapy is defined as administering intravenous fluids to achieve a desired goal (Trinooson & Gold, 2013). The optimal maintenance of intravascular volume is the goal of fluid therapy. Achieving proper vascular volumes will create the necessary cardiac stroke volume needed to maintain tissue perfusion.

Historically, static variable measurements such as central venous pressures (CVP) were used as fluid guidance for the goal of optimal cardiovascular endpoints. According to Kayilioglu et al. (2015) in a systematic review of twenty-four studies, no relationship was found between CVP and left ventricle stroke volume. The authors determined that fluid resuscitation decisions based on CVP levels is a poor indicator of body fluid needs and fluid responsiveness. (Kayilioglu et al. (2015) also determined that pulmonary capillary wedge pressure is another static measure of intravascular volume and is incapable of predicting fluid responsiveness.

Lemson (2014) found that the technique of CVP monitoring was a standard guide to fluid therapy beginning in 1959. His research also established the use of CVP and the measurement of intravascular volume status are limited, and then concluded that no relationship exists between

the CVP and fluid responsiveness. Lemson (2014) also established that like the CVP, the pulmonary artery occlusive pressure (PAOP) is unable to predict fluid responsiveness.

Following review of over one hundred studies, Marik et al. (2011) concluded that no relationship between the CVP and fluid responsiveness is evident. Li et al. (2013) found that common standard techniques such as pulmonary artery occlusive pressure (PAOP) are inaccurate indicators of fluid response. With limited fluid response guidance, and the risks associated with static parameter measurements such as pulmonary artery catheters, and central venous catheters, researchers are now examining alternate methods that utilize dynamic parameters.

Per Camach-Navarro et al. (2015), dynamic indices accurately reflect fluid responsiveness when compared to static hemodynamic parameters. Fluid responsiveness is defined as an increase in stroke volume or cardiac output upon fluid loading (Cherpanath, Geerts, Legrand, Schultz, & Groeneveld, 2013). The determination of fluid responsiveness when intravenous fluids are administered will not only aide in hemodynamic stability, but will also optimize fluid volumes. Dynamic parameters use mechanical ventilation-induced changes in preload to track subsequent changes in stroke volume (Camach-Navarro et al. 2015).

### **Body Fluids**

For an anesthesia provider to apply the best practice of intraoperative fluid therapy, he or she must understand the basic physiology of body fluid requirement and fluid losses. Sixty percent of the body weight in the 70kg adult male is made up of water equaling approximately 42 liters. The average adult female weight is made up of 50 percent water. Premature and newborn babies' total body weight contain 70 to 75 percent water. The percentage of water in the body is reduced when the body contains increased body fat. Body fat percentages are built into the calculations and reflect on the water percentages (Hall & Guyton, 2011).

The average adult in good health requires water to balance gastrointestinal losses of 100 to 200ml/day, 500 to 1,000ml insensible loss through the skin and through respiration, and urinary losses of 1,000ml/day. The above population requires 75mEq/kg of sodium and 40mEq/kg of potassium. To put these requirements in perspective, the average healthy adult weighing 70kg will need 2,500ml of water, with 30mEq/L of sodium and 15 to 20mEq/L of potassium (Barash et al., 2012).

### **Body Fluid Compartments**

According to Hall & Guyton (2011), total body fluid is contained in two major compartments, extracellular and intracellular, along with a third small compartment that contains transcellular fluid. The extracellular compartment is divided into interstitial fluid and blood plasma.

The intracellular fluid compartment, 40 percent of body weight, contains about 28 to 42 liters of water. The extracellular fluid compartment, which is the area outside the cells, contain fluid that makes up 20 percent of the body's weight, approximately 14 liters in the average 70kg adult male. As stated, the extracellular compartment is further divided into the interstitial compartment and plasma. Fluids between the two areas are continually mixing due to highly permeable pores of the capillary membranes. Most solutes can pass through the pore, with exception of proteins, which have an increased concentration in plasma (Hall & Guyton, 2011).

Blood, which is comprised of extracellular and intracellular fluid, is found in the compartment known as the circulatory system. The average blood volume in an adult is approximately 5 liters which correlates to 7 percent of the body weight. Of the 7 percent, 60 percent is plasma and 40 percent is red blood cells. The above percentages apply to the 70kg adult male in good health and percentages will vary depending on physiological factors. The

volume of blood in the body is a major factor in the control of hemodynamics (Hall & Guyton, 2011).

### **Fluid Distribution and Regulation**

Adequate fluid maintenance involves proper distribution between fluid compartments. The distribution between plasma and interstitial spaces is largely the result of the balance of hydrostatic and colloid osmotic forces through the capillary membranes, whereas osmosis determines fluid distribution between the intracellular and extracellular compartments. Osmosis is responsible for the movement of small solutes such as sodium, chloride, and other electrolytes across cell membranes. Cell membranes are highly permeable to water, but less permeable to small ions, such as sodium and chloride. This leads to rapid movement of water across membranes leaving the intracellular compartment isotonic in comparison to extracellular (Hall & Guyton, 2011). Diffusion is another physiological process involved with molecule movement across cell membranes. Hall & Guyton (2011), define fusion as the continual movement of molecules in liquids or gases. The important concept of this molecule movement is that ions and colloids move through diffusion.

Hall & Guyton (2011, p. 290) define osmosis as: “The net diffusion of water across a selectively permeable membrane from a region of high water concentration to one that has a lower water concentration”. Hall & Guyton, (2011, p. 51) further state: “If pressure were applied to the sodium chloride solution, osmosis of water into this solution would be slowed, stopped, or even reversed. Solutes added to water, such as sodium chloride, will reduce the water concentration in the respective compartment depending on the osmolarity of the solution. Water diffuses from an area of low solute concentration to an area of high solute, or low water concentration.

The exact amount of pressure required to stop osmosis is called the osmotic pressure of the sodium chloride solution. A sodium chloride solution contains ions and water. The movement water through the cell membrane is unrestricted, whereas the sodium and chloride ions pass with difficulty. This will cause an imbalance of water distribution where the ion molecules displace water, leading the movement of water to the side of the membrane where water was displaced or an osmotic effect. Small changes in extracellular solute concentrations will create large osmotic pressures across a cell membrane. Hall & Guyton, (2011) express that each milliosmole concentration gradient of an impermeable solvent creates approximately 19.3 mmHg of pressure across the cell membrane. The measurement of osmotic pressure gradients is known as tonicity. The numbers show us that when intracellular and extracellular fluids are not at osmotic equilibrium large forces are created to move water across membranes.

### **Replacement Fluids**

Intravenous replacement fluids are solutions designed to use the above physiological principles allowing practitioners to properly balance fluid compartments. According to Hall & Guyton (2011), solutions made to be either isotonic, hypotonic, or hypertonic relate to whether the solution will cause a change in cell volume. Normal osmolarity of blood/serum is about 300-310 mOsm/L.

### **Crystalloids**

Per Hall & Guyton (2011), an isotonic solution, such as 0.9% sodium chloride or 5% dextrose, contain impermeable solutes which cannot pass through the cell membrane. These solutions possess an osmolarity of 282 mOsm/L and result in equilibrium between intra and extracellular water concentration, thus the cell will neither shrink nor swell. This is of clinical importance if the practitioner does not want to change the intra and extracellular balance. A

hypotonic solution, such as 2.5% dextrose or one quarter percent normal saline, contain lower concentrations of impermeable solutes and are less than 282 mOsm/L (Hall & Guyton, 2011). These solutions create a gradient where water will diffuse into the cell to an area of higher solute concentration, which causes the cell to swell. A hypertonic solution, such as dextrose 10% in water (D10W) and dextrose 5% in 0.9% sodium chloride (D5NS), will cause water to shift out of cell (Hall & Guyton, 2011).

According to Hall & Guyton (2011), the calculation of extracellular and intracellular fluid volumes, along with osmolarities, are possible following administration of solutions. With the administration of a hypertonic saline solution, an anesthesia provider would first calculate initial volumes, concentration, and total milliosmoles in each compartment. In order to calculate, one must make the assumption that extracellular volume is 20% and intra-cellular is 40% of body weight. Second, the total milliosmoles added extracellular fluid in two liters of 3.0% sodium chloride which has 3.0g/100ml, or 30grams of sodium chloride per liter.

The molecular weight of sodium chloride is 58.5g/mole, equaling 0.513 mole per liter. Two liters of solution equals 1.026 mole and one mole of sodium chloride and is approximately 2 osmoles; netting 2052 milliosmoles of sodium chloride in the extracellular fluid. Third, calculate the instant effect of adding 2052 milliosmoles of sodium chloride and the two-liter volume to extracellular fluid. The intracellular volume and concentration would not change due to the osmotic effects of the hypertonic solution. The extracellular fluid would effectively contain 2051 milliosmoles of total solute, yielding 5971 milliosmoles. The extracellular volume would then contain 16 liters of volume, allowing the calculation of solute concentration. The calculation is done by dividing 5971 milliosmoles by 16 liters, yielding 373 mOsm/L. The final values will be: extracellular fluid of 16 liters, 373 mOsm/L, and 5,972 mOsm. The intracellular

will contain 28 liters, 280 mOsm/L, and 7,840 mOsm. Total body fluid 44 liters, no equilibrium, and 13, 812 mOsm (Hall & Guyton, 2011).

Finally, a calculation can be done on the effects of volume and concentration after a few minutes when hypertonic saline is administered. This calculation is done by dividing the total milliosmoles by the total volume which equals mOsm/L concentration. These calculations show a result of a five liter increase in extracellular volumes and a three liter decrease intracellularly. The above calculations are essential for the understanding of fluid abnormalities and therapies (Hall & Guyton, 2011).

### **Hemodynamics**

Possessing a knowledge base concerning the physiology of body fluids, and the dynamics of crystalloids, the anesthesia provider will then apply this information to create optimal hemodynamic conditions. According to Marik, Monnet, & Tebuul (2011), a provider managing a patient's hemodynamic status will first assess the adequacy of tissue and organ perfusion. Less than optimal volume administration may result in inadequate tissue perfusion thus leading to organ dysfunction. The administration of too much fluid also appears to impede oxygen delivery, leading to poor patient outcomes including GI dysfunction. When looking at the hemodynamics of a critically ill patient, it is important to accurately assess intravascular volume status and cardiac preload. Following volume assessment, determine whether a response from administration of a fluid challenge and increasing stroke volume will be elicited (Marik et al., 2011).

According to Gutierrez et al. (2013), stroke volume is determined by preload, afterload, and contractility. Preload is the volume of blood directed to the heart. Contractility is the force of

the pump. Afterload is the pressure created by the arterial system against the contractility. Together, these forces determine the volume of blood pumped by each heartbeat.

Armed with the knowledge that intraoperative fluid replacement volumes are given to enhance stroke volume, Marik et al. (2011, para. 4) state: “Per the Frank-Starling Principle, as the preload increases left ventricular (LV) stroke volume increases until the optimal preload is achieved at which point the stroke volume remains relatively constant”. Marik et al. (2011, para. 4) further state: “This optimal preload is related to the maximal overlap of the actin-myosin myofibrils. It is important to note that in an intact heart the actin-myosin links cannot be disengaged and hence there is no descending limb of the Frank-Starling Curve”.

Together, the left and right ventricles operate on the ascending portion of the Frank-Starling Curve, providing a functional reserve to the heart in situations of acute stress. Whereas, when the left ventricle is at the flat part of curve fluid loading is ineffective (Marik et al., 2011).

### **Goal- Directed Fluid Therapy**

Goal- directed fluid therapy utilizes static and dynamic indices to achieve hemodynamic stability that is necessary to ensure adequate tissue perfusion and oxygenation. There are several static and dynamic index monitoring methods that will guide the administration of intravenous fluids, vasopressors, or inotropes on a patient which are based on a predetermined algorithm (O’Neal & Shaw, 2015). The optimal maintenance of intravascular volume is the goal of fluid therapy. Achieving proper vascular volumes will create the necessary cardiac stroke volume needed to maintain tissue perfusion.

The determination of intravascular volume in the operating room remains a challenge because of a rapidly changing physiology that is primarily due to cardiovascular responses to anesthetic agents and intraoperative volume losses (Joshi, 2016). Current data suggests, that for

major surgical procedures either restricting intraoperative fluid administration and/or using a goal-directed approach, a decrease in perioperative morbidity and possibly mortality will occur (Joshi, 2016).

### **Literature review**

Rollins & Lobo (2016) found that intraoperative hypovolemia caused by loss of as little as 10% to 15% of blood volume can result in an appreciable fall in splanchnic perfusion, which often outlasts the period of hypovolemia. Following the hypovolemia, GI mucosal acidosis results in GI dysfunction and associated complications. These patients will be unable to tolerate oral or enteral tube feeding, suffer from nausea, vomiting, and abdominal distension, thus causing a delayed discharge. To prevent the above-mentioned GI dysfunction, the practice of goal-directed fluid therapy was implemented.

Rollins & Lobo (2016) described one goal directed fluid therapy method as the administration of relatively small-volume (200–250mL) boluses of fluid in addition to the maintenance intravenous crystalloid to increase stroke volume and cardiac output, improve gut perfusion, and decrease gut mucosal acidosis.

Fixed-volume algorithms historically guide intraoperative fluid therapy. This approach often leads to less than optimal fluid amounts. According to Barash et al. (2012), using calculations has limitations when attempting to determine intraoperative fluid replacement volumes.

Fixed volume therapy estimates intravascular volume by assessing patient history, physical assessment, and laboratory values. Following patient assessment, the provider will develop a plan for fluid therapy. A common formula for fluid therapy is based on normal maintenance requirements, and then by factoring weight, the 4-2-1 rule is used. This empirical

calculation determines the fluid infusion per hour. The other variables factored into the equation are the length of fasting time, blood loss, and third space loss. Together, these values provide a baseline fluid therapy plan (Butterworth, Mackey, & Wasnick, 2015).

A surgical case that began with the fixed volume approach will fail when hemodynamic instability arises. Often, when the provider recognizes negative hemodynamic conditions, the first reaction is a fluid challenge. Administering a fluid challenge is only beneficial if a significant increase in stroke volume is obtained and the increase in stroke volume benefits the patient (Lemson, 2014). Changes in stroke volume can be measured following a fluid challenge which produces a change in preload. A greater than ten percent change in stroke volume, following a fluid challenge, demonstrates that a patient is fluid responsive.

When the increase is evident on the steep part of the Frank-Starling Curve, a further fluid challenge may be warranted (Miller, Roche, & Mythen, 2015). Describing the need to predict fluid responsiveness (Miller et al., 2015, para. 24) state: “Ultimately, anesthesia is as much an art as a science, and the decision to administer fluid therapy should be supported by an apparent need for hemodynamic improvement in the context of a likely volume deficit and by the lack of associated risk”.

According to Cherpanath, Geerts, Legrand, Schultz, & Groeneveld (2013), fluid loading is the cornerstone of resuscitation when a patient is hemodynamically unstable. The problem they found, however, is that only about 50% of these patients respond to fluid loading and show an increase in stroke volume. Rapid fluid loading has demonstrated improved outcomes, although continued fluid loading leading to fluid overload, is associated with increased morbidity and mortality (Cherpanath et al., 2013).

The question is when an anesthesia provider is managing a complex gastrointestinal case requiring more than weight-based calculations to direct fluid therapy, and goal directed fluid therapy is needed, what is the optimal method and how is this method applied? Complex surgical procedures are often accompanied with hypovolemia and hemodynamic instability. The anesthesia provider will require specific and accurate guidance to provide optimal fluid therapy.

Rollins & Lobo (2016) compared intraoperative goal- directed fluid therapy versus conventional fluid therapy in a meta-analysis of randomized controlled trials involving adult patients undergoing elective major abdominal surgery. The aim was to compare the effects of intraoperative goal- directed fluid therapy with conventional fluid therapy on postoperative complications, length of hospital stay, gastrointestinal function, and mortality. The research also sought to determine whether there was a difference in outcomes between studies that used Enhanced Recovery after Surgery (ERAS) protocols for perioperative care versus those that did not follow ERAS.

Research included 23 studies of 2099 patients. 1040 were evaluated for the impact of intraoperative goal-directed fluid therapy and then compared outcomes to 1059 patients receiving conventional fluid therapy. Research included all areas of surgery published in all languages between January 1995 and December 2014, using PubMed, MEDLINE, Web of Science, Google™ Scholar, and Cochrane Library databases.

Results demonstrated that in patients undergoing elective major abdominal surgery, goal-directed fluid therapy was associated with a significant reduction in overall morbidity, length of hospital stay, and first bowel movement when compared with conventional intraoperative fluid therapy (Rollins & Lobo, 2016). However, there were no significant differences in short-term mortality, time to passage of flatus, or risk of paralytic ileus. When the effect of goal- directed

fluid therapy was accompanied by ERAS, there was no statistically significant impact on morbidity and mortality, hospital stay time, time to passage of flatus, or incidence of paralytic ileus (Rollins & Lobo, 2016).

The methodology for conducting goal directed fluid therapy meta-analysis differed greatly between studies, including hemodynamic parameters from an arterial line, pulse pressure variability index from the pulse oximeter, and a noninvasive cardiac output monitoring device. Although the different methods may be considered a limitation, Rollins & Lobo (2016) believed that a variety of methodologies would ensure that the conclusions of this meta-analysis were generalizable to different goal- directed fluid therapy methods.

Limitations between studies involved inconsistent measurement of postoperative fluid administration and input and output, which may significantly impact upon some of the postoperative outcomes (Rollins & Lobo, 2016). Also, the use of emergency drugs such as diuretics and inotropes is not easily measured in review of the literature. Data showing whether compliance with the ERAS standards was followed, was not offered, which may obscure outcome results.

Rollins & Lobo, (2016) found that goal- directed fluid therapy was associated with a significant reduction in overall morbidity, length of hospital stay, and time to passage of feces when compared with conventional intraoperative fluid therapy. However, there were no significant differences in short-term mortality, time to passage of flatus, or risk of paralytic ileus, showing that the benefits of goal-directed fluid therapy remains inconclusive.

Achieving accurate intravascular volume in the operating room remains a challenge because of a rapidly changing physiology that is primarily due to cardiovascular responses to anesthetic agents and intraoperative volume losses (Joshi, 2016). Goal- directed fluid therapy has

demonstrated benefits to patient outcomes, but data remains inconclusive on exactly how to apply goal- directed fluid therapy and to which patient type. Joshi (2016) suggests that for major surgical procedures either restricting intraoperative fluid administration and/or using a goal-directed approach, a decrease in perioperative morbidity and possibly mortality will occur.

The research offered by Rollins & Lobo (2016) effectively shows improved outcomes when using goal- directed fluid therapy versus conventional therapy. Although when incorporating data from the enhanced recovery after surgery pathway results are inconclusive between goal- directed fluid therapy with ERAS versus goal- directed fluid therapy without ERAS. The combined use of ERAS and goal- directed fluid therapy would provide the optimal intraoperative and perioperative fluid balance.

Future research is needed to examine a practical and repeatable goal- directed fluid therapy plan that can become standard practice to high risk surgical patients. Accomplishing this task may require standardizing end points for goal- directed fluid therapy, universal use of the ERAS protocol, eliminating or limiting the use of static or empirical fluid therapy guidance, instituting and identifying the best method for intraoperative dynamic index evaluation.

### **Goal- Directed Fluid Therapy Methods**

There are several static and dynamic index monitoring methods that will guide the administration of intravenous fluids, vasopressors, or inotropes on a patient which are based on a predetermined algorithm (O'Neal & Shaw, 2015). Research has found superior outcomes when using dynamic index versus the long standing static index measurement method (Marik et al., 2011).

### Static Index

Marik et al. (2011) suggest that when practitioners are seeking guidance with fluid therapy, they routinely interpret central venous pressure (CVP) values (static index) to determine volume status. Common wisdom is that low CVP values reflect volume depletion, and high CVP values equate to volume overload. According to Marik et al. (2011), the CVP can be an indirect measure of left ventricle preload, assuming that right atrial pressure and right ventricular stroke volume determines left ventricle filling.

Per Marik et al. (2011), the sum of the above consequences is that left ventricle preload should indicate intravascular volumes. However, critically ill patients or patients receiving anesthesia often have changes in venous tone, intrathoracic pressures, or left and right ventricular compliance. These physiologic changes lead to a poor relationship between the CVP and right ventricular end-diastolic volume.

Noting over 100 studies Marik et al. (2011) found that the CVP is a poor indicator of right ventricle end-diastolic volume. He also noted that the right ventricular end-diastolic volume may not reflect preload reserve as demonstrated on the Frank-Starling Curve. Current research is assessing whether dynamic index monitoring showing changes in stroke volume will estimate preload per the Frank-Starling curve, and thus determine whether the patient is likely to be fluid-responsive (Marik et al., 2011).

In a prospective, single-blinded, randomized study Kumar, Rajan, & Baalachandran, (2016) compared outcomes of stroke volume variation (SVV) versus central venous pressures (CVP) guided fluid therapy during major abdominal surgery. Following ethics committee approval, 60 ASA I and II patients that were undergoing major abdominal surgery

that included the Whipple's procedure, low anterior resection, retroperitoneal tumor, and gastrectomy were randomized into two equal groups.

In the standard care group, the CVP was maintained at 10-12 mmHg while in the intervention group a SVV of 10% was achieved by the administration of fluids. The primary end-points were the length of Intensive Care Unit (ICU) and hospital stay. The secondary end points were intraoperative lactate, intravenous fluid use, requirement for inotropes, postoperative ventilation and return of bowel function (Kumar, Rajan, & Baalachandran, 2016).

The SVV was measured using a Vigileo-FloTrac third generation device. Crystalloids were administered until the SVV was corrected to <10%. Every two hours' arterial blood gas (ABG) analysis was performed intraoperatively. Packed red blood cells were infused if blood loss exceeded allowable limits of colloid. When using a colloid such as HES 130/0.4 concentration over 10 mg/ml for more than four hours, the proximal renal tubular cells may be damaged (Toyoda, D., Shinoda, S., & Kotake, Y.,2014). A goal of a mean arterial pressure >65 mm Hg was achieved by administering a fluid bolus followed by vasopressors, then an inotrope if needed.

Fluid replacement strategies designed to minimize SVV during major abdominal surgery resulted in a shorter postoperative ICU stay and lesser intraoperative fluid requirement as compared to CVP guided fluid replacement. Implementation of fluid replacement guided by a dynamic preload variable (SVV) appeared to have distinct advantages over conventional static variables (CVP) on postoperative ICU stay in abdominal surgery.

Gutierrez et al. (2013), presented a case study where the FloTrac/Vigileo was used to guide fluid therapy. They compared the total fluid administered in the case to a fluid plan using the 4-2-1 rule. The case was choledochojejunostomy for cholelithiasis on a 63-year-old woman

that weighed 64.5kg and fasted for eight hours. The anesthetic plan included general endotracheal anesthesia, two big bore intravenous accesses, and an arterial line with FloTrac/Vigileo monitoring to keep stroke volume variation (SVV) between 10% to 13% for fluid administration guidance. The procedure lasted 4 hours and a total of 2100 mL of intravenous fluid was administered. Total urine output was 725 ml and vital signs remained stable intraoperatively. The patient was extubated in the OR and she was discharged home on post-operative day five. Using the 4-2-1 rule in this case calculates to 6,366 mL crystalloids. The comparison demonstrates that using calculated estimates without real-time guidance, would have led to more fluid than needed and possible overload.

When comparing, the results concerning the ability to predict fluid responsiveness between the Vigileo–FloTrac and CVP measurements, it is important to review the conclusion from Marik et al. (2011). He found limited data supporting a measurable relationship between the static parameter of a CVP and intravascular volume. Marik et al. (2011) believes there are choices other than CVP which use minimally invasive and noninvasive diagnostic tools to assess volume responsiveness

The above literature comparing CVP to SVV measurements presents improved outcomes when SVV and fluid responsiveness are applied to fluid therapy. Anesthesia providers in many settings are currently able to apply the results of these studies by using dynamic monitors such as the Vigileo- FloTrac. Knowing that major abdominal procedures often require arterial lines for beat to beat blood pressure accuracy, a dynamic monitor can be attached to that arterial line for more accurate fluid volumes.

### **Dynamic Index**

Researchers are currently studying data on whether dynamic index measurements will offer improved outcomes by providing an improved evaluation of fluid responsiveness. As mentioned above, static measurements include such methods as central venous pressure and pulmonary capillary wedge pressure. Evidence has demonstrated that static indices provide little value in discriminating responders from non-responders (Soliman et al., 2015). Lacking vital information on whether a patient is responding to a fluid challenge may lead to negative outcomes from the administration of improper fluid volumes. Researchers are currently studying data on whether dynamic index measurements will offer improved outcomes by providing an improved evaluation of fluid response.

According to Soliman et al. (2015), dynamic indices are considered accurate predictors of fluid responsiveness in the ventilated patient. Dynamic indices are cardiopulmonary interactions between pulse pressure variation (PPV), inferior vena cava diameter, superior vena cava diameter, and aortic blood flow which are based on left ventricle stroke volume. It is important to remember, and per Gutierrez et al. (2013), preload, afterload, and contractility determine stroke volume. Preload is the volume of blood directed to the heart. Contractility is the force of the pump. Afterload is the pressure created by the arterial system against the contractility. Together, these forces determine the volume of blood pumped by each heartbeat.

According to Gutierrez, Moore, & Liu. (2013), the dynamic approach to goal-directed fluid therapy utilizes multiple proprietary systems. The systems have developed algorithms for obtaining cardiac output from an arterial waveform, including the FloTrac, LiDCO, and PiCCO systems. These systems vary in terms of how they analyze the arterial pressure waveform, as well as their requirements for invasive line placement and calibration (Gutierrez et al., 2013).

Although small-scale clinical trials using these monitors show promising data, large-scale multicenter trials are still needed to better determine how intraoperative goal-directed therapy with arterial waveform analysis can improve patient outcomes (Gutierrez et al., 2013).

### **Vigileo–FloTrac**

Currently, there are various non-invasive to moderately invasive products that monitor dynamic indices. The Vigileo–FloTrac from Edward Lifesciences, Irvine, CA introduced in 2005 is one example. According to (Soliman et al., 2015), there are three dynamic indices measured by the Vigileo–FloTrac which are stroke volume variation (SVV), pulse pressure (PP), and pulse pressure variation (PPV). SVV is defined as the variation of each contraction of the left ventricle's stroke volume from the mean value during the most recent twenty seconds. PP is defined as the difference between systolic and diastolic arterial blood pressure. PPV is when maximal (PPmax) and minimal (PPmin) values are determined over the same respiratory cycle. A SVV or PPV >10% indicates that stroke volume is sensitive to fluctuations in preload caused by the respiratory cycle and that the patient is fluid responsive (Soliman et al., 2015).

Soliman et al., (2015) presented a prospective study of the Vigileo–FloTrac. The study was conducted by the Department of Critical Care Medicine, Faculty of Medicine at the Cairo University, from September 2009 to December 2010. The study evaluated the ability of the Vigileo–FloTrac to predict fluid responsiveness in patients with acute circulatory failure under complete passive, volume controlled mechanical ventilation and correlating it to manually calculated PPV (Soliman et al., 2015).

Participants included twenty-five patients aged above 18 years with acute circulatory failure requiring fluid resuscitation and mechanical ventilation. The included patients would present with one clinical sign of inadequate tissue perfusion such as: systolic blood pressure less

than 90 mmHg requiring vasopressor drugs, skin mottling, urine output  $<0.5$  ml/kg/h for at least 2 hours, and a heart rate greater than 100 beats per minute (Soliman et al., 2015).

Patients were excluded if their history included cardiogenic shock, acute pulmonary edema, LVEF  $<50\%$ , atrial fibrillation, frequent ectopic beats, significant aortic or mitral valve abnormalities, or renal failure. Participants received a thorough clinical assessment prior to the procedure (Soliman et al., 2015).

Subjects were administered standard general anesthesia induction with muscle relaxation. Mechanical ventilation was administered on volume controlled mode, with settings at a tidal volume 8–10 ml/kg, respiratory rate 12–15 breaths/minute, positive end-expiratory pressure (PEEP) 0–2 cm H<sub>2</sub>O, and positive inspiratory pressure below 30 cm H<sub>2</sub>O. Mean arterial pressure (MAP) was maintained  $>65$  mmHg by norepinephrine. A fluid challenge of 500 ml of an isotonic sodium chloride solution was infused over 10 min (Soliman et al., 2015).

Static and dynamic hemodynamic parameters were taken in supine position before and after a fluid challenge. Static measurements recorded by a trans-thoracic echocardiography including: heart rate, CVP, systolic blood pressure (SBP), diastolic blood pressure (DBP), MAP, and CO. Dynamic measurements were recorded by the Vigileo-FloTrac including: CO, Cardiac index (CI), stroke volume (SV), stroke volume index (SVI), SVV, and PPV (Soliman et al., 2015).

Results of the study found that patients with CI results greater than fifteen percent of baseline measured by trans-thoracic echocardiography were considered fluid responders. The study also found that only 14 patients of the 25 patients (56%) were responsive to fluid. Results of data recorded by the Vigileo-FloTrac found that baseline stroke volume variation showed a

significant ability to differentiate between fluid responders and non-responders with 100% sensitivity and 81.8% specificity.

Soliman et al. (2015) points out that not all hemodynamically unstable patients respond to fluid volume challenges and expansion. His study presented research done on mechanically ventilated patients after receiving a liver transplantation. The data revealed that the ability of SVV to predict fluid responsiveness was only 48%. Data found in a separate study showed that only 68% of patients after coronary artery bypass grafting were responsive to volume expansion when assessed by SVV (Soliman et al., 2015).

Soliman et al. (2015) concluded that baseline stroke volume variation showed a significant ability to differentiate between fluid responders and non-responders, and confirmed that pulse pressure variation as a good index predicting fluid responsiveness.

In a randomized study, (Li et al., 2013) divided fifty patients into two groups undergoing elective gastrointestinal surgery to determine the role of SVV measured by the Vigileo-FloTrac in prediction of fluid responsiveness. The groups were designated as group C, with participants mechanically ventilated with tidal volumes of 8 ml/kg, and respiratory rate of 12/min. The other participant assignment was to group L, with their tidal volumes at 6 ml/kg, and respiratory rate of 16/min. Standard induction and standard monitoring were used in each group. The Vigileo-FloTrac monitored hemodynamic changes such as SVV before and after fluid loading (Li et al., 2013).

According to results found by (Li et al., 2013), volume replacement created significant changes in all hemodynamic variables with exception to heart rate, MAP, CVP, and stroke volume index (SVI). This data suggests that the changes in SVI were significantly correlated

with the changes in SVV and CVP. Changes in SVI were not related to the changes in HR, MAP and SVR.

As stated by Li et al. (2013, para. 19), “changes in SVI were significantly correlated to the SVV before volume replacement, while no correlation was found between the changes in SVI, HR, MAP, CVP, and SVR before volume replacement. Both CVP and SVV can evaluate the volume state, but only SVV can predict the fluid responsiveness under this condition”. The study concluded that GI patients ventilated with low tidal volumes, can have fluid responsiveness predicted when SVV is monitored by the Vigileo-FloTrac (Li et al., 2013).

Suehiro et al., (2014) studied the efficacy of the Vigileo-FloTrac in measuring CO. The article looked at data that showed limitations in CO measurement when low SVR is present. System software updates have demonstrated improvements in CO accuracy when SVR is low, however, the accuracy of this system after acute SVR changes remains an issue of major concern. Due to limited ability to measure CO, the validity of the data provided by the Vigileo-Flo-Trac has been questioned (Suehiro et al., 2014).

Suehiro et al. (2014) reviewed the database of MEDLINE and discovered that perioperative goal-directed fluid therapy with the Vigileo-Flo-Trac has been investigated in various clinical settings. Each setting studied goal-directed fluid therapy utilizing the Vigileo-Flo-Trac. In one study, Mayer, Boldt, Mengisto, Rohm, & Suttner, (2010) investigated sixty high-risk patients undergoing major abdominal surgery, and reported that the length of the hospital stay and postoperative complications were reduced significantly. In a recent study by Ramsingh, Sanghvi, Gamboa, Cannesson, & Applegate (2013), results showed that in major abdominal surgery, patients monitored by the Vigileo-FloTrac maintaining SVV<12% was associated with a faster return of gastrointestinal function and higher quality of gastrointestinal

recovery scores. Suehiro et al. (2014) concluded that the Vigileo-FloTrac is an accurate predictor of fluid responsiveness measured by SVV (Suehiro et al., 2014), although demonstrates potential limitations in measuring cardiac output due to the systems loss of accuracy when SVR fluctuates.

According to Gutierrez, Moore, & Liu (2013), the dynamic approach to goal-directed fluid therapy utilizes multiple proprietary systems. The systems have developed algorithms for obtaining cardiac output from an arterial waveform, including the FloTrac, LiDCO, and PiCCO systems. These systems vary in terms of how they analyze the arterial pressure waveform, as well as their requirements for invasive line placement and calibration (Gutierrez et al., 2013). Although small-scale clinical trials using these monitors show promising data, large-scale multicenter trials are still needed to better determine how intraoperative goal-directed therapy with arterial waveform analysis can improve patient outcomes (Gutierrez et al., 2013).

### **Discussion**

An anesthesia provider standing at the head of the bed, and behind the ether screen, understands that every organ system of the patient is his or her responsibility, and that these systems must be protected from the deleterious effects of surgery. The goal is to achieve system wide homeostasis and to keep the patient as close to physiological baseline as possible. This review of literature has demonstrated that fluid therapy is impactful on a patient's physiology, and is an important component in anesthesia care. Importantly, intravenous fluids administered properly will be instrumental in achieving positive outcomes.

Various fluid replacement techniques are utilized, but when major procedures are performed, the anesthetist must manage fluids with a desired goal and obtain guidance to predict fluid responsiveness. This is known as goal-directed fluid therapy and often the goal is based on

hemodynamic stability. Research is currently supporting the use of SVV measurement by such products as the Vigileo Flo-Trac as being superior to historically used PAWP or CVP.

In short duration procedures on healthy patients, traditional empirical formula fluid calculations will provide adequate fluid guidance. Whereas, during complex procedures on unstable patients the guidance of the Vigileo Flo-Trac is needed. The Vigileo Flo-Trac's monitoring of SVV allows providers to predict fluid responsiveness which is important for optimal fluid challenges. Too much or too little fluid volume can lead to disastrous results. Accurate measurement of fluid responsiveness will result in the administration of optimal fluid volumes, and has proven to result in positive outcomes. Furthermore, optimal volume replacement will specifically reduce the incidence of gastrointestinal (GI) dysfunction, will lead to a reduction in heart rate, and achieves optimal hemodynamics necessary for tissue perfusion.

### **Limitations**

Limitations between studies involved inconsistent measurement of postoperative fluid administration and input and output, which may significantly impact postoperative outcomes (Rollins & Lobo, 2016). Studies offered incomplete data on whether compliance to the Enhanced Recovery After Surgery (ERAS) standards were adhered to. This led to obscured comparative outcome results. Also, the use of emergency drugs such as diuretics and inotropes is not easily measured in review of the literature.

Suehiro et. al (2014) found limitations in the efficacy of the Vigileo-FloTrac measuring of cardiac output when low systemic vascular resistance is present. Despite software updates improving cardiac output accuracy, measurements after acute systemic vascular resistance changes remains an issue of major concern. Due to limited ability to measure CO, the validity of the data provided by the Vigileo-FloTrac has been questioned (Suehiro et al., 2014).

An important limitation affecting all dynamic indices data when studying goal-directed fluid therapy by systems such as the Vigileo-FloTrac, involves the measurement of stroke volume variation (SVV). First, SVV is found to be inaccurate in patients that are spontaneous breathing. Secondly, tidal volumes must be greater than 8ml/kg to facilitate significant changes in preload. Third, arrhythmias cause inaccuracies in SVV and PPV. In addition, a mechanically ventilated patient with pulmonary hypertension or right ventricular failure may have a decrease in left ventricular preload (Marik et al., 2011).

Future research is needed to examine a practical and repeatable goal-directed fluid therapy protocol that can become standard practice to high risk surgical patients. In a healthcare climate where reimbursement is low and costs are high, institutions continue to follow traditional fluid replacement protocols, and thus are hesitant to purchase devices such as the Vigileo-FloTrac until data shows superior outcomes.

Accomplishing the task of goal-directed fluid therapy best practices through research requires: standardizing end points, comparable use of the ERAS protocol, comparing dynamic index data and eliminating confounding data from static or empirical fluid therapy guidance, and then identifying the best method for intraoperative dynamic index evaluation.

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