Fluid and Hemodynamics

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KEYWORDS

• Fluid therapy • Goal-directed therapy • Cardiac output monitoring
• Enhanced recovery

KEY POINTS

- Enhanced Recovery After Surgery (ERAS) pathways can improve perioperative fluid and hemodynamic therapy by avoiding preoperative dehydration and reducing postoperative dependence on intravenous fluids.
- Perioperative fluid management practices have changed over time, shifting away from liberal fluid therapy toward more restrictive or goal-directed approaches.
- Goal-directed hemodynamic therapy (GDHT) which uses cardiac output monitoring to optimize volume status and avoid perioperative hypotension has been shown to improve outcomes.
- Intraoperative mean arterial pressure is increasingly important, with hypotension in the operating room associated with worse postoperative outcomes.
- Within ERAS programs, high-risk patients are most likely to benefit from perioperative GDHT, and institution-specific approaches are likely ideal during the implementation of such programs.

INTRODUCTION

Appropriate hemodynamic management is a critical component of care in the perioperative patient. Surgery induces a significant inflammatory response which may vary based on the condition of the patient, the urgency of surgical intervention, the type of procedure, and the volume of blood loss. Physiologic changes in the perioperative period can lead to capillary leakage and redistribution of fluids, activation of fluid and sodium retention pathways, and significant metabolic changes.[1,2] Anesthesia induces hypotension due to peripheral vasodilation and altered cardiac function, and the use of neuraxial blockades may lead to vasoplegia and venodilation.[3,4] Although a complicated subject, appropriate hemodynamic optimization of the patient during surgery is key to managing the potentially harmful effects of the surgical stress response. Over the years there has been a multitude of studies evaluating various fluid administration practices in the operating room (OR), leading to changes in the practice of perioperative care. Changing fluid management practices in the OR and clinical evidence,

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particularly in the setting of Enhanced Recovery After Surgery (ERAS) pathways, have created questions and debate surrounding the optimal intraoperative fluid and hemodynamic management strategies for the surgical patient.

Hemodynamic management refers to interventions or therapy that aim to maintain certain levels of cardiovascular blood flow and pressure. The intended result is adequate tissue perfusion and oxygenation in the presence of the surgical stress response. Hypovolemia and hypotension lead to reduced organ perfusion and postoperative complications.[5] On the other hand, excessive volume administration can lead to equally poor outcomes, and the effects of hypervolemia on postoperative complications are well-described.[6–9] Thus, the goal for the anesthesia provider is to find the proper balance between hypovolemia and excessive fluid volume administration (**Fig. 1**). However, fluid requirements may be somewhat different in ERAS settings when compared with more traditional perioperative care. The two key concepts in perioperative fluid and hemodynamic therapy, and the overarching focus of this chapter, are the maintenance of circulatory "flow" and "pressure" in the surgical patient.

FLUID REQUIREMENTS IN AN ENHANCED RECOVERY AFTER SURGERY PATHWAY

In an ERAS setting, the preoperative elements of the pathway aim to bring the patient to surgery when they are at or near a euvolemic state. Emergency settings, in contrast, involve patients in a state of physiologic stress, typically via infection, systemic inflammatory response syndrome (SIRS), or hemorrhage. Elective or scheduled surgery represents a more controlled environment for perioperative management. Traditionally,

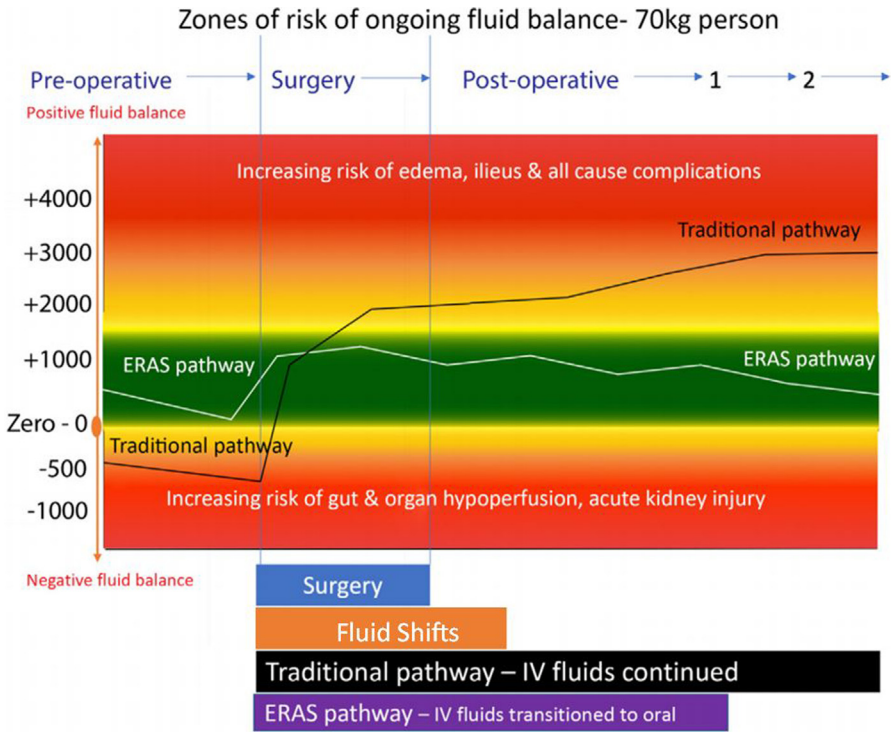

Fig. 1. Comparison of fluid management between ERAS pathways and traditional perioperative care.

however, elective patients were expected to have a prolonged period of *nil per os* (NPO) starting the night before surgery.[10] This would lead to the patient becoming dehydrated, which would then necessitate aggressive, high-volume fluid therapy during surgery.[11] As advanced hemodynamic or cardiac output monitoring was lacking in the typical patient, the volume of fluid administered in surgery was typically determined using traditional vital signs monitoring, urine output, blood loss, and clinical judgment. ERAS pathways operate differently. Rather than prolonged preoperative dehydration followed by excessive perioperative fluid administration, certain elements of ERAS work to improve and simplify fluid and hemodynamic management in the perioperative period:

- Preoperative oral fluid intake: patients are allowed to drink clear liquids up until 2 hours before the start of surgery, avoiding preoperative dehydration.
- Carbohydrate loading: preoperative carbohydrate drinks counteract the catabolism of preoperative fasting and serve to maintain hydration.
- Preference for minimally invasive surgical techniques: laparoscopic surgery and the avoidance of open procedures, when possible, help to reduce physiologic derangement and insensible fluid losses.
- Correction of anemia: patients with anemia at baseline are referred for intravenous iron infusions to improve the oxygenation of tissues during the surgical stress response.

These elements act as a continuum of care across the preoperative, intraoperative, and postoperative periods.[12] Each phase of the process is critical. The preoperative elements of ERAS, when appropriately applied, help to ensure the patient arrives without significant physiologic derangement or hypovolemia. This in turn lowers the threshold to avoid under-perfusion and simplifies hemodynamic management. Improved perioperative fluid therapy and hemodynamics, without excessive intravascular volume administration, improve organ and tissue perfusion. This leads to fewer complications such as acute kidney injury (AKI), infections, pulmonary complications, and various other morbidities (see **Fig. 1**). This in turn can achieve the reductions in length of stay (LOS) and costs that are associated with ERAS pathways in various studies.

APPROACHES TO INTRAOPERATIVE FLUID THERAPY

A critical component to maintaining perfusion is to ensure adequate volume in the vasculature, as this is the first step to ensuring optimized circulatory "flow." Various approaches to intraoperative IV fluid therapy have developed over the years, but the overarching strategies are "fixed volume" versus "goal-directed" or individualized therapy. In the literature on intraoperative fluid therapy, there are many studies and clinical reviews which use a variety of vague and poorly defined terms such as "restrictive" and "liberal" fluid plans and various "goal-directed fluid" or "hemodynamic" therapies. Thus, a detailed review of these concepts is necessary.

Fixed Volume Strategies

With the increasing awareness of the consequences of hypervolemia, modern perioperative practice moved toward intraoperative fluid administration that was more "restrictive" than older, traditional therapies.[12,13] In the past it was common for patients to receive 4 to 5L of crystalloid during surgery.[13–15] This was done with the assumption that the patient was experiencing severe physiologic stress by the nature of the surgical procedure and thus had high volume requirements. Clinical evidence, however, began to show evidence toward more restrictive fluid administration plans improving outcomes.[14,16,17] The concept involves giving the patient only the amount

of fluid that is physiologically necessary to both maintain perfusion and avoid volume overload. The "restrictive" approach, though, has never been clearly defined, and this term is used with a high degree of subjectivity. "Zero balance" approaches, which aim to keep the patient at a net-even level of fluid during their surgical admission, have also been advocated, but their relation to "restrictive" plans, or if they are different, remain unclear in the literature.[18,19]

There is a generalized belief that ERAS protocols advocate for a "zero-balance" or "restrictive" approach to intraoperative fluid therapy. This is a misconception. ERAS pathways advocate a balance between fluid "restriction" and volume overload, in full awareness of the complications of both. Some recent evidence has shown that ERAS pathway implementation is associated with a higher incidence of postoperative AKI, and an association with overly-restrictive approaches should not be ignored.[20–22] Myles and colleagues demonstrated this phenomenon in the RELIEF trial. In this study of nearly 3000 patients undergoing major abdominal surgery, they randomized patients to a "restrictive" plan, which aimed to achieve a net "zero-balance" of fluid and a "liberal" fluid plan. The restrictive group received a bolus of 5 cc/kg at the start of surgery and 5 cc/kg/h of maintenance fluid during surgery. The liberal group received a 10 cc/kg bolus and 8 cc/kg/h of maintenance fluid. This resulted in the restrictive patients receiving 1.7 L of crystalloid versus 3.0 L in the liberal group. Postoperative median fluid balance was +1.38 L in the restrictive group than +3.09 L in the liberal group. The study identified no difference in 1-year disability-free survival between the groups but found the restrictive group to have a higher incidence of AKI (8.6% vs 5.0%, $P<.001$). The results of the trial underscore the importance of avoiding approaches that overly-restrict fluid administration, particularly given the well-described association of AKI with mortality and costs.

Given the current evidence, fluid approaches within ERAS that rely on clinical judgment and protocolized, weight-based fluid administration, as opposed to goal-directed or individualized therapies, should likely target a weight gain of 1 to 2 kg of fluid by postoperative day 1.

Goal-Directed Therapies

Goal-directed approaches in the OR have been studied for over 30 years. This concept was initially studied by Shoemaker and colleagues, who in 1988 demonstrated that targeting supra-normal values for cardiac index and oxygenation dramatically improved rates of postoperative mortality in major surgery patients.[23] In the following years, there have been a multitude of clinical trials that evaluated different forms of goal-directed approaches within various patient populations.[24,25] Regarding intraoperative fluid management, goal-directed fluid therapy (GDFT) is defined as the use of cardiac output monitoring to guide the administration of fluid. The concept behind GDFT is the optimization of stroke volume to ensure optimal "flow" and perfusion of tissues.[26] Optimized perfusion ensures adequate organ function and aids in wound healing in the perioperative patient.[27,28] Typically, GDFT entails fluid administration in response to the stroke volume, and it aims to determine the patient's position on the Frank–Starling curve (**Fig. 2**). Following a fluid challenge, if the stroke volume does not increase by at least 10%, then the patient is considered not volume-responsive and additional fluid, in this case, is not likely to benefit. Various protocols and procedures have been studied, and no single methodology or "protocol" for GDFT is recommended. Some study protocols used maintenance fluid, typically 1 to 5 cc/kg/h depending on the type of surgery, whereas some mandated only fluid boluses that are administered in response to a drop in stroke volume.[12,29,30] For practical use of these approaches, a provider's level of comfort or experience will likely dictate

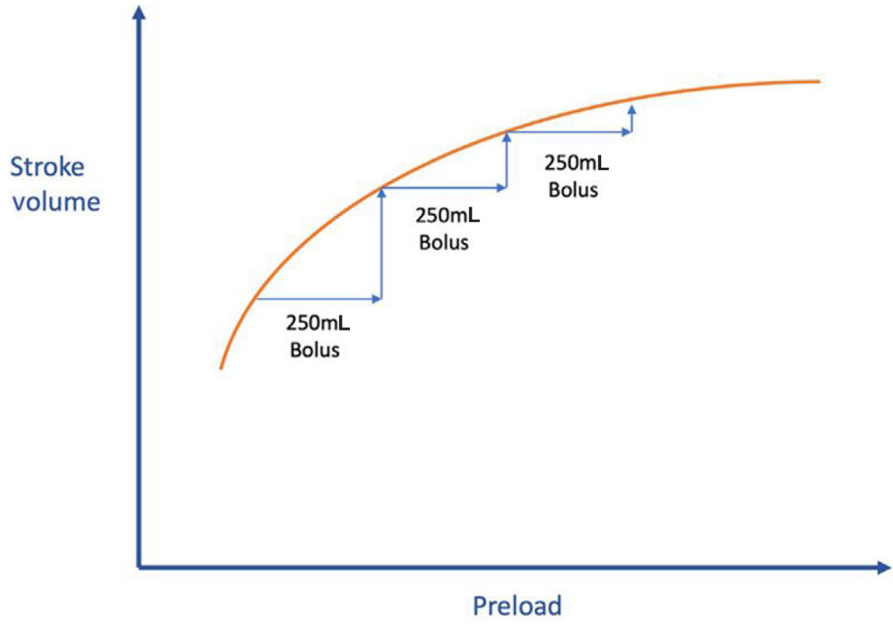

Fig. 2. Frank–Starling curve demonstrating concept behind goal-directed fluid therapy. Small fluid blouses are used to determine the patient's position on the curve.

the use, type, and amount of maintenance fluid. However, the key concept is to avoid excessive fluid administration at baseline and to give additional fluid as dictated by cardiac output monitoring.

CARDIAC OUTPUT MONITORING TECHNIQUES

Several devices monitor cardiac output with varying degrees of invasiveness and monitors exist for each potential setting. Each device has its benefits and drawbacks, but the choice of device is ultimately left to provider preference and familiarity. Some of the frequently used methodologies are reviewed here.

Pulmonary Artery Catheter

In the past, monitoring of cardiac output required a pulmonary artery catheter (PAC) and thermodilution. This technique involves cold fluid intermittently injected into the right atrium while the resulting temperature change is calculated in the pulmonary artery. This is then used to calculate the cardiac output.[31] Devices that provide continuous cardiac output monitoring via the PAC are available.[32] Given its invasiveness and the complications associated with the PAC, its use in modern practice is limited. It is mainly used at provider discretion for those with major cardiac disease, right ventricular dysfunction, or in those who are otherwise extremely high risk for surgery. While the PAC with thermodilution is still considered by some as the standard for cardiac output monitoring, newer and farless invasive technologies have been developed for use in modern perioperative care.

Esophageal Doppler Monitor

The esophageal Doppler monitor (EDM) is well-validated and has been used in many clinical trials on GDFT. This probe is similar in size to a nasogastric tube and is inserted

into the esophagus following the induction of anesthesia. When directed at the aorta, the device tracks the velocity of blood flow through the aorta in relation to time. Using the estimated aortic cross-sectional area, it can derive stroke volume and cardiac output.[33] The EDM does have some limitations: the patient must first be asleep before insertion, and the probe must be adjusted occasionally to track aortic blood flow should the probe or patient change position.

Arterial Waveform Analysis

Multiple platforms use arterial waveform analysis technology to determine stroke volume and cardiac output. These devices require an arterial line. Using the stroke volume, blood pressure, systemic vascular resistance, and arterial compliance, the arterial line probe can generate stroke volume and cardiac output. In simple terms, the stroke volume can be calculated when arterial compliance is known by the expected change in arterial blood volume between systole and diastole.[34] These devices have also been well-validated and used in certain GDFT studies.

Thoracic Bioimpedance and Bioreactance

Bioimpedance is a technology that uses the circulating fluid volume in the thoracic cavity to derive cardiac output. This relies on the difference in electrical conduction between the fluid/liquid and solid components of the body. By emitting an alternating current from multiple skin pads and utilizing the changes in electrical conductance or impedance through the thoracic cavity, the circulating blood volume can be calculated. This in turn is related to the stroke volume and cardiac output.[35,36] Bioreactance uses the same principle but was developed to improve the signal-to-noise ratio and usability of bioimpedance. It uses the phase shift of the electrical signal, which is related to the thoracic blood flow.[37,38] A benefit of these devices is that they are completely noninvasive, using the placement of electrodes on the skin that are similar to electrocardiogram leads.

AVOIDANCE OF HYPOTENSION

A second key concept in hemodynamic therapy is the maintenance of adequate mean arterial pressure (MAP). Hypotension in the OR is associated with adverse outcomes, and maintaining adequate MAP is a key component of perioperative care. This was illustrated in a retrospective cohort analysis of intraoperative vital signs data by Salmasi and colleagues of more than 57,000 patients.[39] Postoperative myocardial injury and AKI were strongly associated with intraoperative MAPs below the absolute threshold of 65 mm Hg. This risk was increased with lower blood pressures and a longer duration of hypotension. Other studies similarly showed a significant increase in myocardial injury, AKI, and mortality following perioperative hypotension. Sun and colleagues reviewed more than 5000 noncardiac surgical patients and showed odds ratios of 2.34 and 3.53 for AKI with 11 to 20 min and greater than 20-min exposures to a MAP of less than 55 mm Hg respectively.[40] Monk and colleagues showed increased 30-day mortality risk with a similar pattern concerning the duration and depth of intraoperative hypotension.[41] Other studies have shown the same associations, which reiterate the critical importance of maintaining adequate arterial pressure during surgery.[42–44]

COMBINING FLOW AND PRESSURE: GOAL-DIRECTED HEMODYNAMIC THERAPY

Incorporation of the control of MAP with a GDFT approach is defined as goal-directed *hemodynamic* therapy (GDHT). While sometimes used interchangeably with GDFT, GDHT incorporates the avoidance of hypotension into these protocols (**Fig. 3**). This

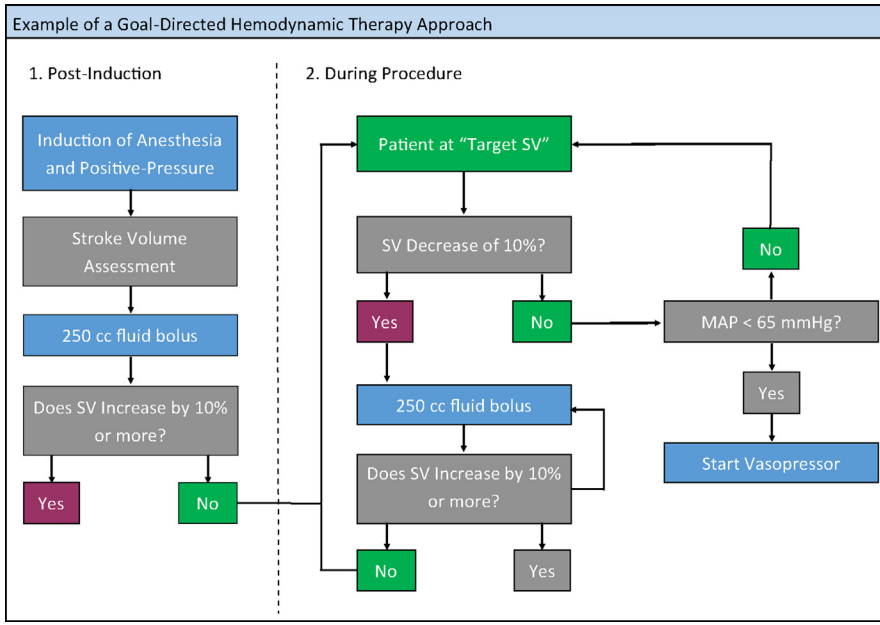

Fig. 3. Goal-directed hemodynamic therapy: a practical guide. • The concept of stroke volume optimization aims to ensure adequate but not excessive circulating blood volume to maintain tissue perfusion. • When cardiac output monitoring is available, small fluid challenges or boluses are given to patients while their stroke volume is monitored. These are typically 100 to 250 cc boluses given rapidly over 5 to 10 minutes with the patient supine. The stroke volume is then monitored for 5 additional minutes following completion of the bolus, and a 10% increase in SV is generally considered "volume-responsive."[27,45] • The approach signals the general location of the patient on the Frank–Starling curve. The intent is to have the patient on the "flat" part of the curve, which signifies normovolemia. If the SV does not rise at least 10%, then additional fluid is not likely to benefit. • The SV is typically "optimized" just after induction of anesthesia and before the start of surgery. Fluid boluses are given until the stroke volume does not increase by 10%. However, typically a maximum of 500 to 750 cc are used for this to prevent excessive volume administration in patients with normal cardiac function. • The SV is then maintained during surgery. If the stroke volume drops 10% or more, then a fluid challenge is given. If the patient responds to this fluid bolus, additional fluid is given until the SV does not rise 10%. • Several surgical factors may affect the stroke volume, including (1) patient positioning, (2) peritoneal insufflation for laparoscopic surgery, and (3) ventilation changes. When SV changes of 10% or more occur in relation to these factors, a fluid challenge while monitoring SV can ensure the patient remains euvolemic. • Alternatively, dynamic indices such as stroke volume variation (SVV) or pulse pressure variation (PPV) may also be used in place of or in addition to SV. These indices use change in intrathoracic pressure during positive pressure ventilation to "simulate" small fluid challenges. Large variations in arterial pressure or stroke volume are attributed to hypovolemia. Typically an SVV of 10% to 12% is considered volume-responsive. Before using these variables, however, certain conditions must be met: (1) the patient cannot be spontaneous breathing, (2) tidal volumes must be greater than 8 mL/kg, (3) no cardiac arrhythmias are present, and (4) the thoracic cavity is not open.

ensures adequate "flow" or circulatory volume while maintaining adequate "pressure" to help ensure adequate organ and tissue perfusion. However, in the literature the two are typically discussed as the same, given the differences of various hemodynamic endpoints of the methodologies studied in clinical trials. GDHT has historically been

associated with a significant reduction in complications and mortality, particularly in studies following the principle of optimizing flow followed by the use of vasoactive drugs to achieve a target MAP.[24,30,46]

The FEDORA trial published by Calvo-Vecino and colleagues[30] in 2018 is an example of such principles. It was a prospective, multicenter randomized control trial studying 420 patients assigned to intraoperative goal-directed hemodynamic therapy (GDHT) versus traditional therapy. Eligible patients underwent major abdominal, urologic, gynecologic, or orthopedic surgery with both laparoscopic and open surgical approaches. The primary outcome was moderate or severe complications (AKI, SSI, pulmonary edema, ARDS) occurring within 180 days of surgery. Patients in the GDHT group had hemodynamic monitoring with an EDM to guide fluid, vasopressor, and inotrope administration. Fluid boluses of 250 cc were given to achieve an optimal stroke volume, after which either vasopressors or inotropes were started to maintain MAP of greater than 65 mm Hg and a cardiac index of greater than 2.5 L/min/m^2. Compared with traditional therapy, the GDHT group had a lower risk of AKI (1.44% vs 8.53%) ARDS (0.48% vs 5.69%), cardiopulmonary edema (0% vs 6.16%), pneumonia (1.91% vs 8.53%), superficial SSI (0.96% vs 4.74%), and deep SSI (1.91% vs 8.06%). Secondary outcomes also demonstrated shorter average hospital LOS (5 vs 7 days) and shorter average ICU LOS (16h vs 24h) in the GDHT group than traditional therapy. The OPTIMISE trial published in 2014 was a randomized, multicenter trial in the United Kingdom of 734 patients over age 50 undergoing major gastrointestinal surgery.[29] Patients were randomized to a cardiac output-guided hemodynamic algorithm versus standard therapy. The intervention group protocol maximized stroke volume and maintained a continuous infusion of dopexamine, and the patients were to maintain a MAP of greater than 60 mm Hg with vasopressor support as needed. Results showed the intervention group achieved a reduction in the primary outcome (moderate or severe complication or mortality within 30 days of surgery) and improvement in mortality at 180 days despite the trial reporting nonsignificance for the primary endpoint. In a meta-analysis incorporating 95 randomized trials, goal-directed therapy was associated with a lower risk of mortality (odds ratio (OR): 0.66, 95% confidence interval (CI): 0.50–0.87), AKI (OR: 0.73; 95% CI: 0.58–0.92), and pneumonia (OR: 0.69; 95% CI: 0.51–0.92) and led to shorter hospital LOS (−0.90; 95% CI: −1.32 to −0.48) when compared to standard fluid management.[24] In their analysis, the authors excluded older studies that used a PAC to monitor cardiac output, as they believed the clinical practice of GDHT has changed significantly with the incorporation of novel cardiac output monitoring devices.

In goal-directed therapy studies, some evidence suggests that the timing of fluid administration may be a key factor in improving outcomes. Studies, such as FEDORA, have shown that the volume of fluid administered between patients was not significantly different between GDHT and control groups.[30,47] A hypothesis is that occult instances of hypoperfusion, which would not be identified by traditional monitoring techniques, may be apparent by the drop in cardiac output. Studies on intraoperative hypotension, as mentioned previously, that show an association with increased complications with brief periods of intraoperative hypotension lend evidence to this.[39,41,42]

Overall, GDHT has been shown to reduce perioperative organ dysfunction and improve outcomes. However, while many studies show benefit, the heterogeneity of the trials in their populations, endpoints, and methodologies make specific conclusions difficult to establish from meta-analyses on this topic. In addition, the control groups from older studies represent what was considered usual care at the time, which was typically liberal intraoperative fluid therapy. Thus, some studies which have evaluated GDHT against the modern perioperative practice have shown less

benefit, likely due to an improvement in our understanding of the consequences of excessive volume administration and the prevalence of carefully monitored fluid management within ERAS pathways.

THE ROLE OF GOAL-DIRECTED HEMODYNAMIC THERAPY IN ENHANCED RECOVERY AFTER SURGERY PATHWAYS AND PRACTICAL IMPLEMENTATION

The role of GDHT within ERAS pathways has been debated, as there is some evidence that ERAS programs may "blunt" the benefits of GDHT in certain populations. Lobo and Rollins demonstrated this in a meta-analysis in 2016 evaluating studies of goal-directed therapy specifically within ERAS programs.[48] They found no statistical difference in postoperative morbidity, mortality, or overall LOS when intervention and control patients were both managed within an ERAS pathway. Given advances in modern practice and the improvements seen in ERAS, one can conclude that not all patients should be managed with intraoperative GDHT. On this point, the World ERAS Society recommends that GDHT be used in high-risk patients or procedures with an anticipated high intravascular volume shift or loss.[49] Patients undergoing short procedures or who lack significant comorbidities are less likely to benefit from a GDHT program. While benefits may be questionable in some populations, when appropriately executed GDHT does not result in patient harm.[12] However, there is some evidence of an association of ERAS programs with AKI.[21] Weiner and colleagues evaluated the incidence of AKI in colorectal surgery patients following the implementation of an ERAS pathway and found that the incidence of AKI, by the Kidney Disease Improving Global Outcomes definition, nearly doubled.[20] This finding was mirrored in similar studies.[21,22] Higher ASA status, the presence of comorbidities, and reduced preoperative renal function are known risk factors for the development of perioperative AKI.[50] Paired with the lack of harm associated with intraoperative GDHT, there is a strong argument in favor of GDHT approaches to intraoperative fluid therapy in such high-risk patients. As has been emphasized, not all patients are expected to benefit, as low-risk patients undergoing low-risk procedures likely require a very large number to treat before any benefit is observed. However, those at high risk of postoperative complications, or patients undergoing highly morbid procedures, are expected to benefit based on the current evidence and societal guidelines.

Implementation of intraoperative GDHT is a complex subject. Based on existing evidence, it is wise for institutions to approach GDHT implementation based on their patient populations and the prevalence of comorbidities. Health systems serving a surgical population with high rates of comorbidities or who routinely perform high-risk surgeries are likely to see the most benefits. Inevitably it relies on resource allocation and availability of minimally or noninvasive cardiac output monitoring. Regarding which specific patients should have GDHT during surgery, this is likely best left at the discretion of the institution or physician group. A multidisciplinary team of surgeons and anesthesiologists should set clear institutional recommendations on which patients will be managed with GDHT. Given the marginal benefits, as demonstrated in the literature, in low-risk patients already managed with an ERAS pathway, including all patients in GDHT is likely not feasible or a wise allocation of resources. One approach would be to classify certain planned operation types, such as all major colonic or rectal resections, all liver resections, multi-level spinal surgery, and others, as cases where GDHT should be used. Additionally, patients who are high-risk by certain criteria, such as ASA status, baseline renal function, or other comorbidities, should also receive GDHT, but again this would be determined by the patient population served. Complications such as AKI, infections, or prolonged ileus should be

tracked and reviewed by a multidisciplinary team, and changes to the GDHT protocol or the institutional inclusion criteria should be considered when appropriate. As in any clinical guidance, however, it is essential to maintain provider autonomy regarding patient care. While GDHT in high-risk patients, avoidance of hypotension, and careful monitoring of fluid needs are recommended as components of ERAS pathways, each patient is different and perioperative therapy should be tailored appropriately with clinical judgment.

SUMMARY

Many of the principles in ERAS pathways act to improve and simplify perioperative fluid and hemodynamic therapy. With the rising popularity of ERAS, perioperative fluid management over the last several years has shifted away from liberal fluid therapy to more restrictive and goal-directed approaches. Alongside this, there is an increased awareness of the relationship between intraoperative hypotension and increased postoperative complications, and maintaining adequate intraoperative MAP is a critical component of care. GDHT, made possible for most patients by minimally or noninvasive cardiac output monitoring, has shown an ability to improve outcomes. However, within ERAS pathways its role is likely best suited to high-risk patients or those undergoing high-risk procedures. Health systems or providers seeking to implement GDHT and other perioperative therapies should pursue institutional-specific practices tailored to their respective populations. By using an integrated approach that incorporates the preoperative, intraoperative, and postoperative components of ERAS, modern surgical care can move toward a reduction in both perioperative complications and health care costs.

CLINICS CARE POINTS

- ERAS pathways improve preoperative volume status, aiming to keep the patient at or near a euvolemic state on arrival to the operating room.
- Overly restrictive intraoperative fluid administration practices have shown increased rates of acute kidney injury within ERAS pathways. Providers should also be aware that the definition of "restrictive" fluid therapy has changed over time.
- Hypotension during surgery should be avoided given its strong association with postoperative complications such as renal and myocardial injury.
- Individualized intraoperative GDHT protocols, through optimizing volume status and avoiding hypotension, have demonstrated an ability to improve outcomes in high-risk surgical patients.
- When guided by cardiac output monitoring, the timing of fluid administration during surgery is likely a key factor in improving organ perfusion.
- Institutions implementing goal-directed approaches within their ERAS pathways should tailor these programs to their patient populations. Implementation and auditing of such programs should be managed by multidisciplinary teams of surgeons and anesthesiologists.

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