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REVIEW ARTICLE/BRIEF REVIEW

Fluid management and goal-directed therapy as an adjunct to Enhanced Recovery After Surgery (ERAS)

Gestion des liquides et traitement ciblé en annexe de la Récupération rapide après la chirurgie (RRAC)

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Abstract *Optimal perioperative fluid management is an important component of Enhanced Recovery After Surgery (ERAS) pathways. Fluid management within ERAS should be viewed as a continuum through the preoperative, intraoperative, and postoperative phases. Each phase is important for improving patient outcomes, and suboptimal care in one phase can undermine best practice within the rest of the ERAS pathway. The goal of preoperative fluid management is for the patient to arrive in the operating room in a hydrated and euvolemic state. To achieve this, prolonged fasting is not recommended, and routine mechanical bowel preparation should be avoided. Patients should be encouraged to ingest a clear carbohydrate drink two to three hours before surgery. The goals of intraoperative fluid management are to maintain central euvolemia and to avoid excess salt and water. To achieve this, patients undergoing surgery within an enhanced recovery protocol should have an individualized fluid management plan. As part of this plan, excess crystalloid should be avoided in all patients. For low-risk patients undergoing low-risk surgery, a "zero-balance" approach might be sufficient. In addition, for most patients undergoing major surgery, individualized goal-directed fluid therapy (GDFT) is recommended. Ultimately, however, the additional benefit of GDFT should be determined based on surgical and patient risk factors. Postoperatively, once fluid intake is established, intravenous fluid administration can be discontinued and restarted only if clinically indicated. In the absence of other concerns, detrimental postoperative fluid overload is not justified and "permissive oliguria" could be tolerated.*

Résumé *La gestion périopératoire optimale des liquides est un élément important des programmes de récupération rapide après la chirurgie (RRAC). La gestion des liquides dans le cadre de la RRAC doit être vue comme un continuum au travers des phases pré-, per- et postopératoires. Chaque phase est importante pour améliorer la condition du patient et des soins sous-optimaux au cours d'une de ces phases peuvent miner les meilleures pratiques déployées tout au long de la RRAC. L'objectif de la gestion préopératoire des liquides est de faire en sorte que le patient entre en salle d'opération correctement hydraté et dans un état euvolémique. Pour y parvenir, un jeûne prolongé n'est pas recommandé et le nettoyage mécanique de l'intestin est à éviter. Les patients doivent être encouragés à absorber une boisson claire riche en hydrates de carbone, deux à trois heures avant la chirurgie. Les buts de la gestion peropératoire des liquides sont de maintenir une euvolémie centrale et d'éviter un excès de sel et d'eau. Pour y parvenir, les patients subissant une intervention chirurgicale dans le cadre d'un protocole de récupération rapide devraient avoir un programme personnalisé de gestion des liquides. Dans le cadre de ce plan, l'excès de cristalloïdes doit être évité chez tous les patients. Pour des patients à faible risque subissant une intervention chirurgicale à faible risque, une approche « d'équilibre*

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zéro » pourrait être suffisante. De plus, pour la majorité des patients subissant une chirurgie majeure, une thérapie liquidienne individualisée à objectif déterminé (GDFT) est recommandée. Au bout du compte, cependant, l'avantage supplémentaire de la GDFT doit être déterminé en fonction des facteurs de risque liés au patient et à la chirurgie. En postopératoire, une fois la reprise de consommation de fluides, leur administration par voie intraveineuse peut être interrompue et n'est reprise qu'en cas d'indication clinique. En l'absence d'autres préoccupations, une surcharge liquidienne postopératoire est nuisible et non justifiée alors qu'un certain degré d'oligurie « permissive » peut être toléré.

Enhanced Recovery After Surgery (ERAS) or "Fast Track" programs integrate a range of perioperative interventions to maintain physiological function and facilitate postoperative recovery after major surgery. Enhanced Recovery After Surgery programs also aim to attenuate the stress response during surgery and to increase patient participation during the postoperative recovery period. There are several elements of ERAS programs that are new and specific to this approach. They bring together two best practices, organization of care and clinical management, with the goal of consistent delivery of optimum care within an evidence-based clinical pathway.

The goals of ERAS pathways are to decrease postoperative complications and to facilitate earlier recovery after major surgery. Optimal perioperative fluid management, an important component of this approach, is frequently underappreciated. In one study, a change in fluid management alone on the day of surgery has been shown to reduce postoperative complications by 50%.[1]

Fluid management within ERAS should be viewed as a continuum through the preoperative, intraoperative, and postoperative phases. Each phase is important for improving patient outcomes, and suboptimal care in one phase can undermine best practice within the rest of the ERAS pathway. For instance, several litres of crystalloid given on postoperative day one to chase reduced urine output (UOP) can cause postoperative ileus and delay discharge from hospital.[2] Yet, fluid management decisions in the postoperative environment are frequently left to the most junior member of the team.

This article reviews best practice evidence-based fluid management for patients undergoing surgery within an ERAS pathway. We review the evidence for optimal care throughout the patient's journey and also address the evidence supporting best practice fluid management in common clinical scenarios such as fluid management in laparoscopic surgery and low perioperative UOP.

Preoperative fluid management

The goal of preoperative fluid management is for the patient to arrive in the operating room in a hydrated and euvolemic state. Prolonged fasting is not recommended. The American Society of Anesthesiologists' guidelines recommend intake of clear fluids until two hours before induction of anesthesia.[3] A Cochrane review in adult patients provided robust evidence that reducing the preoperative fasting period for clear fluids to two hours does not increase complications.[4] Prolonged fasting (from midnight) does not reduce gastric content or raise the pH of gastric fluid.

Routine mechanical bowel preparation (MBP) should also be avoided. Mechanical bowel preparation contributes to preoperative dehydration and is unpleasant for the patient.[5,6] Recent evidence suggests that MBP does not decrease anastomotic leakage, wound infection, or mortality (for the majority of patients),[7] and it may even have a tendency towards a higher incidence of spillage of bowel contents due to formed stool being replaced by liquid bowel contents.[8] The patient population in which MBP is indicated is still a matter of debate amongst surgeons, and it is often given for "handling" reasons, with some surgeons arguing that MBP facilitates easier laparoscopic surgery.[9]

Ingesting a clear carbohydrate drink containing a relatively high concentration of complex carbohydrates two to three hours before surgery reduces preoperative thirst, hunger, and anxiety[10] and has the added advantage of reducing postoperative insulin resistance.[11] Within 90 min, 400 mL of a clear 12.5% carbohydrate drink containing mainly maltodextrins (with no fat or protein) empties completely from the stomach and, therefore, can safely be given up to two hours before induction of anesthesia.[12,13]

The combination of these preoperative techniques enables the patient to come to the operating room in a "fed" state. Patients undergoing surgery within an ERAS protocol are less likely to be fluid responsive after induction of anesthesia when compared with patients undergoing traditional fluid management preoperatively.[14]

Intraoperative fluid management

The goals of intraoperative fluid management are to maintain central euvolemia and to minimize excess salt and water. This can be achieved with background maintenance fluid therapy combined with volume therapy (fluid challenges) for restoration of intravascular volume.

Maintenance fluid therapy

Maintenance fluid requirements are needed to replace losses from the body via UOP and insensible perspiration,

which are less than commonly thought. Direct measurement of the basal evaporation rate has shown that typical evaporative fluid losses during major abdominal surgery are 0.5-1 $mL \cdot kg^{-1} \cdot hr^{-1}$.[15] In addition, until recently, liberal administration of fluid was commonplace to replace third-space losses. The third space was originally described as an all-consuming nonfunctional compartment where fluid can get sequestered during major surgery.[16] It has never been localized, and tracer studies do not support its existence.[17] Therefore, empiric filling of this "space" is not needed, and the term should be abandoned – fluid is either intravascular or shifted into the interstitium.[17]

Administering more fluid (typically crystalloid) than is needed has been associated with harm.[1,2] Administration of excessive fluid will result in hypervolemia and a subsequent increase in intravascular hydrostatic pressure with release of atrial natriuretic peptides that can damage the endothelial glycocalyx.[18] The glycocalyx is a layer of membrane-bound proteoglycans and glycoproteins that coats healthy vascular endothelium. It plays an important role in managing vascular permeability by acting as a second barrier to extravasation. Unfortunately, it is easily damaged; sepsis or hypervolemia can cause damage to the glycocalyx and, thus, leakage. Therefore, intravenous fluid that is given without evidence of hypovolemia can damage the glycocalyx and shift out of the circulation into the interstitial space (commonly referred to as "third spacing").[19]

The most common manifestation of excessive fluid administration is edema of the gut wall and prolonged ileus. Even a modest positive salt and water balance causing a weight gain of 3 kg after elective colonic resection has been shown to be associated with delayed recovery of gastrointestinal function, increased rate of complications, and extended hospital stay.[2] Furthermore, a study in rats undergoing a bowel resection and anastomosis showed that excessive crystalloid results in submucosal intestinal edema, lower anastomotic bursting pressure, and a decrease in the structural stability of intestinal anastomoses in the early postoperative period.[20]

Maintenance fluid requirements during surgery can be delivered with a 1-3 $mL \cdot kg^{-1} \cdot hr^{-1}$ infusion of a balanced crystalloid solution.[19,21] The aim should be to maintain preoperative body weight. The term, fluid restriction, should be abandoned as it implies causing deliberate hypovolemia; the published regimens using a "restrictive" fluid strategy aim to maintain preoperative body weight. A better term to describe low crystalloid therapy regimes is zero-balance fluid therapy – with the aim of maintaining central euvolemia while minimizing excess salt and water.[22]

For many patients, minimizing excess fluid with a zero-balance approach will be sufficient for their clinical needs (see section on matching monitoring needs to patient and surgical risk). Nevertheless, in more major surgery with greater blood loss and more complex fluid shifts, boluses of fluid may be required to maintain euvolemia. This is frequently referred to in the literature as volume therapy.

Volume therapy – the fluid challenge

Volume therapy is typically used to replace blood loss or fluid/protein shifts from the circulation. When there is evidence of intravascular hypovolemia, a fluid challenge is recommended to test volume responsiveness. This should be given rapidly over five to ten minutes,[23] and although there is no consensus on the type of fluid given, most trials in the operating room showing an improved outcome were performed with a colloid.[24-32]

Importantly, hemodynamic instability does not equate with volume responsiveness; indeed, only 50% of hemodynamically unstable patients in the operating room are "volume responders".[33] Moreover, volume responsiveness does not always mean that a fluid bolus is needed. The clinical decision to give a fluid challenge must be made in the context of a likely volume deficit (e.g., hemorrhage) rather than a low systemic vascular resistance. For example, if there is no reason to suspect a volume deficit and the blood pressure is low, judicious use of a vasopressor may then be prudent.

Furthermore, traditional monitors used to guide fluid management, such as heart rate (HR), blood pressure (typically measured as mean arterial pressure [MAP]), UOP, and central venous pressure (CVP), are unreliable indicators of volume status. When blood is lost from the circulation, the normal physiologic response is splanchnic vasoconstriction to shift blood from the splanchnic circulation and maintain core perfusion of vital organs. In a study where healthy volunteers were phlebotomized to approximately 75% of their baseline blood volume, neither HR nor MAP changed appreciably after blood loss, though gastric tonometry (a marker of splanchnic perfusion) decreased reliably.[34] Therefore, HR and MAP can function only as rough indicators of patient status that can trigger intervention, such as a fluid challenge,[35] and cannot be used reliably to measure changes in central blood volume or as an indicator of hypovolemia.[36] Nevertheless, in cases of sudden unexpected blood loss with hypotension, a fluid challenge should be given with the goal of restoring blood pressure and, therefore, perfusion and oxygen delivery.

Central venous pressure monitoring has also been shown to be a poor predictor of volume responsiveness.[37] A recent systematic review showed that CVP is not able to identify which patients need more fluid and concluded that routine CVP measurement should be discontinued in the intensive

care unit (ICU), operating room, and emergency department.[38] Urine output is also frequently monitored as a crude marker of renal function and volume status; yet, in the perioperative period, oliguria (defined as UOP < 0.5 mL·kg^{-1}·hr^{-1}) is extremely common and often occurs as a neurohormonal response to surgical stress, rendering it an unreliable marker of volume status.[39]

Goal-directed fluid therapy

Goal-directed fluid therapy (GDFT) utilizes a cardiac output monitor to individualize fluid therapy. The technique is also referred to in the literature as stroke volume (SV) optimization, as the goal is to optimize the patient's SV throughout the perioperative period. Multiple studies have shown that GDFT may reduce complications after major surgery.[40,41] Results of several meta-analyses have rendered a similar conclusion – GDFT can reduce complications after major surgery by 25-50%.[27,42,43]

There are two important questions that we should ask in order to individualize fluid therapy. First, how do we measure the response to a fluid challenge, and equally important, how do we predict if a patient will respond to a fluid challenge?

The best way to monitor the response to a fluid challenge (change in preload) is to monitor the subsequent change in SV. An increase in SV of $> 10\%$ shows that the patient is fluid responsive on the steep part of the Frank-Starling curve and may benefit from a further fluid challenge. Once the patient is euvolemic and on the plateau of the Frank-Starling curve, further fluid challenges will not increase SV by 10% and are not likely to be beneficial. A fluid challenge can therefore identify and simultaneously treat volume depletion while avoiding deleterious consequences of fluid overload through its small volume and targeted administration.[23] Although the exact fluid challenge varies in the literature, it should be given over a short period of time (less than ten minutes) so that the response can be easily observed.

This theory is almost certainly an oversimplification of complex intraoperative hemodynamics.[44] Some patients (particularly if aerobically fit) may be volume responsive but may not need fluid.[45] 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.

In this context, it is important to be able to predict whether a patient will be fluid responsive without actually giving fluid so that unnecessary fluid boluses can be avoided. Multiple studies have shown that fluid responsiveness is best predicted by the dynamic indices such as stroke volume variation (SVV), pulse pressure variation (PPV), and systolic pressure variation (SPV). A PPV or SVV of $> 13\%$ is highly predictive of fluid responsiveness.[46] Dynamic parameters can also alert the anesthesia provider to episodes of hypovolemia before there is any change in HR, BP, or SV.[28,47] Nevertheless, it is important to reiterate that, while the dynamic parameters are robust indicators of volume responsiveness, this does not necessarily mean that the patient needs volume. Like all measured variables, they should not be used in isolation, trends and the fluid and hemodynamic priorities of the patient should always be considered. In other words, the need for fluid therapy should be supported by a desire for hemodynamic improvement that is greater than the associated risk.[33]

The dynamic variables also have a number of significant limitations. Pulse pressure variation and SVV require a constant R-R interval (i.e., normal sinus rhythm) and "normal" pressures in the chest and abdomen; otherwise, their predictive value is decreased.[48] The dynamic variables arise from heart-lung interactions during positive pressure variation; therefore, any change in tidal volume and /or intrathoracic pressure will affect the interaction.[49] A tidal volume < 8 mL·kg^{-1} decreases this interaction and, thus, decreases the negative predictive value of PPV, SVV, or SPV. In other words, a patient may have a low PPV but may actually be volume responsive. Conversely, raised intrathoracic pressures will exaggerate the heart-lung interaction and raise the threshold for volume responsiveness.[50,51] Finally, unless dynamic monitors provide an accurate assessment of cardiac output, they are poor at distinguishing absolute hypovolemia from apparent hypovolemia due to a low systemic vascular resistance.[52] Again, it is vital to assess volume responsiveness within the overall context of the patient and the likelihood that a volume deficit is present.

Goal-directed fluid therapy within an ERAS protocol

Several recent studies performed to test the effectiveness of GDFT within an ERAS protocol have failed to find the same benefit on postoperative outcomes as that found in earlier studies. Perhaps this is not surprising, as significant improvement in perioperative fluid management within an ERAS protocol, particularly in the past 15 years, has facilitated significant improvement in the quality of care in control groups of fluid management studies. Srinivasa *et al.* randomized 85 patients to GDFT or no GDFT within an ERAS protocol.[14] The protocol utilized in the GDFT study was identical to that used in the Noblett study of GDFT in 2006 before the introduction of an ERAS protocol (Fig. 1).[25] While the GDFT protocol used in both studies was the same, the overall fluid management was substantially different and illustrates the change in practice that has occurred over the last ten years.

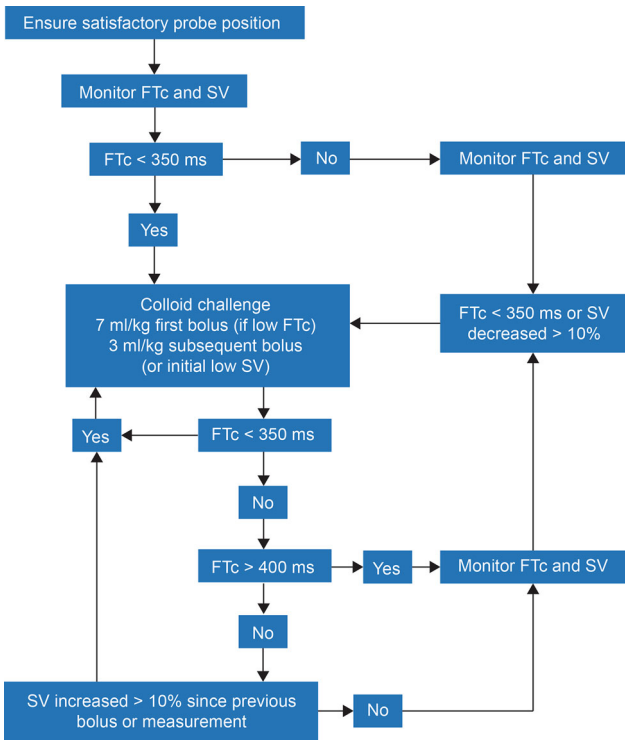

Fig. 1 Fluid administration protocol adapted from the studies by Noblett[25] and Srinivasa.[14] Note: We recommend that this algorithm, or any algorithm, be used in conjunction with an assessment of the whole patient to determine if a fluid bolus is necessary

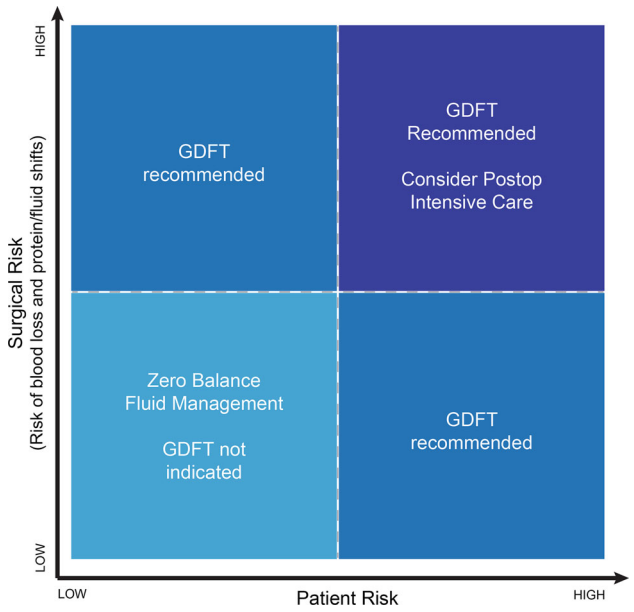

Fig. 2 A risk-adapted matrix to match monitoring needs to patient and surgical risk

In the Noblett study, all patients were fasted and received preoperative bowel preparation. There was no fluid protocol in the control group. Total fluid given intraoperatively was 3,834 mL in the control group and 3,638 mL in the GDFT group. Most patients were fluid responsive after induction of anesthesia, which is to be expected after fasting and bowel preparation, and the GDFT group had a significantly improved cardiac index (CI) at the end of the procedure compared with the control group (3.8 $L \cdot min^{-1}$ *vs* 3.2 $L \cdot min^{-1}$, respectively; $P = 0.01$). This resulted in a significant reduction in major complications (2% *vs* 15%, respectively; $P = 0.04$) and length of hospital stay (seven days *vs* nine days, respectively; $P = 0.005$).

In contrast, in the Srinivasa study, all patients were cared for within an established ERAS program. The program included a preoperative oral carbohydrate drink on the morning of surgery, avoidance of routine bowel preparation, avoidance of prolonged fasting, and a zero-balance (fluid restriction) regime with a 1,500 mL limit on crystalloid use in both groups. Total intraoperative fluid given in both groups was much lower overall than previous GDFT studies outside of an ERAS program (1,994 mL in the GDFT group *vs* 1,614 mL in the control group). Importantly, there was no difference in CI at the end of the procedure between the two groups, and no difference in complications or length of stay.

Brandstrup also found no benefit with GDFT compared with a zero-balance regime within an enhanced recovery program.[22] Again, the total fluid needed was low (1,491 mL in the zero-balance group *vs* 1,876 mL in the GDFT group). In addition, when this volume of fluid is needed in an established ERAS program, it is unsurprising that GDFT does not achieve any benefits. The zero-balance approach used in this study was also very intensive and may require more manpower. Finally, and extremely importantly, in both the Srinivasa and Brandstrup studies, GDFT was not associated with harm when compared with a zero-balance strategy.[14,22]

Matching monitoring needs to patient and surgical risk

What conclusions can we draw from these recent studies of GDFT within an ERAS protocol? Undoubtedly, ERAS protocols have made intraoperative fluid management easier. Within an ERAS protocol, patients are much less likely to be fluid responsive upon arrival in the operating room. Therefore, it seems likely that GDFT is unlikely either to cause harm or to add benefit in healthy patients undergoing uneventful surgery within an ERAS pathway (Fig. 2).

Nevertheless, even within ERAS protocols, a number of patients still receive preoperative bowel preparation and have significant comorbidities and prolonged surgery with blood loss. While ERAS programs may have raised the threshold for benefit, there will continue to be patients

Table Enhanced recovery partnership recommended cases for goal-directed fluid therapy[21]

Major surgery with a 30-day mortality rate of > 1%
Major surgery with anticipated blood loss of > 500 mL
Major intra-abdominal surgery
Intermediate surgery (30-day mortality > 0.5%) in high-risk patients (age > 80 years, history of LVF, MI, CVA, or peripheral arterial disease)
Patients with ongoing evidence of hypovolemia and / or tissue hypoperfusion (e.g., persistent lactic acidosis)
Unexpected blood loss and /or fluid loss requiring > 2 litres of fluid replacement

LVF = left ventricular failure; MI = myocardial infarction; CVA = cerebrovascular accident

(some expected, some unexpected) for whom SV optimization will be beneficial. This is similar to any other monitoring device – not all patients' care will benefit from capnography or pulse oximetry, but they are rightly standard of care.

The recently completed multicentre OPTIMISE study focused on GDFT exclusively in 734 high-risk patients undergoing major abdominal surgery.[27] The majority of these patients were managed within an ERAS pathway. In this high-risk population, there was a non-significant trend towards decreased complications in the GDFT group when compared with usual care (36.6% *vs* 43.4%, respectively; $P = 0.07$) and 180-day mortality (7.7% *vs* 11.6%, respectively; $P = 0.08$).

The Enhanced Recovery Partnership in the UK has published a consensus statement based on expert opinion recommending the types of cases in whom GDFT should be used from the outset (Table).[21] We recommend that all patients should have an individualized plan for fluid management that matches the monitoring needs with patient and surgical risk (Fig. 2). Ultimately, the need for GDFT is specific to the patient, surgeon, procedure, and institution. Before making an informed decision about appropriate implementation of GDFT, each institution should compare its outcome and benchmark data for this particular population with those of other institutions. These data should include length of stay, re-admission rate, and mortality.

Implementation of a GDFT pathway within a hospital is not an easy process and involves some upfront costs. Ideally, for successful implementation to occur, there needs to be a desire for change at a clinician and management level. The presence of an anesthesia champion to lead the process is one of the most important factors to ensure successful implementation.

Postoperative fluid management

Early oral intake in the postoperative period should be encouraged. There is no advantage in keeping patients fasted after elective gastrointestinal resection – early feeding reduces the risk of infection and length of stay and is not associated with an increased risk of anastomotic dehiscence.[53,54]

If intravenous fluid therapy is required, excess salt should be avoided, as patients do not have the same ability to excrete sodium and chloride postoperatively.[2] Most patients will be in positive sodium and fluid balance; hence, for patients requiring intravenous fluids, the aim should be to administer low-sodium low-volume fluids to enable patients to return their sodium and fluid balance to zero over the perioperative period. In high-risk patients, consideration should be given to continuing GDFT into the postoperative period.[27]

Once oral fluid intake is established, intravenous fluid administration can be discontinued. This can occur in the postanesthesia care unit, with intravenous fluids restarted only if clinically indicated. If intravenous fluids are to be given, the clinician should always ask the question, "What are we giving fluids for?"[21] The average patient without ongoing fluid deficits or losses should be encouraged to drink at least 1.75 $L \cdot day^{-1}$ to meet their daily fluid requirements.[55] Patients with a thoracic epidural who are hypotensive and normovolemic do not benefit from additional excess fluid.[56] They should be treated either by reducing, modifying, or discontinuing the epidural or pharmacologically with vasopressors. In the absence of other concerns and in the setting of normovolemia, permissive oliguria should be tolerated (see section on perioperative UOP).

Which fluid should I use?

A balanced crystalloid solution should be used during surgery (e.g., lactated Ringer's [LR], Plasma-Lyte®, or Normosol-R®) to provide maintenance fluid therapy.

Postoperatively, a solution with reduced salt is required for maintenance, e.g., dextrose saline.

Normal saline (NS) or solutions formulated in NS, such as colloids suspended in saline, should not be used routinely as they cause a predictable hyperchloremic metabolic acidosis which is associated with harm.[57-62] In particular, hyperchloremic acidosis has been shown to reduce gastric blood flow and decrease gastric intramucosal pH in elderly surgical patients.[58] It has also been shown to reduce renal blood flow velocity and renal cortical tissue perfusion in healthy volunteers.[63] Importantly, there is a lack of studies showing a benefit from administration of NS. Therefore, NS should not be used outside of a very few specific indications, e.g., hypochloremic metabolic alkalosis as a result of high upper gastrointestinal (GI) losses.

Most goal-directed fluid algorithms have used a colloid solution for fluid boluses. This is based on the principle that, in the setting of hypovolemia, a colloid will restore blood pressure, and therefore organ perfusion, faster and with less volume. Nevertheless, in clinical practice, the superiority of colloids over crystalloids remains unresolved. A recent study comparing crystalloids with colloids for fluid boluses within a GDFT algorithm found no difference in the primary outcome of postoperative GI morbidity at postoperative day five.[64] Nevertheless, there was a significantly higher 24-hr positive fluid balance in the crystalloid group, and 38% of patients in this group required a rescue colloid bolus (median volume 750 mL). There was also minimal blood loss in both groups, which is the setting in which a colloid may be most beneficial. In an animal model of hemorrhagic shock, restoration of blood pressure was four times faster with hydroxyethyl starch (HES) than with LR ($P < 0.001$) and required fourfold less volume ($P = 0.04$).[65] Avoidance of excess crystalloid is also the most important independent predictor of outcomes within an enhanced recovery protocol.[66] Although it is possible that a crystalloid could be used effectively for fluid challenges, this remains uncertain; therefore, in our opinion, a colloid is still the rational choice, especially if fluid challenges are given only in the context of blood loss and objective hypovolemia.

The choice of colloid is controversial, with recent studies in ICU patients showing an increase in renal injury when HES is used in the post-resuscitation phase of critical illness.[67,68] In contrast, there is a possible benefit to the use of colloids together with HES when used in the early phase of resuscitation in the setting of hypovolemia.[69] The key likely lies in the context – in the context of perioperative surgical patients with an intact glycocalyx, when renal injury is much less common than in the ICU, there is no current evidence that HES is associated with harm.[70] Nevertheless, it seems prudent to avoid HES (and gelatins) when there is pre-existing renal injury.

Common clinical challenges

Fluid management in laparoscopic surgery

The principles of fluid management in laparoscopic surgery are the same as for open surgery. A zero-balance approach may be sufficient for simple laparoscopic surgery on healthy patients with limited blood loss within an ERAS pathway. For all other surgery, GDFT should be considered.

Nevertheless, the pneumoperitoneum (PP) and frequent changes in position can make GDFT more challenging. After induction of PP, there will be an elevation of intra-abdominal pressure (IAP) that will decrease chest wall compliance and consequently increase pleural pressure swings for a given tidal volume.[71] Consequently, PP can increase SVV, PPV, and SPV independently of changes in blood volume.[50,72] Does this mean, however, that the dynamic variables are less useful or that we can keep the indices but raise the threshold?

In a porcine model, Renner *et al.* found that PPV is a sensitive and specific predictor of fluid responsiveness during PP, although the threshold value for fluid responsiveness increased dramatically from 11.5% (mean intra-abdominal pressure [IAP] = 7 mmHg) up to 20.5% (mean IAP = 26 mmHg).[72] The ability of SVV to measure fluid responsiveness remained until the IAP was raised above 25 mmHg when it was abolished.

During laparoscopic surgery, IAP is normally much lower, at approximately 15 mmHg. Guinot *et al.* found that SVV measured by esophageal Doppler was reliable and predicted fluid responsiveness with PP < 15 mmHg with an area under the curve = 0.92 (95% CI 0.82 to 0.98) and no change in the threshold for fluid responsiveness.[73] Conversely, Hoiseth *et al.* also found no difference in the threshold for fluid responsiveness with PP < 15 mmHg but showed that both PPV and SVV were relatively poor at predicting fluid responsiveness.[74]

Despite these conflicting results in practice, consideration should be given to the limitations of each dynamic index and the dynamic variables used in combination with changes in SV to ensure that fluid boluses are given at the appropriate time to improve hemodynamics without any increase in risk.

Finally, practitioners should be aware that a steep Trendelenburg position in combination with PP can also lead to a significant decrease in SV and cardiac output that return to baseline after deflation of the PP in the supine position.[75] In this position and in the absence of hemorrhage, preload is maintained or increased so that hypotension would unlikely be due to volume deficit. These changes are less noticeable when the degree of Trendelenburg position is < 15°.[76] Nevertheless, it is important to reset the baseline SV after any change in PP or position.

Low perioperative UOP

Low perioperative UOP is common. The major concern is that oliguria is a sign of developing renal failure, and as a result, surgeons and anesthesiologists strive to maintain UOP most commonly with boluses of intravenous fluid.

There is increasing evidence, however, that intraoperative UOP may not reflect fluid status or predict renal failure.[39] There are other mechanisms that may cause low UOP, including intraoperative releases of stress

hormones. Hahn showed that the clearance of fluids during general anesthesia is only a small fraction of that observed when awake.[77,78]

Over 20 years ago, two studies showed that intraoperative urinary output was not predictive of postoperative renal insufficiency in patients undergoing aortic reconstruction.[79,80] Recently, in an observational study of over 65,000 patients undergoing noncardiac surgery, intraoperative oliguria, defined as UOP < 0.5 mL·kg^{-1}·hr^{-1}, was not associated with renal failure.[39] Conversely, as well as other detrimental effects, such as GI function, positive fluid balance has been shown to be associated with in increased incidence of acute kidney injury (AKI) after major surgery.[81] Fluid overload results in tissue edema; in an encapsulated organ such as the kidney, tissue edema may participate directly in the progression of AKI as the kidney lacks the capacity to accommodate additional volume without an increase in interstitial pressure and compromised organ blood flow.[82]

Within an ERAS protocol, postoperative hypotension and low UOP are common within the first 24 hr, whereas renal dysfunction is extremely rare.[83] Therefore, in the absence of other concerns, detrimental postoperative fluid overload is not justified, and "permissive oliguria" can be tolerated. Transient hypotension in the context of neuraxial blockade is usually treated more effectively, if needed, with vasopressors rather than with fluids. This is an expert opinion, however, and there is very little guidance in the literature.

During laparoscopic surgery, there is even less fluid clearance due to a direct pressure effect of PP on the renal vasculature, resulting in reduced renal blood flow.[84-86] In a study of laparoscopic bariatric surgery, UOP was found not to be an indicator of volume status, and the authors recommended that "the routine administration of more fluids to enhance diuresis during these operations is futile".[87]

Conclusion

Perioperative fluid management is important. Both hypovolemia and excessive fluid administration are associated with harm. Enhanced recovery protocols have improved outcomes after major abdominal surgery. An added benefit is that patients are more likely to arrive in the operating room without significant fluid deficit, which consequently aids intraoperative fluid management.

Goal-directed fluid therapy has been shown to decrease hospital length of stay and complications after major surgery. Nevertheless, in the setting of an enhanced recovery program, this benefit may be less than in older studies when crystalloid excess in the control group was the norm. Ultimately, the additional benefit of GDFT should be determined based on surgical and patient risk factors.

We recommend that patients undergoing surgery within an enhanced recovery protocol should have an individualized fluid management plan. As part of this plan in all patients, crystalloid excess should be avoided with a zero-balance fluid strategy. For most patients undergoing major surgery, an individualized approach using GDFT is recommended. Nevertheless, GDFT should not be used in isolation; trends and the fluid and hemodynamic priorities of the patient should always be considered.

Key points

- Perioperative fluid management is important. Both hypovolemia and excessive fluid administration are associated with harm.
- Prolonged fasting before major abdominal surgery is not justified and is not supported by evidence.
- Maintenance fluid requirements during surgery should be delivered with the aim to maintain preoperative body weight. This is known as zero-balance fluid therapy.
- Goal-directed fluid therapy aims to replace losses from the circulation and to optimize stroke volume throughout the perioperative period. Goal-directed fluid therapy has been shown to reduce hospital length of stay and complications after major surgery and, therefore, may have added benefits in higher risk patients within an ERAS pathway.
- In the postoperative period, enteral nutrition and oral fluid intake should be commenced at the earliest opportunity, and the intravenous line should then be discontinued.
- In the absence of other concerns, perioperative oliguria should be tolerated.

Conflicts of interest Timothy E. Miller: Honoraria – Edwards Lifesciences. Anthony M. Roche: Consultant for Deltex Medical and PATH. Michael (Monty) Mythen: Consultant Deltex, Edwards Lifesciences. Grants Deltex, Smiths Medical. Honoraria and travel Baxter, Fresenius-Kabi.

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