Perioperative Fluid Management in the Enhanced Recovery after Surgery (ERAS) Pathway

Alyssa Cheng-Cheng Zhu, MD¹ Aalok Agarwala, MD, MBA¹ Xiaodong Bao, MD, PhD¹

¹Department of Anesthesia, Critical Care and Pain Medicine, Massachusetts General Hospital, Boston, Massachusetts

Clin Colon Rectal Surg 2019;32:114–120.

Address for correspondence Aalok Agarwala, MD, MBA, Division of General Surgery Anesthesia, Department of Anesthesia, Critical Care and Pain Medicine, Massachusetts General Hospital, 55 Fruit Street, GRB 444, Boston, MA 02114 (e-mail: aagarwala@mgh.harvard.edu).

Abstract

Fluid management is an essential component of the Enhanced Recovery after Surgery (ERAS) pathway. Optimal management begins in the preoperative period and continues through the intraoperative and postoperative phases. In this review, we outline current evidence-based practices for fluid management through each phase of the perioperative period. Preoperatively, patients should be encouraged to hydrate until 2 hours prior to the induction of anesthesia with a carbohydrate-containing clear liquid. When mechanical bowel preparation is necessary, with modern isoosmotic solutions, fluid repletion is not necessary. Intraoperatively, fluid therapy should aim to maintain euvolemia with an individualized approach. While some patients may benefit from goal-directed fluid therapy, a restrictive, zero-balance approach to intraoperative fluid management may be reasonable. Postoperatively, early initiation of oral intake and cessation of intravenous therapy are recommended.

Keywords

- Enhanced Recovery after Surgery
- fluid management
- goal-directed fluid therapy

Modern perioperative care in colorectal surgery is guided by Enhanced Recovery after Surgery (ERAS) pathways.¹ Initially developed in Europe in the 1990s to reduce variability and improve outcomes, these sets of recommendations aim to provide preoperative, intraoperative, and postoperative interventions to decrease complications and enhance patient recovery.² Most pathways include preadmission counseling, modified preoperative preparation (bowel preparation, fasting, carbohydrate loading), standardized thromboembolism and antimicrobial prophylaxis, standardized anesthetic approaches (fluid management, opioid-sparing multimodal analgesia, postoperative nausea and vomiting [PONV] prophylaxis), an emphasis on laparoscopy-assisted surgical techniques, and a standardized approach to postoperative care (fluid management, nasogastric intubation, surgical drains, urinary catheters, analgesia, early feeding, and early mobilization).³

Multiple randomized clinical trials have shown that ERAS protocols have resulted in shorter hospital lengths of stay (LOS), a reduction in complications such as postoperative ileus and surgical site infection, as well as a reduction in costs and readmissions.^{3–7} However, despite showing success in improv-

ing patient outcomes, it has been difficult to study the benefit of each component of ERAS management on its own, as many studies have suffered from incomplete implementation of ERAS. A review of 14 studies that evaluated outcomes after ERAS implementation showed that none had used all ERAS modalities.⁸ In addition, a recent analysis from international, multicenter ERAS registry data showed that overall compliance with ERAS protocols was approximately 75% but with significant variation between both centers and elements.⁹

Fluid management is one component of successful ERAS pathways, and as with other single components, there has been limited research focusing specifically on fluid management as part of ERAS. One study, however, was able to identify perioperative fluid management as an independent predictor for improved clinical outcome, finding that each additional liter of intravenous (IV) fluid given on the day of surgery led to a 16% increased risk of postoperative symptoms delaying recovery, and a 32% increase in the risk of postoperative complications.¹⁰ Given the importance of fluid management to the success of ERAS pathways, a joint consensus statement was recently released between the American Society for Enhanced Recovery and Perioperative Quality Initiative to

create a framework for perioperative fluid management within ERAS for colorectal surgery.¹¹

Controversy continues over certain elements of ERAS such as use of mechanical bowel preparation (MBP) and goal-directed fluid therapy (GDFT), and optimal perioperative fluid management requires continued investigation; however, research does exist. In this review, we will discuss current evidence-based strategies for fluid management in patients undergoing colorectal surgery within the ERAS pathway.

Preoperative Fluid Management

Oral Intake

Traditionally, patients have been instructed to remain fasting after midnight the night before surgery as standard practice for reducing pulmonary aspiration risk. Currently, the most widely followed guidelines, published by the American Society of Anesthesiologists (ASA), recommend fasting from solid foods 8 hours prior and from clear liquids 2 hours prior to the induction of anesthesia.¹² A Cochrane review concluded that compared with a standard fast (nil per os [NPO] after midnight), a shortened fluid fast which in some included studies involved fluid intake up until 90 minutes prior to surgery did not result in an increased risk of aspiration or increased morbidity as compared with the previous standard NPO recommendations.¹³

The long period of fasting that was previously promoted, often greater than 12 hours, can lead to hypovolemia and increased metabolic stress and insulin resistance.^{14,15} Correction of the fluid deficit related to preoperative fasting improved dizziness and drowsiness.¹⁶ However, if patients are allowed to continue oral fluid intake as per current ASA guidelines, IV fluid replacement is likely unnecessary.

Insulin resistance is another complication associated with long fasts. A prospective cohort study showed that for each 1 mg/kg/min decrease in insulin sensitivity, there was an overall increased incidence of major complications, including death, need for intra-aortic balloon pump, dialysis, stroke, or infection (odds ratio [OR]: 2.23).¹⁷ Of note, the study showed that the risk for severe infection was significantly higher as insulin sensitivity decreased (OR: 4.98). Insulin resistance can also lead to postoperative hyperglycemia which has been associated with a 30% increase in risk of a postsurgical infection with every 40-point increase from normoglycemia (<110 mg/dL).¹⁸ Initial studies made use of glucose infusions as a way to combat the carbohydrate depletion caused by overnight fasts.^{19,20} These studies showed that glucose infusions normalized postoperative insulin sensitivity when compared with controls, introducing the idea that undergoing surgery in a carbohydrate-fed state as compared with a fasted state was advantageous. In a 2016 randomized controlled trial (RCT) to evaluate the impact of an ERAS pathway on insulin resistance, patients were randomized to either an ERAS protocol or a conventional care. Patients in the ERAS group received 875 mL of carbohydrate-rich (157 g) fluid until 2 hours before the surgery, while patients in the conventional group began fasting at midnight and did not receive any carbohydrate-

rich fluid. While no difference was found overall between the ERAS and conventional groups, a subgroup of patients with elevated preoperative insulin resistance had significant improvement in their insulin resistance on postoperative day 1 (POD 1) in the ERAS group as compared with the control.²¹

Oral carbohydrate loading leads to other beneficial effects as well. In 2014, a Cochrane review discussed the results of 27 trials where patients received at least 45 g of carbohydrates within 4 hours before surgery or anesthesia. A carbohydrate load led to a shortened time to flatus by 0.39 days (95% confidence interval [CI]: 0.70–0.07) and a small reduction in length of hospital stay by 0.30 days (95% CI: 0.56–0.04) compared with traditional fasting requirements or placebo controls.²² However, the systematic review did not find evidence that the carbohydrate load was associated with any increase or decrease in postoperative complications. A second meta-analysis which included 21 RCTs showed that in patients undergoing major abdominal surgery, preoperative carbohydrate treatment resulted in a reduced length of stay by 1.08 days (95% CI: –1.87 to –0.29).²³ In addition, perioperative discomfort and anxiety has been found to be decreased when given a carbohydrate drink on the morning of surgery.²⁴ In one study, patients provided a carbohydrate-rich beverage had decreased levels of malaise and weakness even 24 hours after the operation.²⁵

Current evidence suggests that long periods of fasting should not be routinely recommended. While adhering to published guidelines, patients should be encouraged to drink clear liquids until 2 hours prior to the induction of anesthesia for colorectal surgery, which should include a carbohydrate-rich drink to mitigate insulin resistance.

Bowel Preparation

Mechanical bowel preparation was introduced in the 1940s and was associated with the theoretical benefits of reduced surgical site infection, reduced anastomotic leakage, and a reduction in colonic bacterial load.²⁶ However, many of these initial benefits have now been disproven. For example, MBP has not been shown to decrease the amount of bacteria in the colon and does not reduce contamination of the peritoneal cavity.²⁷ There is also no increase in anastomotic leak or septic complications without the use of MBP.^{28,29}

Not only have studies shown no benefit with MBP, but some evidence has shown that it may be harmful. One RCT in patients undergoing elective surgery for colon cancer with primary anastomosis showed that patients who received preoperative MBP had an increased incidence of wound infection and intra-abdominal infection, as well as an increased time to first flatus and a lower prealbumin level on the first postoperative day.³⁰ Another study in patients admitted for elective colorectal surgery found that the incidence in wound infection was 24% in patients who received MBP versus 12% in the control group.³¹ MBP has also been shown to contribute to hypovolemia. Junghans et al demonstrated low intrathoracic blood volume index of patients who underwent bowel preparation and overnight fasting consistent with relative hypovolemia.³²

Even though the majority of current literature does not support the use of MBP, it continues to be used. A 2010 survey of the American Society of Colon and Rectal Surgeons showed that 76% of participants always used MBP, while 19% used it selectively.³³ One potential benefit of MBP was highlighted in a retrospective analysis of 32,359 patients using the American College of Surgeons National Surgery Quality Improvement Program (NSQIP) database, in which patients were stratified as either receiving no bowel preparation, MBP, oral antibiotics alone, or both MBP *plus* oral antibiotics. They found that the use of MBP alone was not associated with any decreased risk of surgical site infection compared with no bowel preparation. However, they did find that both oral antibiotics and oral antibiotics *plus* MBP were associated with a decreased risk of surgical site infections.³⁴

While the use of MBP itself is controversial, the type of MBP used is also still under debate. The three categories of MBP include osmotic agents, stimulant laxatives, or a combination of both. While many MBP regimens exist, the most common preparations use either polyethylene glycol (PEG), an isosmotic agent, or sodium phosphate, a hyperosmotic agent. Theoretically, PEG, with an osmotically balanced electrolyte solution, minimizes significant fluid and electrolyte shifts. One downside of PEG is that for adequate bowel preparation, large volumes, approximately 4 L, of PEG need to be ingested. An RCT in young, healthy outpatients between PEG and sodium phosphate showed that patient satisfaction and acceptability were significantly higher in the sodium phosphate group.²⁸ Sodium phosphate requires significantly less volume ingested (8–16 ounces). However, sodium phosphate has been linked with acute phosphate nephropathy in certain patients, especially those with compromised renal function, inadequate hydration, and those on angiotensin-converting enzyme inhibitors or angiotensin receptor blockers.³⁵ In addition, it has been shown to cause electrolyte disturbances in elderly patients, and in patients with renal insufficiency and cardiovascular disease.³⁶ The American Society of Colon and Rectal Surgeons, Association of Gastrointestinal Endoscopy, and Society of American Gastrointestinal and Endoscopic Surgeons consensus guidelines on bowel preparation for colonoscopy currently recommend an individualized approach to MBP without significant evidence to support one regimen over the other except in specialized populations where sodium phosphate has proven to lead to adverse effects.³⁷

At this time, it is recommended that MBP, and any specific regimen used, should be employed in a patient-specific manner.

Intraoperative Fluid Management

The goal of intraoperative fluid management is to maintain end-organ perfusion with an adequate circulating volume. Hypovolemia can lead to an increased risk of organ hypoperfusion, sepsis, and multiorgan failure. Hypervolemia can be equally dangerous leading to peripheral and pulmonary edema as well as increasing incidence of postoperative ileus.³⁸ As such, maintaining euvolemia should be the goal for intraoperative fluid management.

There have been various fluid management strategies implemented to achieve this goal. Traditionally, large abdominal surgeries have been associated with significant dehydration from both preoperative fasting and bowel preparation, as well as intraoperative losses due to bleeding and third spacing. To account for these losses, patients undergoing these procedures often received intraoperative fluid in the range of 10 to 15 mL/kg. However, multiple randomized controlled studies have shown that greater perioperative fluid administration in major abdominal surgery has been associated with increased complication rates, prolonged duration of recovery, and increased hospital length of stay.^{38–43} These studies have resulted in a recommendation for a more “restrictive” approach to guide fluid management as compared with the traditional “liberal” approach. There is, however, a lack of uniformity in the amount of fluid that is defined as “restrictive” versus “liberal” in these trials. In an effort to further define these terms, a meta-analysis performed by Varadhan and Lobo defined a restricted fluid therapy as less than 1.75 L/day and a liberal fluid therapy as greater than 2.75 L/day. They also created another category, “balanced” fluid therapy, which they defined as fluid administration between 1.75 and 2.75 L/day. Either overly restrictive or overly liberal fluid regimens were labeled as “unbalanced.” Using these definitions, nine RCTs that each had different definitions of a restrictive or liberal fluid therapy were reclassified. They found that when fluid regimens were re-examined as those in a state of fluid “balance” versus “imbalance,” those in a state of fluid balance had 59% fewer complications and a 3- to 4-day reduction in hospital stay.⁴⁴ While this meta-analysis did not focus on fluid therapy within the ERAS pathway, it highlighted the necessity of an individualized and balanced approach to fluid management.

Within the context of ERAS pathways, there are currently two fluid management strategies under debate: GDFT and individualized zero-balance or “restrictive” fluid regimens.⁴⁵ These regimens are discussed in further detail in later sections.

Goal-Directed Fluid Therapy versus Zero-balance Fluid Regimen

Goal-directed fluid therapy is based on optimization of preload to achieve a certain goal in stroke volume, cardiac index, or oxygen delivery. GDFT was first introduced in the late 1980s in high-risk surgical patients using pulmonary artery catheter (PAC) to assess for optimization of global tissue oxygen delivery and oxygen consumption.⁴⁶ With technological advancement, minimally invasive monitors are now being used for GDFT using various technologies to produce clinically similar results to the PAC.⁴⁷ The use of transesophageal Doppler, for example, has been associated with decreased mortality and hospital stay. In major abdominal surgery, a systematic review showed that the use of transesophageal Doppler was associated with fewer complications, intensive care unit admissions, as well as a faster return of normal gastrointestinal function.⁴⁸

Initial studies evaluating the effectiveness of GDFT were not done in combination with ERAS protocols. A large meta-analysis recently assessed GDFT both in the setting of ERAS and without.⁴⁹ This analysis contained 23 RCTs, only 10 of which used GDFT with an ERAS protocol. They found that

when GDFT was used to guide fluid therapy in conjunction with ERAS, there was no reduction in morbidity, mortality, hospital length of stay, or postoperative ileus. However, they did find that in older studies when GDFT was used as compared with conventional fluid therapy, it was related to a 24% reduction in morbidity and decreased hospital length of stay of 1.55 days. One explanation for the lack of significant added benefit of GDFT to ERAS pathways is that a significant shift in fluid management has occurred over the last decade leading to an overall decrease in intraoperative fluid therapy.

A zero-balance fluid regimen, which has often been termed the “restrictive” fluid strategy, aims to minimize postoperative weight gain by maintaining intravascular normovolemia. This is accomplished with replacement of measured fluid losses without a replacement of loss to third spacing, and maintenance of appropriate hemodynamic variables with use of vasopressors.⁵⁰ While in the past GDFT likely led to significantly less fluid infused as compared with traditional fluid regimens, Phan et al compared GDFT to a restrictive fluid therapy and demonstrated that patients receiving esophageal Doppler-driven GDFT received a larger volume of intraoperative fluid as compared with the restrictive therapy group. They also noted no difference in complication rates or length of stay between the two groups.⁵⁰

Other studies have also compared GDFT with “restrictive” fluid strategies. A 2012 randomized, double-blinded, multicenter trial utilizing an ERAS protocol by Brandstrup et al included 150 patients undergoing colorectal resection that were randomized to either zero-balance or esophageal Doppler-guided GDFT.⁵¹ In the zero-balance group, patients were given a colloid maintenance infusion as well as colloid to replace lost blood, volume for volume. In the setting of hypotension that was not secondary to hypovolemia, vasopressors were used. In the Doppler group, colloid fluid therapy was guided by stroke volume. This study found no significant difference between the two groups in length of stay, need for vasopressors, or complications. A subsequent RCT studying 85 patients following an ERAS pathway found that patients who were randomized to receive either GDFT or zero-balance, “restrictive” fluid therapy had no difference in surgery recovery time, length of hospital stay, or complications.⁵²

Currently, there remains limited research examining the benefit of GDFT under ERAS protocols. Though transesophageal Doppler has been recommended under many ERAS guidelines, individualized patient selection continues to be important. One RCT compared the benefits of GDFT in aerobically fit versus aerobically unfit patients. Patients were defined as unfit if their oxygen consumption at the anaerobic threshold was less than 8.0 mL of oxygen/kg/min. Both fit and unfit patients were then randomized to receive either GDFT or standard fluid therapy. Standard fluid therapy was guided by the individual anesthetist, while the GDFT was guided by transesophageal Doppler and stroke volume optimization. Patients in both GDFT groups (fit and unfit) received significantly greater amounts of colloid in response to stroke volume optimization protocol, and made significantly greater amounts of urine. Results showed that in patients who were aerobically fit, there was actually a detrimental effect of GDFT, with

increased time to readiness for discharge in the GDFT group versus the control (7.0 vs. 4.7 days, $p = 0.01$) and longer length of stay (8.8 vs. 6 days, $p = 0.01$). There were no significant differences between time to readiness for discharge and length of hospital stay in the unfit group.⁵³ This study highlights that while there may still exist a subset of high-risk patients who would benefit from GDFT within ERAS, further studies need to be conducted to identify this group.

Monitoring in Goal-Directed Fluid Therapy

The first device used to guide goal-directed fluid management was the PAC.⁴⁶ As technology has advanced, less invasive monitors have become available utilizing a variety of technologies, including esophageal Doppler, arterial pressure waveform analysis, electrical bioimpedance analysis, and photoplethysmography. While many of these technologies have not been utilized in studies directly measuring the impact of fluid management within ERAS protocols, they represent advancements that may allow GDFT to be used more frequently due to their less invasive nature.^{54,55}

Most studies involving GDFT within the context of ERAS have relied on transesophageal Doppler. The transesophageal Doppler makes use of the Doppler principle to measure the velocity of blood flow at the level of the descending aorta. This velocity is then used with nomogram data on the cross-sectional area of the aorta to calculate stroke volume and cardiac output.⁵⁶ One of the most commonly used devices (CardioQ; Deltex Medical, Chichester, UK) uses a nomogram based on patients' age, height, weight, and gender.^{54,55}

Several commercial devices have used arterial pressure waveform to provide continuous cardiac output measurement (FloTrac/Vigileo, Edwards Lifesciences, Irvine, CA; PiCCO, Pulsion Medical Systems, Munich, Germany; LiDCOrapid, LiDCO Group, plc., London, UK).^{57,58} These devices use technology that expands on observations by Erlanger and Hooker in 1904 that stroke volume and pulse pressure are directly proportional.⁵⁹ Using the arterial pressure waveform from an arterial line, these systems can provide information on cardiac output, stroke volume, stroke volume variation, and systemic vascular resistance.

Thoracic electrical bioimpedance systems are a form of noninvasive cardiac monitoring that applies a low-voltage, high-frequency current through the thorax using surface electrodes. Cardiac filling and ejection lead to oscillation in impedance to this applied current with stroke volume being proportional to the amplitude of oscillation. However, this technology is limited by intrathoracic fluid such as pleural effusion and interference from chest wall movement. In an effort to overcome these limitations, electrical bioimpedance cardiography was developed. This technology, currently available in the NICOM system (Cheetah Medical, Newton Center, MA), continues to use chest electrodes to emit an alternating current. However, as compared with bioimpedance which focused on changes in amplitude, bioimpedance technology uses changes in frequency for its cardiac output measurement.⁵⁸

Photoplethysmography has also been introduced as a technology for noninvasive cardiac output measurement. One of the newest devices is the ClearSight system (Edwards

Lifesciences, Irvine, CA) which uses a volume clamp technique with an inflatable finger cuff to provide information on stroke volume and cardiac output along with other hemodynamic parameters.⁶⁰

In the context of ERAS, esophageal Doppler continues to be the most supported by current evidence. However, the introduction of several newer and even less-invasive technologies may lead to further study of GDFT in the perioperative setting, and will hopefully lead to better evidence for which patients might most benefit from its use.

Fluid Type

Research focused solely on the benefits of various intraoperative fluid types in the context of ERAS is currently lacking. Most studies involving GDFT in ERAS protocols have used hydroxyethyl starch (HES) as the bolus fluid of choice. However, HES products have been found to increase the risk of acute kidney injury and renal replacement therapy in critically ill patients.^{61–63} Secondary to these findings, HES use was banned in critically ill patients by the European Medicines Agency in 2013 and a black box warning of increased kidney injury and death with use of HES was placed by the U.S. Food and Drug Administration (FDA).^{64,65}

Following these announcements, HES use has been questioned not only in the critically ill population but also perioperatively. One trial randomized patients undergoing colorectal surgery to receive either HES or crystalloid as the bolus fluid of choice in GDFT and found that there was no benefit in using HES over crystalloid.⁶⁶ A recent meta-analysis analyzed six RCTs that compared the use of colloids versus crystalloids in intraoperative GDFT in noncardiac surgery. This meta-analysis found that there was no difference in postoperative complications when using either crystalloids or colloids; however, GDFT with colloids was associated with a trend toward increased mortality.⁶⁷

Continued debate exists surrounding the appropriate fluid type in GDFT and ERAS protocols. Due to their ability to increase intravascular volume more reliably and for a longer period of time than crystalloids, colloids have earned a place in many ERAS pathways. However, without the availability of HES, the only colloid available in many institutions is albumin, and the cost-benefit ratio of using albumin versus crystalloid for intraoperative care is still unknown. Further study is needed to compare crystalloid versus albumin in the perioperative setting, and the effect on perioperative complications, morbidity, and mortality. In addition, newer starch solutions have been developed that may have the benefits of colloids with a reduced risk of harms attributed to previous generations of starch solutions, though this remains unclear.^{68,69}

Postoperative Considerations

Duration of NPO Status

Patients undergoing colorectal surgery should be offered early enteral feeding. Traditionally, patients were kept NPO for bowel rest to protect against an anastomotic leak and to prevent against PONV. However, early enteral feeding has been shown to be beneficial. Carr et al found that patients who were

provided enteral feeding did not have an increase in gut mucosal permeability that was noted in the control group.⁷⁰ El Nakeeb et al conducted a RCT which showed that early oral feeding was associated with faster passage time to flatus as well as stool in the early feeding group. They also found that hospital stay was significantly shorter in the early feeding group.⁷¹ A systematic review including 11 studies found that early feeding reduced the risk of infections of all forms (relative risk: 0.72).⁷²

Given that early enteral feeding leads to decreased gut edema and faster time to flatus and stool along with shorter hospital stays, early enteral feeding is currently recommended. In addition, patients are better able to preserve intravascular volume and maintain fluid balance when given control over fluid intake.

Maintenance Fluids

Research has shown that maintenance requirements for fluid range from 1.75 to 2.75 L/day.⁴⁴ However, in the past, patients undergoing major colorectal surgery received fluid administration far in excess of this goal. One randomized, controlled trial showed that a weight gain of 3 kg after elective colonic resection was associated with an increased complication rate and hospital stay as well as a delay in gastrointestinal recovery.⁴¹

Institutions have since adopted more restrictive fluid management strategies as part of ERAS protocols that eliminate use of maintenance fluids once adequate oral intake has commenced.^{73,74} One study of patients' fluid balance postoperatively under use of an ERAS protocol revealed no clinically significant fluid overload or electrolyte disturbances.⁷⁵ Careful monitoring of fluid status should be continued in the postoperative period to maintain fluid balance.

Conclusion

ERAS protocols are associated with improved outcomes. Fluid management is a cornerstone of ERAS management with important elements in the preoperative, intraoperative, and postoperative periods.

Patient care in these pathways should aim for a euvolemic state. In the preoperative setting, this involves minimizing fasting from clear liquids to 2 hours prior to the start of anesthesia, with ingestion of a carbohydrate-rich beverage. MBP with isoosmotic regimens can be provided in appropriate patient settings with attention to fluid balance. Intraoperative fluid management should aim for zero-balance with appropriate patient populations receiving further hemodynamic guidance with goal-directed fluid therapy. Patients should be encouraged to eat and drink soon after surgery with limited intravenous fluid therapy postoperatively.

Continued investigation is necessary to better identify those patient populations who are most affected by mechanical bowel preparation and those who will benefit most from goal-directed fluid therapy, as well as to identify which monitors might be most helpful and whether there is an optimal type of fluid for ERAS patients.

Conflict of Interest

None declared.

References

- 1 Gustafsson UO, Scott MJ, Schwenk W, et al; Enhanced Recovery After Surgery Society. Guidelines for perioperative care in elective colonic surgery: Enhanced Recovery After Surgery (ERAS®) Society recommendations. *Clin Nutr* 2012;31(06):783–800
- 2 Kehlet H. Multimodal approach to control postoperative pathophysiology and rehabilitation. *Br J Anaesth* 1997;78(05):606–617
- 3 Zhuang C-L, Ye X-Z, Zhang X-D, Chen B-C, Yu Z. Enhanced recovery after surgery programs versus traditional care for colorectal surgery: a meta-analysis of randomized controlled trials. *Dis Colon Rectum* 2013;56(05):667–678
- 4 Eskicioglu C, Forbes SS, Aarts M-A, Okrainec A, McLeod RS. Enhanced recovery after surgery (ERAS) programs for patients having colorectal surgery: a meta-analysis of randomized trials. *J Gastrointest Surg* 2009;13(12):2321–2329
- 5 Walter CJ, Collin J, Dumville JC, Drew PJ, Monson JR. Enhanced recovery in colorectal resections: a systematic review and meta-analysis. *Colorectal Dis* 2009;11(04):344–353
- 6 Adamina M, Kehlet H, Tomlinson GA, Senagore AJ, Delaney CP. Enhanced recovery pathways optimize health outcomes and resource utilization: a meta-analysis of randomized controlled trials in colorectal surgery. *Surgery* 2011;149(06):830–840
- 7 Varadhan KK, Neal KR, Dejong CH, Fearon KC, Ljungqvist O, Lobo DN. The enhanced recovery after surgery (ERAS) pathway for patients undergoing major elective open colorectal surgery: a meta-analysis of randomized controlled trials. *Clin Nutr* 2010;29(04):434–440
- 8 Ahmed J, Khan S, Lim M, Chandrasekaran TV, MacFie J. Enhanced recovery after surgery protocols - compliance and variations in practice during routine colorectal surgery. *Colorectal Dis* 2012;14(09):1045–1051
- 9 ERAS Compliance Group. The impact of enhanced recovery protocol compliance on elective colorectal cancer resection: results from an international registry. *Ann Surg* 2015;261(06):1153–1159
- 10 Gustafsson UO, Hausel J, Thorell A, Ljungqvist O, Soop M, Nygren J; Enhanced Recovery After Surgery Study Group. Adherence to the enhanced recovery after surgery protocol and outcomes after colorectal cancer surgery. *Arch Surg* 2011;146(05):571–577
- 11 Thiele RH, Raghunathan K, Brudney CS, et al; Perioperative Quality Initiative (POQI) I Workgroup. American Society for Enhanced Recovery (ASER) and Perioperative Quality Initiative (POQI) joint consensus statement on perioperative fluid management within an enhanced recovery pathway for colorectal surgery. *Perioper Med (Lond)* 2016;5:24
- 12 American Society of Anesthesiologists Committee. Practice guidelines for preoperative fasting and the use of pharmacologic agents to reduce the risk of pulmonary aspiration: application to healthy patients undergoing elective procedures: an updated report by the American Society of Anesthesiologists Committee on Standards and Practice Parameters. *Anesthesiology* 2011;114(03):495–511
- 13 Brady M, Kinn S, Stuart P. Preoperative fasting for adults to prevent perioperative complications. *Cochrane Database Syst Rev* 2003;(04):CD004423
- 14 Thorell A, Nygren J, Ljungqvist O. Insulin resistance: a marker of surgical stress. *Curr Opin Clin Nutr Metab Care* 1999;2(01):69–78
- 15 Keane PW, Murray PF. Intravenous fluids in minor surgery. Their effect on recovery from anaesthesia. *Anaesthesia* 1986;41(06):635–637
- 16 Holte K, Kehlet H. Compensatory fluid administration for preoperative dehydration—does it improve outcome? *Acta Anaesthesiol Scand* 2002;46(09):1089–1093
- 17 Sato H, Carvalho G, Sato T, Lattermann R, Matsukawa T, Schricker T. The association of preoperative glycemic control, intraoperative insulin sensitivity, and outcomes after cardiac surgery. *J Clin Endocrinol Metab* 2010;95(09):4338–4344
- 18 Ramos M, Khalpey Z, Lipsitz S, et al. Relationship of perioperative hyperglycemia and postoperative infections in patients who undergo general and vascular surgery. *Ann Surg* 2008;248(04):585–591
- 19 Ljungqvist O, Thorell A, Gutniak M, Häggmark T, Efendic S. Glucose infusion instead of preoperative fasting reduces postoperative insulin resistance. *J Am Coll Surg* 1994;178(04):329–336
- 20 Nygren JO, Thorell A, Soop M, et al. Perioperative insulin and glucose infusion maintains normal insulin sensitivity after surgery. *Am J Physiol* 1998;275(1, Pt 1):E140–E148
- 21 Fujikuni N, Tanabe K, Tokumoto N, et al. Enhanced recovery program is safe and improves postoperative insulin resistance in gastrectomy. *World J Gastrointest Surg* 2016;8(05):382–388
- 22 Smith MD, McCall J, Plank L, Herbison GP, Soop M, Nygren J. Preoperative carbohydrate treatment for enhancing recovery after elective surgery. *Cochrane Database Syst Rev* 2014;(08):CD009161
- 23 Awad S, Varadhan KK, Ljungqvist O, Lobo DN. A meta-analysis of randomised controlled trials on preoperative oral carbohydrate treatment in elective surgery. *Clin Nutr* 2013;32(01):34–44
- 24 Hausel J, Nygren J, Lagerkranser M, et al. A carbohydrate-rich drink reduces preoperative discomfort in elective surgery patients. *Anesth Analg* 2001;93(05):1344–1350
- 25 Yildiz H, Gunal SE, Yilmaz G, Yucel S. Oral carbohydrate supplementation reduces preoperative discomfort in laparoscopic cholecystectomy. *J Invest Surg* 2013;26(02):89–95
- 26 Dunphy JE. Preoperative preparation of the colon and other factors affecting anastomotic healing. *Cancer* 1971;28(01):181–182
- 27 Fa-Si-Oen PR, Verwaest C, Buitenweg J, et al. Effect of mechanical bowel preparation with polyethyleneglycol on bacterial contamination and wound infection in patients undergoing elective open colon surgery. *Clin Microbiol Infect* 2005;11(02):158–160
- 28 Jung B, Pahlman L, Nyström P-O, Nilsson E; Mechanical Bowel Preparation Study Group. Multicentre randomized clinical trial of mechanical bowel preparation in elective colonic resection. *Br J Surg* 2007;94(06):689–695
- 29 Contant CM, Hop WC, van't Sant HP, et al. Mechanical bowel preparation for elective colorectal surgery: a multicentre randomised trial. *Lancet* 2007;370(9605):2112–2117
- 30 Hu Y-J, Li K, Li L, et al. [Early outcomes of elective surgery for colon cancer with preoperative mechanical bowel preparation: a randomized clinical trial]. *Nan Fang Yi Ke Da Xue Xue Bao* 2017;37(01):13–17
- 31 Santos JC Jr, Batista J, Sirimarco MT, Guimarães AS, Levy CE. Prospective randomized trial of mechanical bowel preparation in patients undergoing elective colorectal surgery. *Br J Surg* 1994; 81(11):1673–1676
- 32 Junghans T, Neuss H, Strohauser M, et al. Hypovolemia after traditional preoperative care in patients undergoing colonic surgery is underrepresented in conventional hemodynamic monitoring. *Int J Colorectal Dis* 2006;21(07):693–697
- 33 Markell KW, Hunt BM, Charron PD, et al. Prophylaxis and management of wound infections after elective colorectal surgery: a survey of the American Society of Colon and Rectal Surgeons membership. *J Gastrointest Surg* 2010;14(07):1090–1098
- 34 Koller SE, Bauer KW, Egleston BL, et al. Comparative effectiveness and risks of bowel preparation before elective colorectal surgery. *Ann Surg* 2018;267(04):734–742
- 35 Markowitz GS, Stokes MB, Radhakrishnan J, D'Agati VD. Acute phosphate nephropathy following oral sodium phosphate bowel purgative: an underrecognized cause of chronic renal failure. *J Am Soc Nephrol* 2005;16(11):3389–3396
- 36 Curran MP, Plosker GL. Oral sodium phosphate solution: a review of its use as a colorectal cleanser. *Drugs* 2004;64(15):1697–1714
- 37 Wexner SD, Beck DE, Baron TH, et al. A consensus document on bowel preparation before colonoscopy: prepared by a task force from the American Society of Colon and Rectal Surgeons (ASCRS), the American Society for Gastrointestinal Endoscopy (ASGE), and the Society of American Gastrointestinal and Endoscopic Surgeons (SAGES). *Gastrointest Endosc* 2006;63(07): 894–890

- 38 Nisanevich V, Felsenstein I, Almog G, Weissman C, Einav S, Matot I. Effect of intraoperative fluid management on outcome after intraabdominal surgery. *Anesthesiology* 2005;103(01):25–32
- 39 Aga Z, Machina M, McCluskey SA. Greater intravenous fluid volumes are associated with prolonged recovery after colorectal surgery: a retrospective cohort study. *Br J Anaesth* 2016;116(06):804–810
- 40 González-Fajardo JA, Mengibar L, Brizuela JA, Castrodeza J, Vaquero-Puerta C. Effect of postoperative restrictive fluid therapy in the recovery of patients with abdominal vascular surgery. *Eur J Vasc Endovasc Surg* 2009;37(05):538–543
- 41 Lobo DN, Bostock KA, Neal KR, Perkins AC, Rowlands BJ, Allison SP. Effect of salt and water balance on recovery of gastrointestinal function after elective colonic resection: a randomised controlled trial. *Lancet* 2002;359(9320):1812–1818
- 42 Brandstrup B, Tønnesen H, Beier-Holgersen R, et al; Danish Study Group on Perioperative Fluid Therapy. Effects of intravenous fluid restriction on postoperative complications: comparison of two perioperative fluid regimens: a randomized assessor-blinded multicenter trial. *Ann Surg* 2003;238(05):641–648
- 43 McArdle GT, McAuley DF, McKinley A, Blair P, Hoper M, Harkin DW. Preliminary results of a prospective randomized trial of restrictive versus standard fluid regime in elective open abdominal aortic aneurysm repair. *Ann Surg* 2009;250(01):28–34
- 44 Varadhan KK, Lobo DN. A meta-analysis of randomised controlled trials of intravenous fluid therapy in major elective open abdominal surgery: getting the balance right. *Proc Nutr Soc* 2010;69(04):488–498
- 45 Rahbari NN, Zimmermann JB, Schmidt T, Koch M, Weigand MA, Weitz J. Meta-analysis of standard, restrictive and supplemental fluid administration in colorectal surgery. *Br J Surg* 2009;96(04):331–341
- 46 Shoemaker WC, Appel PL, Kram HB, Waxman K, Lee TS. Prospective trial of supranormal values of survivors as therapeutic goals in high-risk surgical patients. *Chest* 1988;94(06):1176–1186
- 47 Lees N, Hamilton M, Rhodes A. Clinical review: goal-directed therapy in high risk surgical patients. *Crit Care* 2009;13(05):231
- 48 Abbas SM, Hill AG. Systematic review of the literature for the use of oesophageal Doppler monitor for fluid replacement in major abdominal surgery. *Anaesthesia* 2008;63(01):44–51
- 49 Rollins KE, Lobo DN. Intraoperative goal-directed fluid therapy in elective major abdominal surgery: a meta-analysis of randomized controlled trials. *Ann Surg* 2016;263(03):465–476
- 50 Phan TD, D'Souza B, Rattray MJ, Johnston MJ, Cowie BS. A randomised controlled trial of fluid restriction compared to oesophageal Doppler-guided goal-directed fluid therapy in elective major colorectal surgery within an Enhanced Recovery After Surgery program. *Anaesth Intensive Care* 2014;42(06):752–760
- 51 Brandstrup B, Svendsen PE, Rasmussen M, et al. Which goal for fluid therapy during colorectal surgery is followed by the best outcome: near-maximal stroke volume or zero fluid balance? *Br J Anaesth* 2012;109(02):191–199
- 52 Srinivasa S, Taylor MHG, Singh PP, Yu T-C, Soop M, Hill AG. Randomized clinical trial of goal-directed fluid therapy within an enhanced recovery protocol for elective colectomy. *Br J Surg* 2013;100(01):66–74
- 53 Challand C, Struthers R, Sneyd JR, et al. Randomized controlled trial of intraoperative goal-directed fluid therapy in aerobically fit and unfit patients having major colorectal surgery. *Br J Anaesth* 2012;108(01):53–62
- 54 Renner J, Grünewald M, Bein B. Monitoring high-risk patients: minimally invasive and non-invasive possibilities. *Best Pract Res Clin Anaesthesiol* 2016;30(02):201–216
- 55 Meng L, Heerdt PM. Perioperative goal-directed haemodynamic therapy based on flow parameters: a concept in evolution. *Br J Anaesth* 2016;117(Suppl 3):iii3–iii17
- 56 Schober P, Loer SA, Schwarte LA. Perioperative hemodynamic monitoring with transesophageal Doppler technology. *Anesth Analg* 2009;109(02):340–353
- 57 Manecke GR. Edwards FloTrac sensor and Vigileo monitor: easy, accurate, reliable cardiac output assessment using the arterial pulse wave. *Expert Rev Med Devices* 2005;2(05):523–527
- 58 Sangkum L, Liu GL, Yu L, Yan H, Kaye AD, Liu H. Minimally invasive or noninvasive cardiac output measurement: an update. *J Anesth* 2016;30(03):461–480
- 59 Erlanger J, Hooker D. An experimental study of blood-pressure and of pulse-pressure in man. Baltimore, MD: Physiological Laboratory of the Johns Hopkins University; 1904
- 60 Thiele RH, Bartels K, Gan T-J. Inter-device differences in monitoring for goal-directed fluid therapy. *Can J Anaesth* 2015;62(02):169–181
- 61 Mutter TC, Ruth CA, Dart AB. Hydroxyethyl starch (HES) versus other fluid therapies: effects on kidney function. *Cochrane Database Syst Rev* 2013;(07):CD007594
- 62 Haase N, Perner A, Hennings LI, et al. Hydroxyethyl starch 130/0.38–0.45 versus crystalloid or albumin in patients with sepsis: systematic review with meta-analysis and trial sequential analysis. *BMJ* 2013;346:f839
- 63 Rochwerg B, Alhazzani W, Gibson A, et al; FISSH Group (Fluids in Sepsis and Septic Shock). Fluid type and the use of renal replacement therapy in sepsis: a systematic review and network meta-analysis. *Intensive Care Med* 2015;41(09):1561–1571
- 64 Safety Alerts for Human Medical Products > Hydroxyethyl Starch Solutions: FDA Safety Communication - Boxed Warning on Increased Mortality and Severe Renal Injury and Risk of Bleeding. Available at: <https://www.ema.europa.eu/en/medicines/human/referrals/hydroxyethyl-starch-solutions-infusion>. Accessed January 9, 2019
- 65 European Medicines Agency - Human medicines - Hydroxyethyl starch solutions for infusion. Available at: http://www.ema.europa.eu/ema/index.jsp?curl=pages/medicines/human/referrals/Hydroxyethyl_starch-containing_solutions/human_referral_prac_000012.jsp&mid=WC0b01ac05805c516f. Accessed April 9, 2017
- 66 Yates DR, Davies SJ, Milner HE, Wilson RJ. Crystalloid or colloid for goal-directed fluid therapy in colorectal surgery. *Br J Anaesth* 2014;112(02):281–289
- 67 Ripollés J, Espinosa Á, Casans R, et al. Colloids versus crystalloids in objective-guided fluid therapy, systematic review and meta-analysis. Too early or too late to draw conclusions. *Braz J Anesthesiol* 2015;65(04):281–291
- 68 Hartog CS, Kohl M, Reinhart K. A systematic review of third-generation hydroxyethyl starch (HES 130/0.4) in resuscitation: safety not adequately addressed. *Anesth Analg* 2011;112(03):635–645
- 69 Westphal M, James MF, Kozek-Langenecker S, Stocker R, Guidet B, Van Aken H. Hydroxyethyl starches: different products–different effects. *Anesthesiology* 2009;111(01):187–202
- 70 Carr CS, Ling KD, Boulos P, Singer M. Randomised trial of safety and efficacy of immediate postoperative enteral feeding in patients undergoing gastrointestinal resection. *BMJ* 1996;312(7035):869–871
- 71 El Nakeeb A, Fikry A, El Metwally T, et al. Early oral feeding in patients undergoing elective colonic anastomosis. *Int J Surg* 2009;7(03):206–209
- 72 Lewis SJ, Egger M, Sylvester PA, Thomas S. Early enteral feeding versus “nil by mouth” after gastrointestinal surgery: systematic review and meta-analysis of controlled trials. *BMJ* 2001;323(7316):773–776
- 73 Miller TE, Thacker JK, White WD, et al; Enhanced Recovery Study Group. Reduced length of hospital stay in colorectal surgery after implementation of an enhanced recovery protocol. *Anesth Analg* 2014;118(05):1052–1061
- 74 Thiele RH, Rea KM, Turrentine FE, et al. Standardization of care: impact of an enhanced recovery protocol on length of stay, complications, and direct costs after colorectal surgery. *J Am Coll Surg* 2015;220(04):430–443
- 75 Boersema GS, van der Laan L, Wijsman JH. A close look at postoperative fluid management and electrolyte disorders after gastrointestinal surgery in a teaching hospital where patients are treated according to the ERAS protocol. *Surg Today* 2014;44(11):2052–2057