

# Review Article

## Peri-operative fluid management to enhance recovery

R. Gupta<sup>1</sup> and T. J. Gan<sup>2</sup>

*1 Assistant Professor, 2 Professor and Chairman, Department of Anaesthesia, Stony Brook University School of Medicine, Stony Brook, New York, USA*

### Summary

‘Enhanced recovery after surgery’ protocols implement a series of peri-operative interventions intended to improve recovery after major operations, one aspect of which is fluid management. The pre-operative goal is to prepare a hydrated, euvolaemic patient by avoiding routine mechanical bowel preparation and by encouraging patients to drink clear liquids up to two hours before induction of anaesthesia. The intra-operative goal is to achieve a ‘zero’ fluid balance at the end of uncomplicated surgery: goal-directed fluid therapy is recommended for poorly prepared or sick patients or those undergoing more complex surgery. The postoperative goal is eating and drinking without intravenous fluid infusions. Postoperative oliguria should be expected and accepted, as urine output does not indicate overall fluid status.

*Correspondence to: T. J. Gan*

*Email: tong.gan@stonybrookmedicine.edu*

*Accepted: 5 October 2015*

### Introduction

Postoperative ‘fast-track’ programs evolved into ‘enhanced recovery after surgery’ pathways, which implement a series of pre-operative, intra-operative and postoperative interventions to enhance recovery after major operations. The goal is to minimise postoperative side-effects and to encourage patient activity. Peri-operative care is co-ordinated through evidence-based protocols, from the pre-operative clinic to the postoperative care team. The reliable delivery of evidence-based care is the mainstay of enhanced recovery.

An important aspect of peri-operative care is fluid management. Peri-operative fluid overload has been associated with increased morbidity [1], and its avoidance may improve outcomes after major elective gastrointestinal and thoracic surgery [2]. A multicentre Danish study showed that intra-operative fluid restriction, independent of the amount of fluid given before or after surgery, halved the rate of postoperative complications [3]. Litres of crystalloid administered on the

first postoperative day have been associated with postoperative ileus and delayed hospital discharge [4]. Hypoproteinaemia caused by crystalloid infusion may delay gastric emptying, small bowel transit and cause postoperative ileus [5–7]. Peri-operative fluid management deserves more scrutiny by anaesthetists, surgeons and other members of the healthcare team.

In this review, we evaluate the evidence for fluid management in patients undergoing surgery within an enhanced recovery pathway.

### Pre-operative fluid management

The patient should come to the operating room in a ‘fed’, euvolaemic state as this reduces the haemodynamic effects caused by the induction of anaesthesia, compared with a ‘starved’, hypovolaemic state [8]. Guidelines recommend the consumption of clear fluids up to two hours before anaesthesia [9]. A 12.5% maltodextrin carbohydrate drink is an alternative to water, 400 ml of which are emptied from the stomach

within 90 min of ingestion [10, 11]. Carbohydrate drinks decrease hunger, thirst, and anxiety [12] and reduce postoperative insulin resistance [13]. Although a single randomised controlled trial reported that hospital stay was unaffected by pre-operative carbohydrate drink [14], a recent multicentre analysis of observational data reported that pre-operative carbohydrate loading was independently associated with a reduced length of stay after colorectal resection [15].

Routine mechanical bowel preparation increases the incidence and severity of pre-operative dehydration, whereas its avoidance does not increase complications [14, 16]. Mechanical bowel preparation is unpleasant for the patient. It does not decrease mortality but might increase the rate of infection and sepsis secondary to spillage of liquefied bowel contents as opposed to solid stool, and might increase the rate of anastomotic leakage [17]. The disadvantages of mechanical bowel preparation may be ameliorated by oral antibiotics. A retrospective analysis of 8415 colorectal resections concluded that the addition of oral antibiotics to bowel preparation significantly reduced rates of surgical site infections from 12.0% to 6.5%,  $p < 0.001$ , and shortened median hospital stay from 5 to 4 days,  $p < 0.001$  [18]. The authors concluded that mechanical bowel preparation without oral antibiotics should be abandoned, but that preparation with antibiotics was better than no bowel preparation at all. There remains a lack of consensus about which patients should have mechanical bowel preparation [19].

## Intra-operative fluid management

Intra-operative fluid management should maintain the patient in a euvoletic state. Excessive fluid (colloid or crystalloid) should be avoided. Maintenance fluid infusion, in conjunction with small (200–250 ml) boluses of fluid, achieves this objective. In contrast to 'restrictive' fluid therapy, which implies deliberate hypovolaemia [20], the aim is 'zero-balance' fluid management, with the goals of avoiding fluid excess and maintaining pre-operative hydration and weight [21].

### *Maintenance fluid therapy*

Maintenance fluid should be administered to maintain a patient's pre-operative weight, by replacing losses from urine, sweat and other routes. Infusions of balanced

crystalloid should not exceed  $3 \text{ ml.kg}^{-1}.\text{h}^{-1}$ , as evaporative losses are typically only  $0.5\text{--}1.0 \text{ ml.kg}^{-1}.\text{h}^{-1}$  during major abdominal surgery, lower than originally thought. Replacement of 'third-space' loss, describing a non-functional compartment that can sequester a significant amount of fluid intra-operatively [22], is not supported by tracer studies [23]: fluid is either intravascular or interstitial [20, 23].

Excessive fluid administration can harm the patient significantly [3, 4]. Hypervolaemia increases intravascular hydrostatic pressure, damaging the endothelial glycocalyx that mediates vascular permeability, contributing to fluid retention in the interstitial space [24]. Oedema of the gut wall with resultant ileus is the most common manifestation of excessive fluid therapy after major bowel surgery. Excessive fluid administration in rats causes significant intestinal oedema after bowel resection, with a substantial decrease in the structural stability of the intestinal anastomosis [25]. In humans, a modest 3 kg fluid weight gain after elective colonic resection is associated with delayed recovery of gastrointestinal function, an increased rate of complications and a prolonged hospital stay [4].

### *Bolus fluid therapy*

Blood loss and fluid shifts must be accounted for and replaced as necessary. Signs or symptoms of intravascular hypovolaemia should be treated with a rapid infusion of fluid over 5–10 min [26]. Patients with haemodynamic instability are not necessarily volume-depleted and rapid infusion should only be administered when hypovolaemia is evident or likely. Even so, rapid infusion only improves haemodynamic stability in fewer than half of patients, and responders should not be assumed to be hypovolaemic [27]. Additional administration of vasopressors may help to determine the effect of reduced vascular tone in causing relative hypovolaemia.

Heart rate, blood pressure, urine output and central venous pressure are not reliable measures of volume status. Acute blood loss of up to 25% of the circulating volume, for example, is not associated with rapid or significant changes in heart rate and/or blood pressure, because splanchnic vasoconstriction maintains core perfusion [28]. Systematic review has concluded that central venous pressure does not accurately identify

which patients required fluid therapy, how much they require or whether routine monitoring of central venous pressure is of value in the operating room, emergency department or the intensive care unit [29]. Neurohormonal responses to surgical stress reduce urine output below  $0.5 \text{ ml.kg}^{-1}.\text{h}^{-1}$ , without indicating a need for fluid administration [30].

### **Goal-directed fluid therapy**

Goal-directed fluid therapy extrapolates fluid responsiveness from measurable haemodynamic changes, according to the Frank–Starling law in patients without myocardial disease [31]. Several meta-analyses of multiple studies have concluded that goal-directed fluid therapy reduces complications, such as nausea, postoperative hemodynamic instability and shortens hospital stays after major surgery by 25–50% [32, 33].

Fluid responsiveness can also be predicted without administration of a fluid bolus. A number of cardiovascular measurements vary during the ventilatory cycle, such as stroke volume, pulse pressure and systolic pressure, the amplitude of their variation indicating the degree of hypovolaemia. These are more sensitive for hypovolaemia than changes in heart rate and blood pressure, allowing for earlier therapeutic intervention [34, 35]. Variation in the stroke volume or pulse pressure of at least 13% predicts fluid responsiveness [31], although fairly constant R-R intervals [36], with constant intrathoracic pressure and tidal volumes above  $7 \text{ ml.kg}^{-1}$  [36] are needed for accurate interpretation. When lower tidal volumes are used, as is often the case in clinical practice, the predictive value of these dynamic indices substantially decreases [37]. These indices should not be used in isolation, but should be combined with other clinical measurements to determine the presence of hypovolaemia.

### **Goal-directed fluid therapy for enhanced recovery**

Goal-directed fluid therapy appears to be less effective in the context of an enhanced recovery protocol, probably because the patient is unlikely to be hypovolaemic at induction of anaesthesia. Goal-directed fluid therapy reduced the rate of gastrointestinal complications and the length of hospital stay (by two days) after major elective surgery among patients who did not follow an

enhanced recovery protocol [38]. In a similar study of fasted patients who were hypovolaemic on induction of anaesthesia, goal-directed fluid therapy also reduced hospital stay by two days, even though the amount of fluid infused intra-operatively was the same (approximately 3.7 l) as for patients who did not have fluid guided by oesophageal Doppler readings [39]. In this study, goal-directed therapy patients had a higher mean (SD) cardiac index at the end of surgery than controls:  $3.8 (1.3) \text{ l.min}^{-1}$  vs.  $3.2 (1.2) \text{ l.min}^{-1}$ ,  $p = 0.01$ . There were also fewer postoperative complications, 1/50 vs. 8/51,  $p = 0.043$ . Other studies of goal-directed fluid therapy as part of an enhanced recovery protocol after colorectal surgery, have involved less fluid administration (approximately 1.5 l) and have not found improvements in outcome [9, 28].

### **Postoperative fluid management**

Postoperative fluid management aims to maintain a euvolaemic state and continues to assess fluid responsiveness, particularly in high-risk patients [40]. Most patients are less able to excrete fluid and sodium postoperatively, which they retain [4].

Eating and drinking soon after gastrointestinal resection should be encouraged, as feeding is associated with a reduced risk of infection and a decreased length of stay, without an increase in the risk of anastomotic dehiscence [20]. Intravenous fluids should be discontinued and not restarted unless there is a clinical indication. Patients without ongoing fluid deficit or losses should drink at least 1.75 l water each day [41]. Normovolaemic patients made hypotensive by neuraxial anaesthesia should not be infused with fluid [14]. Instead, the dose of epidural local anaesthetic should be reduced, accompanied by vasopressor infusion. Postoperative oliguria should not trigger intravenous fluid infusion, as fluid retention is a normal neurohormonal response to stress.

### **Fluid choice**

Balanced crystalloid solutions, such as lactated Ringer's solution, are recommended for intra-operative infusion [42], whereas reduced salt solutions, such as dextrose saline, are preferred postoperatively [20]. Normal saline, as a crystalloid or as part of a colloid should be avoided, because hyperchloraemic acidosis has been associated with reduced gastric blood flow, a decrease

in gastric intramucosal pH, a reduction in renal blood flow velocity and reduced renal cortical tissue perfusion [43–47], although it may be beneficial in upper gastrointestinal surgery to correct hypochloraemic metabolic alkalosis [20].

There is no consensus on whether to use crystalloid or colloid for goal-directed fluid boluses. In principle, colloids are believed to restore blood pressure, and therefore organ perfusion, faster than crystalloids [20]. Patients given crystalloid boluses usually receive higher cumulative volumes than patients given colloid boluses, but without affecting outcome [47]. Colloids may be preferable to crystalloid [20], but increase the risk of bleeding, especially when larger volumes of older types of hydroxyethyl starch are used [39, 48], compared with newer starches [49, 50].

Starches increase renal injury rates in the critically ill, although this problem has not been shown for scheduled surgery [51, 52]. In June 2013, the United States Food and Drug Administration recommended that hydroxyethyl starch should not be used in patients with pre-existing renal dysfunction. It also recommended monitoring renal function for at least 90 days after hydroxyethyl starch had been given and to discontinue it at the first sign of renal injury or coagulopathy [53]. These recommendations were based on the Crystalloid versus Hydroxyethyl Starch 'CHEST' trial and the Scandinavian Starch for Severe Sepsis '6S' trial, which reported relative risks (95% CI) of 1.21 (1.00–1.45) and 1.35 (1.01–1.80), respectively, for renal replacement therapy after starch infusion [49, 50].

It is unclear whether results on starch use from critically ill populations apply to scheduled peri-operative care. Hydroxyethyl starch 6% has been found to be nephrotoxic after orthotopic liver transplantation [54], but not after prostatectomy [55], although this may be explained by transplant patients being more susceptible to renal damage caused by starch.

## Common clinical challenges

### *Fluid management in laparoscopic surgery*

The limited fluid shifts that accompany simple laparoscopic procedures can be readily tolerated by healthy prepared patients without the need for goal-directed therapy. Fluid administration during more complex laparoscopic procedures in sicker patients may benefit

from goal-directed therapy. However, pneumoperitoneum and head-down positions make goal-directed fluid therapy indices difficult to interpret. Increased intra-abdominal pressure decreases ventilatory compliance, which increases the ventilatory pressure required to deliver a given tidal volume [56], in turn increasing the variation in haemodynamic indices during volume-controlled ventilation without the blood volume changing [57, 58]. For instance, Høiseth et al. reported the variation in pulse pressure that determined fluid responsiveness was 20.5% with an intra-abdominal pressure of 26 mmHg, but was 11.5% with an intra-abdominal pressure of 7 mmHg [58], and found that the correlation between stroke volume variation and fluid responsiveness only existed below an intra-abdominal pressure of 25 mmHg, in contrast to a study by Kambhampati et al. which did not find a pressure threshold for correlation [59].

### *Peri-operative urine output*

Traditionally, intra-operative urine output has been assumed to correlate with intravascular volume, with oliguria predicting postoperative renal failure. Postoperative acute renal failure is commonly attributed to pre-renal acute tubular necrosis, treated by maintaining renal blood flow with intravenous infusions of fluid and vasoconstrictors. However, an observational study of over 65 000 patients undergoing non-cardiac surgery suggest these assumptions are wrong, finding no significant correlation between the prevalence of postoperative acute renal failure and intra-operative urine output less than  $0.5 \text{ ml.kg}^{-1}.\text{h}^{-1}$ , regardless of the pre-operative risk of developing acute renal failure. In addition, a positive postoperative fluid balance is associated with increased risks of acute kidney injury and gastrointestinal dysfunction [59]. These suggest that within an enhanced recovery protocol, oliguria should be anticipated and permitted, without detrimentally affecting outcome.

## Conclusion

Enhanced recovery protocols are associated with improved outcomes and reduced volumes of intravenous peri-operative fluid. Emphasis on the detrimental effects of hypovolaemia, which accompanied traditional patient preparation, has been replaced by

concern about the harmful effects of hypervolaemia and hyperchloraemia. Excess fluid administration causes oedema and postoperative ileus. Patients should be anaesthetised in the euvoelaemic 'fed' state and should be given intra-operative fluids according to protocol to decrease the risk of complications and to hasten recovery. Intra-operative goal-directed fluid protocols have decreased postoperative complications and hospital length of stay, particularly following induction of anaesthesia in hypovolaemic, starved patients, but have yet to demonstrate similar benefits in enhanced recovery studies, sicker patients having complex surgery excepted. Patients should receive individualised fluid management plans that take into account their co-morbidities and operative complexity. A zero-balance fluid approach should be employed, using balanced salt crystalloid solutions rather than 0.9% saline for fluid maintenance. Eating and drinking should be encouraged postoperatively and oliguria should be accepted.

## Competing interest

No external funding or competing interests declared.

## References

- Lowell JA, Schifferdecker C, Driscoll DF, Benotti PN, Bistran BR. Postoperative fluid overload: not a benign problem. *Critical Care Medicine* 1990; **18**: 728–33.
- Slinger PD. Perioperative fluid management for thoracic surgery: the puzzle of postpneumonectomy pulmonary edema. *Journal of Cardiothoracic and Vascular Anesthesia* 1995; **9**: 442–51.
- Brandstrup B, Tønnesen H, Beier-Holgersen R, et al. Effects of intravenous fluid restriction on postoperative complications: comparison of two perioperative fluid regimens: a randomized assessor-blinded multicenter trial. *Annals of Surgery* 2003; **238**: 641–8.
- 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**: 1812–8.
- Woods MS, Kelley H. Oncotic pressure, albumin and ileus: the effect of albumin replacement on postoperative ileus. *American Journal of Surgery* 1993; **59**: 758–63.
- Nisanevich V, Felsenstein I, Almogy G, Weissman C, Einav S, Matot I. Effect of intraoperative fluid management on outcome after intraabdominal surgery. *Anesthesiology* 2005; **103**: 25–32.
- Durr ED, Hunt DR, Roughneen PT, Andrassy RJ, Rowlands BJ. Hypoalbuminemia and gastrointestinal intolerance to enteral feeding in head injured patients. *Gastroenterology* 1986; **90**: 1401.
- Srinivasa S, Taylor MH, Singh PP, Yu TC, Soop M, Hill AG. Randomized clinical trial of goal-directed fluid therapy within an enhanced recovery protocol for elective colectomy. *British Journal of Surgery* 2013; **100**: 66–74.
- 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: a report by the American Society of Anesthesiologist Task Force on Preoperative Fasting. *Anesthesiology* 1999; **90**: 896–905.
- Nygren J, Thorell A, Jacobsson H, et al. Preoperative gastric emptying. Effects of anxiety and oral carbohydrate administration. *Annals of Surgery* 1995; **222**: 728–34.
- Lobo DN, Hendry PO, Rodrigues G, et al. Gastric emptying of three liquid oral preoperative metabolic preconditioning regimens measured by magnetic resonance imaging in healthy adult volunteers: a randomised double-blind, crossover study. *Clinical Nutrition* 2009; **28**: 636–41.
- Hausel J, Nygren J, Lagerkranser M, et al. A carbohydrate-rich drink reduces preoperative discomfort in elective surgery patients. *Anesthesia and Analgesia* 2001; **93**: 1344–50.
- Nygren J, Soop M, Thorell A, Efendic S, Nair KS, Ljungqvist O. Preoperative oral carbohydrate administration reduces postoperative insulin resistance. *Clinical Nutrition* 1998; **17**: 65–71.
- Holte K, Nielsen KG, Madsen JL, Kehlet H. Physiologic effects of bowel preparation. *Diseases of the Colon and Rectum* 2004; **47**: 1397–402.
- ERAS Compliance Group. The impact of enhanced recovery protocol compliance on elective colorectal cancer resection: results from an international registry. *Annals of Surgery* 2015; **261**: 1153–9.
- Jung B, Lannerstad O, Pahlman L, Arodell M, Unosson M, Nilsson E. Preoperative mechanical preparation of the colon: the patient's experience. *BMC Surgery* 2007; **7**: 5.
- Jung B, Pahlman L, Nyström PO, Nilsson E; Mechanical Bowel Preparation Study Group. Multicentre randomized clinical trial of mechanical bowel preparation in elective colonic resection. *British Journal of Surgery* 2007; **94**: 689–95.
- Morris MS, Graham LA, Chu DI, Cannon JA, Hawn MT. Oral antibiotic bowel preparation significantly reduces surgical site infection rates and readmission rates in elective colorectal surgery. *Annals of Surgery* 2015; **261**: 1034–40.
- Gustafsson UO, Scott MJ, Schwenk W, et al. Guidelines for perioperative care in elective colonic surgery: Enhanced Recovery After Surgery (ERAS(R)) Society recommendations. *Clinical Nutrition* 2012; **31**: 783–800.
- Miller TE, Roche AM, Mythen M. Fluid management and goal-directed therapy as an adjunct to Enhanced Recovery After Surgery (ERAS). *Canadian Journal of Anesthesia* 2015; **62**: 158–68.
- 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? *British Journal of Anaesthesia* 2012; **109**: 191–9.
- Shires T, Williams J, Brown F. Acute change in extracellular fluids associated with major surgical procedures. *Annals of Surgery* 1961; **154**: 803–10.
- Jacob M, Chappell D, Rehm M. The 'third space' – fact or fiction? *Best Practice and Research. Clinical Anaesthesiology* 2009; **23**: 145–57.
- Chappell D, Jacob M, Hofmann-Kiefer K, Conzen P, Rehm M. A rational approach to perioperative fluid management. *Anesthesiology* 2008; **109**: 723–40.
- Marjanovic G, Villain C, Juettner E, et al. Impact of different crystalloid volume regimens on intestinal anastomotic stability. *Annals of Surgery* 2009; **249**: 181–5.

26. Cecconi M, Parsons AK, Rhodes A. What is a fluid challenge? *Current Opinion in Critical Care* 2011; **17**: 290–5.
27. Marik PE, Lemson J. Fluid responsiveness: an evolution of our understanding. *British Journal of Anaesthesia* 2014; **112**: 617–20.
28. Hamilton-Davies C, Mythen MG, Salmon JB, Jacobson D, Shukla A, Webb AR. Comparison of commonly used clinical indicators of hypovolaemia with gastrointestinal tonometry. *Intensive Care Medicine* 1997; **23**: 276–81.
29. Marik PE, Baram M, Vahid B. Does central venous pressure predict fluid responsiveness? A systematic review of the literature and the tale of seven mares. *Chest* 2008; **134**: 172–8.
30. Kheterpal S, Tremper KK, Englesbe MJ, et al. Predictors of postoperative acute renal failure after noncardiac surgery in patients with previously normal renal function. *Anesthesiology* 2007; **107**: 892–902.
31. Cannesson M, Le Manach Y, Hofer CK, et al. Assessing the diagnostic accuracy of pulse pressure variations for the prediction of fluid responsiveness: a “gray zone” approach. *Anesthesiology* 2011; **115**: 231–41.
32. Miller TE, Roche AM, Gan TJ. Poor adoption of hemodynamic optimization during surgery are we practicing substandard care? *Anesthesia and Analgesia* 2011; **112**: 1274–6.
33. Roche AM, Miller TE, Gan TJ. Goal-directed fluid management with trans-oesophageal Doppler. *Best Practice and Research. Clinical Anaesthesiology* 2009; **23**: 327–34.
34. Benes J, Chytra I, Altmann P, et al. Intraoperative fluid optimization using stroke volume variation in high risk surgical patients: results of prospective randomized study. *Critical Care* 2010; **14**: R118.
35. Kungys G, Rose DD, Fleming NW. Stroke volume variation during acute normovolemic hemodilution. *Anesthesia and Analgesia* 2009; **109**: 1823–30.
36. Perel A, Habicher M, Sander M. Bench-to-bedside review: functional hemodynamics during surgery – should it be used for all high-risk cases? *Critical Care* 2013; **17**: 203.
37. Lansdorp B, Lemson J, van Putten MJ, de Keijzer A, van der Hoeven JG, Pickkers P. Dynamic indices do not predict volume responsiveness in routine clinical practice. *British Journal of Anaesthesia* 2012; **108**: 395–401.
38. Gan TJ, Soppitt A, Maroof M, et al. Goal-directed intraoperative fluid administration reduces length of hospital stay after major surgery. *Anesthesiology* 2002; **97**: 820–6.
39. Van Der Linden P, James M, Mythen M, Weiskopf RB. Safety of modern starches used during surgery. *Anesthesia and Analgesia* 2013; **116**: 35–48.
40. 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. *Proceedings of the Nutrition Society* 2010; **69**: 488–98.
41. Wilkes NJ, Woolf R, Mutch M, et al. The effects of balanced versus saline-based hetastarch and crystalloid solutions on acid-base and electrolyte status and gastric mucosal perfusion in elderly surgical patients. *Anesthesia and Analgesia* 2001; **93**: 811–6.
42. Soni N. British Consensus Guidelines on Intravenous Fluid Therapy for Adult Surgical Patients (GIFTASUP): Cassandra’s view. *Anaesthesia* 2009; **64**: 235–8.
43. Scheingraber S, Rehm M, Sehmisch C, Finsterer U. Rapid saline infusion produces hyperchloremic acidosis in patients undergoing gynecologic surgery. *Anesthesiology* 1999; **90**: 1265–70.
44. Vogt NH, Bothner U, Lerch G, Lindner KH, Georgieff M. Large-dose administration of 6% hydroxyethyl starch 200/0.5 total hip arthroplasty: plasma homeostasis, hemostasis, and renal function compared to use of 5% human albumin. *Anesthesia and Analgesia* 1996; **83**: 262–8.
45. Waters JH, Gottlieb A, Schoenwald P, Popovich MJ, Sprung J, Nelson DR. Normal saline versus lactated Ringer’s solution for intraoperative fluid management in patients undergoing abdominal aortic aneurysm repair: an outcome study. *Anesthesia and Analgesia* 2001; **93**: 817–22.
46. Yates DR, Davies SJ, Milner HE, Wilson RJ. Crystalloid or colloid for goal-directed fluid therapy in colorectal surgery. *British Journal of Anaesthesia* 2014; **112**: 281–9.
47. Base EM, Standl T, Lassnigg A, et al. Efficacy and safety of hydroxyethyl starch 6% 130/0.4 in a balanced electrolyte solution (Volulyte) during cardiac surgery. *Journal of Cardiothoracic and Vascular Anesthesiology* 2011; **25**: 407–14.
48. Martin C, Jacob M, Vicaut E, Guidet B, Van Aken H, Kurz A. Effect of waxy maize-derived hydroxyethyl starch 130/0.4 on renal function in surgical patients. *Anesthesiology* 2013; **118**: 387–94.
49. Myburgh JA, Finfer S, Bellomo R, et al. Hydroxyethyl starch or saline for fluid resuscitation in intensive care. *New England Journal of Medicine* 2012; **367**: 1901–11.
50. Perner A, Haase N, Guttormsen AB, et al. Hydroxyethyl starch 130/0.42 versus Ringer’s acetate in severe sepsis. *New England Journal of Medicine* 2012; **367**: 124–34.
51. Malbrain ML, De Laet I. Functional haemodynamics during intra-abdominal hypertension: what to use and what not use. *Acta Anaesthesiologica Scandinavica* 2008; **52**: 576–7.
52. Tavernier B, Robin E. Assessment of fluid responsiveness during increased intra-abdominal pressure: keep the indices, but change the thresholds. *Critical Care* 2011; **15**: 134.
53. Raghunathan K, Miller TE, Shaw AD. Intravenous starches: is suspension the best solution? *Anesthesia and Analgesia* 2014; **119**: 731–6.
54. Mukhtar A, Abouletouh F, Obayah G, et al. The safety of modern hydroxyethyl starch in living donor liver transplantation: a comparison with human albumin. *Anesthesia and Analgesia* 2009; **109**: 924–30.
55. Kancir AS, Johansen JK, Ekeloef NP, Pedersen EB. The effect of 6% hydroxyethyl starch 130/0.4 on renal function, arterial blood pressure, and vasoactive hormones during radical prostatectomy: a randomized controlled trial. *Anesthesia and Analgesia* 2015; **120**: 608–18.
56. Renner J, Gruenewald M, Quaden R, et al. Influence of increased intra-abdominal pressure on fluid responsiveness predicted by pulse pressure variation and stroke volume variation in a porcine model. *Critical Care Medicine* 2009; **37**: 650–8.
57. Guinot PG, de Broca B, Bernard E, Abou Arab O, Lorne E, Dupont H. Respiratory stroke volume variation assessed by oesophageal Doppler monitoring predicts fluid responsiveness during laparoscopy. *British Journal of Anaesthesia* 2014; **112**: 660–4.
58. Høiseth LØ, Hoff IE, Myre K, Landsverk SA, Kirkebøen KA. Dynamic variables of fluid responsiveness during pneumoperitoneum and laparoscopic surgery. *Acta Anaesthesiologica Scandinavica* 2012; **56**: 777–86.
59. Kambhampati G, Ross EA, Alsabbagh MM, et al. Perioperative fluid balance and acute kidney injury. *Clinical and Experimental Nephrology* 2012; **16**: 730–8.