Intravenous fluid and electrolyte administration in elective gastrointestinal surgery: mechanisms of excessive therapy

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ABSTRACT

INTRODUCTION While clinical guidelines stress the importance of the judicious perioperative intravenous fluid administration, data show that adherence to these protocols is poor. The reasons have not been identified. We therefore audited the magnitude and indications of fluid and electrolyte administration in a teaching hospital. We hypothesised that epidural analgesia is associated with excessive fluid therapy.

MATERIALS AND METHODS Intravenous fluid and electrolyte administration during the day of surgery and the subsequent 2 days in consecutive patients undergoing elective gastrointestinal surgery between November 2013 and May 2014 were retrospectively audited. Timing, volumes and indications were recorded.

RESULTS One hundred patients undergoing elective gastrointestinal resection were studied. Patients received 9030 ml $\pm$ 2860 ml (mean $\pm$ standard deviation) intravenous fluids containing a total of 1180 ml $\pm$ 420 mmol sodium and resulting in a cumulative fluid balance of +5120 ml $\pm$ 2510 ml; 44% $\pm$ 14% of total volumes were given in theatre. Nearly all fluid was given for maintenance, 100% (96–100%, interquartile range), with 17 patients only receiving replacement or resuscitation. Independent predictors of increased volumes included open surgery, upper gastrointestinal surgery, increased duration and epidural analgesia but not body weight. Postoperative fluid volume was the only independent predictor of postoperative complication grade ($P = 0.0044$).

CONCLUSIONS Despite published guidelines, perioperative fluid and electrolyte administration were excessive and were associated with postoperative morbidity. Substantial volumes were administered in theatre. Nearly all administration was for maintenance, yet patients received approximately five times the amount of sodium required. Epidural analgesia was an independent predictor of fluid volumes but body weight was not.

KEYWORDS

Epidural analgesia – IV fluid

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Introduction

Despite data from a series of randomised trials^{1,2,5} and subsequent clinical guidelines^{4,5} stressing the importance of judicious use of intravenous fluids and electrolyte therapy in hospitalised patients, perioperative fluid management continues to be a challenge in daily practice. Fluid overloading, in particular, has been shown to be associated with excess morbidity. Recent observational data demonstrate that significant fluid overloading remains prevalent in surgical patients, even in the setting of mature enhanced-recovery after surgery programmes.^{6,7}

The first step in addressing this issue is to identify the causes of this excessive perioperative fluid and electrolyte administration, yet few data have been published on which patients are affected or when and why excess intravenous

fluid and electrolytes are administered. There are several potential reasons for excessive perioperative fluid and electrolyte administration, including excess fluid infusion during surgery, inappropriately high maintenance provision after surgery, frequent administration of fluid boluses for oliguria or hypotension and additional fluid therapy to manage the haemodynamic consequences of epidural analgesia.

To clarify the mechanisms of excessive fluid and electrolyte therapy in the postoperative period, we audited fluid and electrolyte therapy during and after gastrointestinal surgery, and studied the settings in which fluid and electrolyte administration occurred beyond routine maintenance requirements. Specifically, we aimed to test the hypothesis that much of the excessive therapy related to the management of fluid and electrolyte requirements are after epidural analgesia.

Methods

This was a retrospective clinical audit carried out at a single site at Salford Royal NHS Foundation Trust, a University of Manchester Teaching Hospital.

Standards

The standards against which practice was compared were the current versions of National Institute of Health and Care Excellence (NICE) clinical guidance on intravenous fluid therapy in adults in hospital⁵ and the British multidisciplinary guidelines on intravenous fluid therapy for adult surgical patients,⁴ relevant sections of which are summarised in Table 1. The available standards provided recommendations mainly on postoperative fluid therapy, with little specific guidance on intraoperative fluid management.

Subjects

One hundred consecutive patients from October 2013 undergoing elective open or laparoscopic gastrointestinal surgery and admitted postoperatively for more than three days were studied. Exclusion criteria were incomplete fluid balance data during more than one time period (see below), perioperative parenteral nutrition, perioperative dialysis and reoperation within 48 hours.

Outcomes and definitions

Four distinct time periods were studied: the operation period started at the time when the first intravenous infusion began in the anaesthesia suite; postoperative day 0 (POD0) began once the patient was admitted to the ward or surgical high-dependency unit (SHDU) and ended at 7am on the morning after; POD1 and POD2 were the subsequent two days. The operation period therefore included a period of anaesthetic and surgical care, as well as time in the post-anaesthesia care unit.

Demographic data, preoperative weight and height and blood test results were recorded. Operations were classified according to their predominant anatomical site (oesophagus, stomach, small bowel, colon or rectum) and surgical approach where open and converted cases were classified as open and cases completed laparoscopically were classified as laparoscopic. The use of epidural analgesia (if functional for more than 24 hours) and goal-directed fluid therapy (by any method of monitoring) were recorded.

Intravenous fluids administered were classified either as continuous infusions or bolus infusions. One bolus was defined as any fluid given in a volume of 250 ml within a 60-minute period or less. The indication for each bolus was recorded as either isolated oliguria (without concomitant hypotension or blood loss) or other cause (hypotension or blood loss, whether or not this was associated with oliguria). An established definition of perioperative oliguria was used (hourly urine output below 0.5 ml/kg).⁸ Oral and enteral fluid administration, stoma output and additional losses including drain output and vomiting were also recorded. The administration of electrolytes, including any potassium administered, was calculated based on the nature of fluids administered. Electrolyte content in intravenous medication and blood products (where relevant) were assumed to correspond to those of 0.9% saline.

On POD2, the patient's weight was recorded (standing on ward scales), as were biochemical measurements of renal function (estimated glomerular filtration rate, eGFR, and plasma concentrations of creatinine). As postoperative weight was not available for most patients, the preoperative weight was used for the POD2 calculation of eGFR.

Patients were followed up for 30 days postoperatively or until the time of discharge, whichever was later. For each patient, the most serious complications within this period were recorded and graded using the Clavien–Dindo scale.⁹ The diagnoses of specific complications documented by the

Table 1 Key recommendations from the National Institute for Health and Care Excellence (NICE) and Guidelines on Intravenous Fluid Therapy for Adult Surgical Patients (GIFTASUP) used as standards in the present audit of perioperative fluid therapy.

Recommendations related to	NICE	GIFTASUP
Intraoperative fluid volumes	No specific advice.	Fluids should be given to achieve an optimal value of stroke volume.
Postoperative fluid provision route	The oral or enteral route should be used if feasible and safe.	A return to oral fluid administration should be achieved as soon as possible.
Postoperative fluid volumes	For maintenance, 25–30 ml/kg/day fluids should be given.	For maintenance, 1.5–2.5 l/day should be given.
Postoperative electrolyte provision	For maintenance, sodium 1 mmol/kg/day, potassium 1 mmol/kg/day and chloride 1 mmol/kg/day should be given. Additional fluids should only be given to compensate for existing deficit, abnormal losses or redistribution.	For maintenance, sodium 50–100 mmol/day, potassium 40–80 mmol/day should be given. Additional amounts should only be given to correct deficit or continuing losses.
Clinical monitoring of fluid therapy	Clinical examination, National Early Warning Score (NEWS), fluid balance charts and weight.	Clinical examination, fluid balance charts and regular weighing.

clinical teams were recorded. The following complications were considered potentially related to fluid overloading: postoperative wound infection, ileus, exacerbation of heart failure and oedema prompting administration of diuretics.

Statistical analysis

Data are reported as proportions, mean plus or minus standard deviation or median (interquartile range), as appropriate. The following were evaluated as proposed predictors of increased perioperative fluid administration: increased body weight, increased American Society of Anesthesiologists class, epidural analgesia, duration of surgery, open surgery, oesophageal or gastric surgery.

Putative predictors of fluid balance and complication grade were analysed by univariate regression and backwards stepwise linear and logistic multivariable regression analysis using the Akaike information criterion (JMP Version 10, SAS Institute Inc., Cary, NC, USA). Five putative predictors were entered in the multivariable analyses.

Table 2 Demographic and operative data for 100 patients undergoing elective gastrointestinal surgery.		
	Patients (n)	SD
Age (years)	60	± 14
ASA class:		
1	3	
2	61	
3	34	
4	2	
Weight (kg)	77.2	± 20.9
Body mass index (kg ⁻²)	26.4	± 6.1
Preoperative diagnosis of hypertension	31	
Duration of intraoperative period (hours)	6.4	± 2.6
Epidural analgesia working ≥ 24 hours after surgery	58	
Intraoperative goal-directed fluid therapy	42	
Surgical approach:		
Open	47	
Laparoscopic	53	
Type of surgery:		
Oesophagus	23	
Stomach	16	
Small bowel	11	
Colon	35	
Rectum	15	

Results

A total of 164 consecutive patients were operated on between November 2013 and May 2014. Sixty-four patients were excluded; 57 due to incomplete fluid balance data, 5 due to commencement of total parenteral nutrition within 48 hours, one due to perioperative dialysis and one due to the need for reoperation within 48 hours. Demographics and operative data are presented in Table 2. Thirty-nine patients underwent upper gastrointestinal and 61 lower gastrointestinal surgery. Clinical outcomes are presented in Table 3. Including all grades, 70 of the 100 (70%) patients studied had a complication, of whom 8 had a severe complication (grade IIIa or higher) and 1 died from a cardiac arrest shortly following a reoperation for small bowel obstruction on POD20; 34 patients suffered 40 complications potentially associated with excess fluid administration (Table 3). The median length of postoperative stay was 10.5 days (interquartile range 7–15 days).

Fluid administration

Over the study period of some three days, the total volume of intravenous fluids administered was 9030 ml ± 2860 ml (Figure 1a). Nearly 50% of this volume was administered during the operation period, lasting some 6 hours (Figure 1, Table 4). The mean infusion rate during the operation period was 607 ml/hour; during the first postoperative night it was 124 ml/hour and on POD1 and POD2 it was 85 ml/hour and 68 ml/hour, respectively.

Table 3 Thirty-day clinical outcomes of 100 patients undergoing elective gastrointestinal surgery.	
Complications	Patients (n)
Within 30 days	70
Most severe graded:	
I	10
II	51
IIIa	2
IIIb	1
IVa	5
IVb	0
V	1
Specific complications:	
Superficial surgical site infection	18
Ileus	18
Exacerbation of heart failure	2
Oedema prompting administration of diuretics	2
Pneumonia	5
Anastomotic dehiscence	0
Intraabdominal or pelvic abscess	2

As rates of fluid administration were frequently changed during the operation, it was not possible to classify fluids into continuous and bolus administration during this period. After surgery, nearly all intravenous fluids administered were given as continuous infusions, while minimal amounts of fluid boluses were given (Table 4); 44 patients received a total of 55 fluid boluses, 18 for apparently isolated oliguria and 37 for other indications.

Oral and enteral intake was modest following surgery, with a mean cumulative intake by the end of POD2 of 1850 ml (0–9390 ml) (Figure 1b); 94 patients received oral or enteral fluids during the study period.

Fluid balance

Urine output during operation was recorded in 72 patients, for whom cumulative urine output and cumulative net fluid balance for the three-day study period was calculated (Figures 2c and d). Urine output during operation was 848 ml $\pm$ 502 ml and during the entire study period of three days it totalled 5240 ml $\pm$ 1800 ml. The fluid balance was calculated for each day, including additional fluid losses such as vomitus and drain output. The cumulative fluid balance

for the operation period was +3340 ml $\pm$ 1450 ml and for the entire study period it was +5120 ml $\pm$ 2510 ml (Figure 1d). Body weight was recorded on the POD1 or POD2 in only seven patients (data not shown).

Electrolyte administration

The choice of intravenous fluids during and after surgery was heavily skewed towards isotonic fluids, with hypotonic crystalloids making up 3% of the intravenous fluid administered during the operation period, and 9% during the postoperative period. Negligible volumes of colloids and blood products were used during both periods (data not shown).

The cumulative administration of sodium during the study period of approximately 3 days was 1180 mmol $\pm$ 420 mmol; of chloride, 880 mmol $\pm$ 310 mmol, and of potassium, 46 mmol $\pm$ 20 mmol (Figure 2a-c).

Blood results of 93 patients were available preoperatively and on POD2. The average GFR did not change and was 78 $\pm$ 17 ml/minute/1.73m² before surgery and 80 $\pm$ 18 ml/minute/1.73m² after surgery (P = 0.99).

Table 4 Volumes and indications of intravenous fluid administration in 100 patients undergoing gastrointestinal surgery in the intraoperative and postoperative periods.

Fluids	Operation	Postoperative day		
		0	1	2
Mean duration (hours $\pm$ SD)	6.4 $\pm$ 2.6	12.0 $\pm$ 2.2	24	24
Total IV volume (ml $\pm$ SD)	3890 $\pm$ 1550	1490 $\pm$ 660	2030 $\pm$ 980	1620 $\pm$ 1110
Continuous infusion (ml $\pm$ SD)	n/a	1380 $\pm$ 570	1950 $\pm$ 940	1580 $\pm$ 1 080
Bolus infusion median (range):				
Isolated oliguria (ml)	n/a	0 (0–1000)	0 (0–500)	0 (0–410)
Other causes (ml)	n/a	0 (0–1500)	0 (0–1073)	0 (0–1000)

IV, intravenous; n/a, not available; SD, standard deviation.

Regression Analyses

The five independent variables most strongly associated with increasing intravenous fluid administration during the operation time period were increasing body weight, upper (compared with lower) gastrointestinal surgery, laparotomy (compared with laparoscopy), increasing duration of the operation period and epidural analgesia. On stepwise multivariable regression incorporating these five variables, laparotomy (adjusted difference +313 ml, $P = 0.0035$) and increasing duration (adjusted estimate 7 ml/minute, $P < 0.0001$) were independent predictors, while the other three factors were not.

In the postoperative period, the five variables most strongly associated with increasing fluid volumes were absence of preoperative diagnosis of hypertension, upper (compared with lower) gastrointestinal surgery, laparotomy (compared with laparoscopy), increasing duration of the operation period and epidural analgesia. Body weight was not associated with postoperative volumes. On multivariable analysis, absence of hypertension (adjusted difference +392 ml, $P = 0.047$), upper gastrointestinal surgery (adjusted difference +695 ml, $P = 0.0006$), laparotomy (adjusted difference +454 ml, $P = 0.022$) and epidural analgesia (adjusted difference +524 ml, $P = 0.013$) were independent predictors.

Multivariable logistic regression analysis was performed to identify independent predictors of highest 30-day complication grade (Clavien–Dindo grade). The only predictor identified was volume of postoperative fluid (adjusted estimate 0.0003/ml, $P = 0.0044$), while the other variables were not independently associated with this outcome. The amounts of sodium were not entered with volume due to multicollinearity between the two variables.

Discussion

The present study confirms recent observations suggesting that perioperative fluid and sodium administration well beyond maintenance requirements remains a significant clinical problem^{6,7} and, for the first time, examines when and why excess fluid and sodium are administered.

Compared with national clinical guidance,^{4,5} the mean volume administered on the day of surgery was 270% of recommended maintenance volumes. While recommended volumes were given on POD1 and POD2, most patients also received enteral fluids on these days. The net fluid balance by the end of POD2 was more than 5 litres positive. Warrillow *et al.*⁶ found that, despite knowledge of established clinical guidelines, fluid therapy followed a liberal approach. Similarly, Boeresma *et al.*⁷ found a cohort of enhanced recovery after surgery patients who should have received a restrictive regime were still prescribed more than the required volumes of fluids resulting in a positive balance. In the present study, increased perioperative fluid administration was independently associated with increased 30-day complication grades, consistent with randomised trials of liberal compared with restricted perioperative fluid therapy aiming for a state of zero balance.^{2,5,10,11}

The majority of excessive fluid administration occurred during the operative period. It is acknowledged that fluid requirements during anaesthesia and surgery may be different from normal maintenance requirements. While fluid losses to the so-called third space has been cast in doubt,¹² insensible losses and adverse effects of anaesthetic agents may increase fluid requirements.¹² The lack of clarity regarding optimal intraoperative fluid therapy is reflected both in the lack of specific information during this time period in available clinical guidance^{4,5} and in the finding that intraoperative fluid administration varies tenfold in 2015 audit data.¹⁵ Nevertheless, the present mean volumes of around 4 litres during the operative period lasting some 6 hours are likely to be well beyond any physiological requirements.

Nearly all fluids were administered as continuous maintenance infusions rather than boluses as required in response to oliguria or hypotension. The high maintenance fluid administration may explain why boluses were so rarely needed. While this secured a high urine output, this practice probably contributed to the fluid overloading recorded. In patients treated with smaller volumes of perioperative maintenance fluids, administration of fluid boluses in response to

oliguria may become a significant source of fluid overloading.¹⁴

Regression analyses reveal that body weight was not independently associated with intraoperative or postoperative fluid volumes, suggesting that regimes are not being individualised for each patient. Epidural analgesia was an

independent predictor of postoperative fluid administration. Given the low number of patients who received fluid resuscitation for oliguria or other reasons, including hypotension, the increased fluid administration in patients with epidural analgesia may reflect clinician choice to increase the rates of fluid maintenance in this group of patients.

In addition to the perioperative volume load, administered amounts of sodium, chloride and potassium were recorded. Maintenance requirements for these electrolytes are also well established (Table 1). Studies in perioperative physiology suggest that, if anything, requirements are reduced in surgical trauma, as renal reabsorption of sodium is increased and intracellular potassium is released from injured tissues. In the current study, 510% of normal sodium requirements and 380% of normal chloride requirements were administered during the study period. An audit of current practice by Walsh et al.¹⁵ showed that excessive sodium administration of 390 mmol/day (percentage of daily requirements), was associated with a clinically defined fluid overloaded state. The well-documented effects of chloride overload are also clear from studies comparing saline with balanced salt solutions (which have a substantially reduced chloride content); such studies indicate that chloride overload is associated with a decreased renal perfusion and higher rates of postoperative complications.^{16–18} In contrast, the administration of potassium during the three-day study period amounted to 20% of requirements. The inaccuracies in electrolyte provision as compared with current clinical standards are explained by the near exclusive use of isotonic fluids for all types of fluid infusion, including maintenance fluid infusion. For maintenance infusions, hypotonic fluids with added potassium are required to avoid such discrepancies.

The study also highlighted poor compliance with standards regarding monitoring of fluid therapy. Some 57 of 164 screened patient records (35%) had to be excluded due to incomplete fluid balance data; another 28 (17%) had no record of intraoperative urine output. Only seven patient records of the 100 patients studied contained a body weight the first or second day.

The present study has certain weaknesses. This audit was conducted on a modest population size of 100 patients over a period of 7 months at a single site, limiting the external validity of our findings. Secondly, while this was a very detailed audit based on hour-by-hour fluid balance data, this audit was retrospective and observational so there is the possibility that some volumes of administered fluids or excreted urine were not recorded. Finally, data on plasma concentrations of electrolytes were not recorded.

Conclusions

In conclusion, this study has confirmed findings of continued significant fluid overloading in the present era of greater awareness of the clinical risks associated with this practice, and illustrates this risk by showing that an increasing fluid load was an independent predictor of increasing severity of postoperative morbidity. For the first time, this study also examined when and why perioperative fluid

occurs. In the present setting, a large teaching hospital in England, significant water, sodium and chloride overloading was observed, in particular in the operating theatre and on the first postoperative night. Most fluids were given as continuous maintenance infusions rather than as frequent fluid boluses. Isotonic fluids rich in sodium and poor in potassium were used, including for fluid maintenance. The fluid volumes administered were not related to body weight and many patients had incomplete fluid balance data.

Quality improvement of intravenous fluid therapy would include standardised and weight-based infusion rates of a hypotonic fluid for maintenance purposes, reserving isotonic fluids for resuscitation and replacement purposes and consistent usage of vasopressor therapy when appropriate to decrease the reliance on high rates of volume administration during and after surgery. These strategies require an education programme of all involved staff and a follow-up prospective audit to assess effects of these changes.

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