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Variability in practice and factors predictive of total crystalloid administration during abdominal surgery: retrospective two-centre analysis

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Editor's key points

- Fluid management in abdominal surgery can affect perioperative outcome.
- A retrospective two-centre analysis evaluated fluid administration in relation to provider and procedure type.
- Large variability in crystalloid administration was observed both within and between anaesthesia providers.
- Further studies are necessary to determine effects on clinical outcome.

Background. Variation in clinical practice in the perioperative environment and intensive care unit is a major challenge facing modern medicine. The objective of the present study was to analyse intraoperative crystalloid administration practices at two academic medical centres in the USA.

Methods. We extracted clinical data from patients undergoing intra-abdominal procedures performed at UC Irvine (UCI) and Vanderbilt University (VU) Medical Centres. Limiting data to uncomplicated elective surgery with minimal blood loss, we quantified variability in fluid administration within individual providers, between providers, and between types of procedures using a corrected coefficient of variation (cCOV). Regression was performed using a general linear model to determine factors most predictive of fluid administration.

Results. For provider analysis and model building, 1327 UCI and 4585 VU patients were used. The average corrected crystalloid infusion rate across all providers at both institutions was 7.1 (SD 4.9) ml kg^{-1} h^{-1}, an overall cCOV of 70%. Individual providers ranged from 2.3 (SD 3.7) to 14 (SD 10) ml kg^{-1} h^{-1}. The final regression model strongly favoured personnel as predictors over other patient predictors.

Conclusions. Wide variability in crystalloid administration was observed both within and between individual anaesthesia providers, which might contribute to variability in surgical outcomes.

Keywords: fluid therapy; resuscitation; safety

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Variation in clinical practice in the perioperative environment and intensive care unit has been reported.[1 2] This is commonly defined today as 'variation in the utilization of health care services that cannot be explained by variation in patient illness or patient preferences'.[3] In 2001, the National Institutes of Health identified variance in health-care practices across different institutions and different providers as one of the challenges of modern medicine.[4 5] In 2010, the British National Health Service published the *Atlas of Variation in Healthcare*, which was discussed in a series of articles.[5–7]

This is considerable literature on perioperative fluid management in patients undergoing abdominal surgery,[8] and multiple studies have suggested that a restrictive perioperative crystalloid strategy improves outcome, reducing both morbidity and hospital length of stay.[5 9–13] Moreover, there is increasing evidence that intraoperative fluid administration has a definite effect on surgical patient outcomes (at least in moderate- to high-risk patients).[14] However, it is unclear what volume of crystalloid anaesthetists are administering during routine procedures and whether significant practice variability exists.

We analysed intraoperative crystalloid administration practices at two academic medical centres in the USA without departmental guidelines. We sought to determine whether patient, provider, surgeon, and operative factors were associated with crystalloid infusions rates or total volumes during the most common types of abdominal surgery. Additionally, we sought to quantify variability both within and between specific anaesthesia providers. We hypothesized that total crystalloid administered during abdominal surgery is consistent in the absence of explanatory patient or surgical factors.

Methods

In a two-centre retrospective analysis, we extracted clinical data from patients undergoing abdominal procedures performed at UC Irvine (UCI) and Vanderbilt University (VU), from January 2009 to December 2011 at UCI and from January 2009 to December 2012 at VU using Perioperative Information Management Systems (at UCI, SIS^{TM}, Surgical Information Systems, Alpharetta, GA, USA; and at VU, GasChart, Vanderbilt University Medical Center, Nashville, TN USA). Insitutional review board approval was obtained at VU, and the study was considered insitutional review board exempt at UCI. Neither institution had general departmental guidelines on fluid administration during these periods (i.e. goal-directed fluid therapy was not practiced, nor were there any departmental policies towards fluid administration in moderate- or high-risk surgery).

Patient selection

Patient inclusion and exclusion criteria are shown in Figure 1. After sorting by procedure description, all procedures performed in the specified time frames at both institutions were hand reviewed to exclude procedures that were substantially different from the simple type. For example, 'cholecystectomy with intraoperative cholangiogram' would be included in 'cholecystectomy', but 'hepatic segmentectomy, cholecystectomy' would not. Prostatectomies were specifically excluded

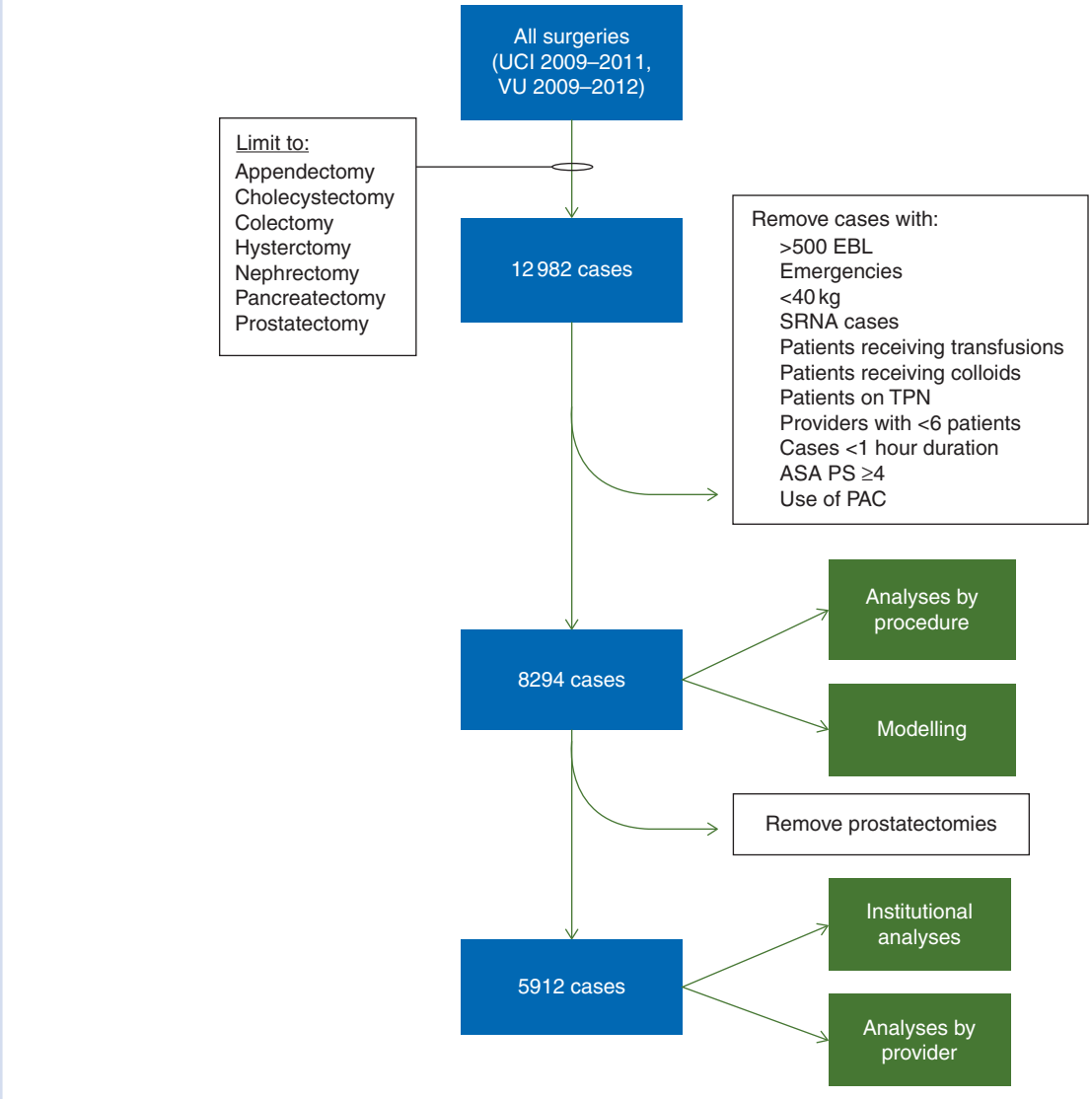

Fig 1 Flow chart of patient selection. Study protocol showing how patients were selected and limited to uncomplicated, low-blood-loss operations. Blue boxes are filtering steps and green boxes are analysis steps. ASA PS, American Society of Anesthesiologists Physical Status Classification; EBL, estimated blood loss; PAC, pulmonary artery catheter; SRNA, Student Registered Nurse Anesthetist (excluded because only one institution has SRNA's); UCI, University of California Irvine; VU, Vanderbilt University.

from the provider analysis at both institutions because of the specific resuscitation guidelines for those procedures at UCI, but were kept for the procedural analysis and modelling as a comparison group (Fig. 1).

In order to reduce baseline variance in procedures, criteria were developed to narrow the patient pool to uncomplicated surgical courses. Emergency procedures were excluded, and nephrectomy for living-donor and transplant procedures were excluded. Rectosigmoid procedures were included in colectomy procedures, but procedures using a transanal approach were excluded. Other exclusion factors are shown in Figure 1. Given that analysis of crystalloids was done on a millilitre per kilogram per hour basis, procedures of <60 min duration were excluded to reduce artificial bias from 'frontloading' of crystalloid during induction. Procedure duration was defined as anaesthesia start to anaesthesia end times. Procedures where a Student Registered Nurse Anesthetist provided care were excluded because only VU had Student Registered Nurse Anesthetists providing care during the study time frame. Procedures done under only spinal or epidural anaesthesia were excluded, though procedures where an epidural was placed for postoperative pain management only were retained. After the previously listed exclusion criteria were applied, we then excluded all procedures by providers or surgeons with fewer than six patients in the data set (Fig. 1).

Data collection

For each patient, we extracted the data shown in Table 1. In order to make comparisons across providers and procedure types, crystalloid administration was corrected using a neutral fluid balance approach.[9] Urine output and blood loss were accounted for using the following formula:

$$\text{Corrected crystalloid} = \text{crystalloid} - \text{estimated blood loss} - \text{urine output}$$

In order to adjust for procedure time and patient body weight, results are expressed as millilitres per kilogram per hour except for the modelling (see next subsection). For analysis, procedures were grouped both by in-room anaesthesia provider (in order to examine variability within and between specific providers) and by procedure type (to examine variability within and between procedures).

Modelling of fluid administration

Finally, after performing the analyses above, we sought to build a model using the variables in Table 1 to examine factors associated with crystalloid administration at each institution. As the model would include duration and patient weight as independent variables, the uncorrected (total) crystalloid administration was used as the dependent model variable. Total crystalloid administration is not normally distributed (only positive values are possible, and the distribution is positively skewed), so a generalized linear model using a γ distribution and log-link for response was used for modelling, which also allowed inclusion of both categorical and scalar independent variables. We first performed a whole model analysis for the entire data set that included only main effects of the patient features listed in Table 1. After running the initial model, plausible variable interactions were tested to account for multilevel effects (e.g. attending by in-room provider, procedure by university) using the corrected Akaike's information criterion[15] to guide model selection because this measure intrinsically penalizes more complicated models over more simple models, reducing over fitting. The final model was considered the 'best' set of predictors of fluid administration from the given data, and independent variables in the models were then characterized in terms of significance, exponentiated coefficients, and 95% confidence intervals (CIs).

Table 1 Variables assessed in the regression model

Patient factors
Age
ASA Class
Sex
Height
Median central venous pressure (if present)
Median haemoglobin
Median heart rate
Median mean arterial pressure
Median temparature
Minimal central venous pressure (if present)
Minimal haemoglobin
Minimal mean arterial pressure
Minimal temperature
Nothing *per os* time
Preoperative haemoglobin
Urine output
Weight
Personnel factors
Anaesthesia attending
Anaesthesia in-room provider
Anaesthesia in-room provider type (resident *vs* certified registered nurse anaesthetist)
Surgeon
Procedural factors
Arterial line used (yes/no)
Central venous line used (yes/no)
Duration (operating room-in to operating room-out)
Estimated blood loss
Epidural used (yes/no)
Laparoscopic (yes/no)
Surgery type
University
Interactions
Attending by in-room provider
Attending by procedure
Attending by surgeon
In-room provider by procedure
In-room provider by surgeon
University by procedure

Statistics

Statistical analysis was performed with SPSS 19 (IBM, Armonk, NY, USA) and Excel 2010 (Microsoft, Redmond, WA, USA). Data are presented as mean (SD) unless otherwise specified. Comparisons between groups or providers were made using Student's unpaired *t*-test (for two-way comparisons) and analysis of variance (ANOVA; for three or more comparisons). Confidence intervals are reported at the 95% level.

Variability in administration is expressed as a corrected coefficient of variation (cCOV). Coefficient of variation (COV) is defined as sample standard deviation divided by sample mean. The advantage of COV is that it is easily interpreted and puts the range of sample distribution in context of the mean.[16] Unfortunately, when making comparisons across samples with large relative differences in the mean, COV will by definition be larger for samples with smaller means even if the absolute range of the sample distribution is smaller. Thus, for the purposes of describing variability in administration within and between providers and procedure types, COV was used for its ease of interpretation, but instead of dividing by the mean of the specific sample in question, the mean of the entire study sample was used as the denominator. The corrected measure preserves ease of interpretation while making comparisons of variability between providers, procedures, and institutions more meaningful.

For clarity, 'attending' anaesthetist refers to the licensed anaesthesia provider supervising a patient, 'resident' refers to a physician anaesthetist trainee, 'CRNA' refers to a Certified Registered Nurse Anesthetist, 'in-room provider' refers to either a resident or a CRNA being supervised, and 'provider' in general refers to any of the above.

Results

Patient selection

After all inclusion and exclusion criteria were applied and after exclusion of prostatectomies, 1327 UCI and 4585 VU patients were obtained for provider analysis and model building. They were performed by 70 UCI (22 CRNAs and 48 residents) and 164 VU in-room providers (89 CRNAs and 75 residents). Each provider had an average of 17 (11) patients at UCI and 26 (20) patients at VU. The demographic data by institution is presented in Table 2.

Overall findings

Average corrected crystalloid infusion rate across all providers at both institutions was 7.1 (4.9) ml kg^{-1} h^{-1}, an overall cCOV of 70%. At UCI, the average rate was 6.7 (5.0) ml kg^{-1} h^{-1} and at VU the average rate was 8.2 (5.3) ml kg^{-1} h^{-1}, representing a cCOV of 70 and 74%, respectively, for the two institutions.

Table 2 Patient characteristics and procedural data. Data are presented as count (percentage of total) or median [25th,75th]

	Vanderbilt University		University of California Irvine	
ASA Class				
I	340	(5)	192	(12)
II	3610	(54)	1014	(64)
III	2754	(41)	384	(24)
Type of surgery				
Appendectomy	343	(5)	175	(11)
Cholecystectomy	929	(13)	281	(18)
Colectomy	891	(13)	142	(9)
Hysterectomy	1151	(17)	415	(26)
Nephrectomy	1063	(16)	158	(10)
Pancreatectomy	417	(6)	162	(10)
Prostatectomy	2119	(31)	257	(16)
Age (yrs)	55	[42,64]	51	[41,65]
Gender (male)	3392	(50)	802	(50)
Height (cm)	172	[164,180]	170	[163,179]
Weight (kg)	84	[71.2,97.6]	76.7	[64,90.7]
Duration of surgery (min)	168	[121,215]	225	[150,345]
Urine output (ml)	165	[0,400]	300	[155,500]
Estimated blood loss (ml)	100	[100,250]	75	[20,150]
Total crystalloid given (ml)	2000	[1500,2750]	2300	[1500,3200]
Corrected crystalloid (ml kg^{-1} h^{-1})	7.5	[5.2,10.6]	7.7	[4.6,12.1]
Epidural used (yes)	68	(1)	171	(11)
Arterial line used (yes)	1005	(15)	275	(17)
Central line used (yes)	138	(2)	112	(7)
Laparoscopic surgery (yes)	3209	(48)	715	(45)

The difference in administration rates between institutions was significant at $P<0.0005$ (95% CI 1.2–1.8). A scatter plot of fluid administration rates showing the duration of procedures is shown in Figure 2.

The overall administration rate in ASA Physical Status Classification I patients was 9.9 (6.2) ml kg^{-1} h^{-1}, with a cCOV of 87%, while ASA Physical Status Classification III patients received an average of 6.9 (4.7) ml kg^{-1} h^{-1}, with a cCOV of 66%. These means were significantly different with $P<0.0005$ (95% CI 2.6–3.5).

Provider variation

Individual providers at each institution exhibited a wide range of fluid administration patterns, both within individual providers across procedures and between providers. At UCI, the lowest provider mean corrected crystalloid volume was 2.3 (3.7) ml kg^{-1} h^{-1} (seven patients) and the highest was 11.8 (5.0) ml kg^{-1} h^{-1} (15 patients). At VU, the lowest provider mean corrected crystalloid volume was 2.9 (1.8) ml kg^{-1} h^{-1} (nine patients) and the highest was 14 (10) ml kg^{-1} h^{-1} (11 patients). The lowest cCOV within individual providers was 27% at UCI and 26% at VU, and the highest was 128% at UCI and 141% at VU. These volumes are not corrected for procedure mix or other procedural factors.

Procedural variation

When grouped by surgical procedure and including prostatectomies, 1590 UCI and 6704 VU patients were identified. The lowest mean corrected crystalloid volume among procedure types was for prostatectomy at both UCI and VU, which was 3.6 and 5.3 ml kg^{-1} h^{-1}, respectively. The highest average for each institution was for appendectomies: 10.4 ml kg^{-1} h^{-1} at UCI and 9.6 ml kg^{-1} h^{-1} at VU. The lowest cCOV for both institutions was seen in prostatectomies; at UCI this was 34% and at VU this was 40%. The highest cCOV at both institutions was seen in appendectomies; at UCI this was 97% and at VU this was 87%.The full data are shown graphically in Figure 3.

Modelling

The significant independent variables, exponentiated coefficients, and 95% confidence intervals resulting from the modelling process are shown in Table 3. There were no significant interactions (e.g. attending by in-room provider or similar) found in the modelling process that improved overall model fit according to corrected Akaike's information criterion compared with direct effects only. The exponentiated coefficient for each variable can be interpreted as the percentage change expected in total crystalloid administration for each unit change in the predictor variable, with the prediction corrected for all of the other elements. For example, from

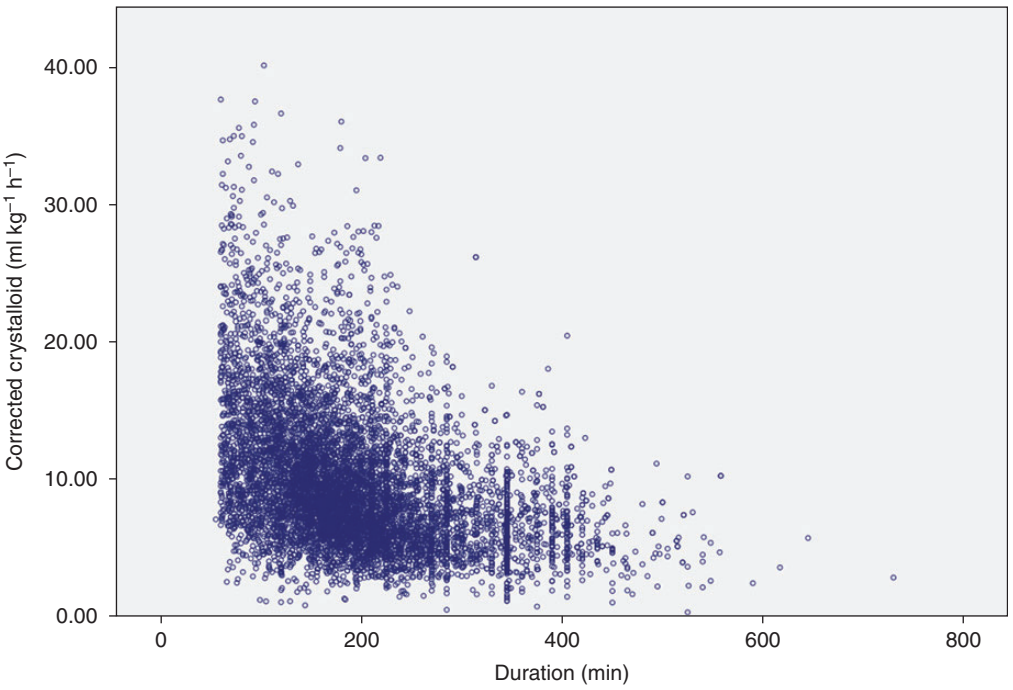

Fig 2 Scatterplot of surgery duration *vs* corrected crystalloid volume. The graph shows the wide distribution of corrected crystalloid administration rates across all uncomplicated procedures at both UCI and VU. Rates range from −5 to 40 ml kg^{-1} h^{-1}, with most between 5 and 15–20 ml kg^{-1} h^{-1}. Of note, this graph suggests that some degree of 'frontloading' is occurring (patients receive large volumes early in procedures, with tapering as procedures go on), but also demonstrates that this phenomenon is highly inconsistent, with many patients receiving no frontloading at all. Thus, frontloading is not a sufficient explanation of the variability obvious in the figure.

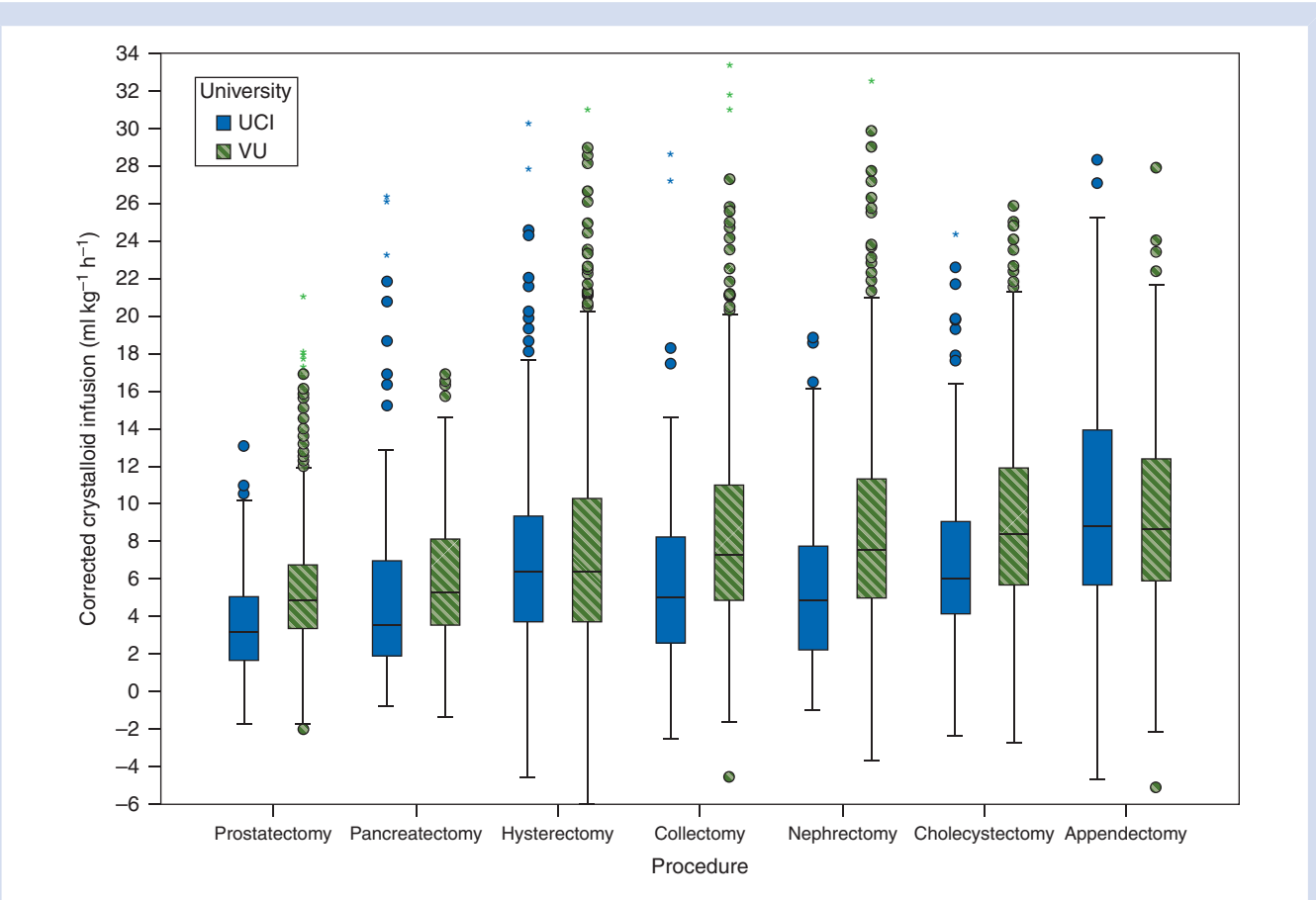

Fig 3 Fluid administration by surgical procedures. Corrected crystalloid infusion rates for procedures at both UCI and VU. Each boxplot is the median and range. For most procedures, about 50% of patients received between 4 and 10 ml kg^{-1} h^{-1} crystalloid; the other 50% obviously fell outside this wide range. Of note, UCI has a specific protocol for crystalloid administration during prostatectomies, and this group had the smallest range of any of the analysed procedures, suggesting that directed protocols can be effective in reducing variability.

Table 3 we see that heart rate has an exponentiated coefficient of 1.002 per beat min^{-1}, meaning that for each increase in heart rate of 10 beats min^{-1} a patient would be expected to receive $1.002^{10}=1.02$ times more fluid during a procedure.

Discussion

This two-centre retrospective observational study assessed crystalloid administration in routine abdominal procedures in the absence of departmental fluid administration guidelines, and found wide inter- and intraprovider variability in infusion volumes. This variability does not appear to be explained by patient or individual surgical factors, and could result from random fluctuations in practice from provider to provider and within providers from patient to patient. There has been a relative resurgence of research interest in fluid administration strategies in recent years, especially with outcome improvements shown by goal-directed protocols and more restrictive approaches to fluid administration.[9 17 18] While there are no definitive 'best practices' for any given surgical procedure or patient, and some amount of variation in administration will be explained by factors not captured in the present study, it is unlikely that both the ranges of 0–3 and 15–20 ml kg^{-1} h^{-1} of corrected crystalloid volume are ideal, but based on these data standard practice encompasses that range of administration and wider.

Administration between providers at both institutions has providers whose interquartile ranges for corrected crystalloid administration do not substantially overlap. It is certainly possible that these providers have different procedure distributions, even given the limited procedure types used in this analysis. However, in looking at the model for total crystalloid administration (Table 3), it is notable that the odds ratios for providers are very widely distributed, especially compared with patient and procedural factors such as duration and blood loss, which while significant have exponentiated coefficients very close to one. Based on these results the, majority of total crystalloid administration volume is predicted by personnel factors as opposed to patient or surgical factors.

Additionally, and independently of the absolute volumes, the range of corrected crystalloid infusions within individual providers is also fairly wide. While some providers were

Table 3 Crystalloid model parameters and significance. CRNA, certified registered nurse anesthetist; CVP, central venous pressure; Hb, haemoglobin; HR, heart rate; MAP, mean arterial pressure; VU, Vanderbilt University. *The exponentiated coefficient for each variable can be interpreted as the percentage change expected in total crystalloid administration for each unit change in the predictor variable, with the prediction having been corrected for all of the other elements in the model. Bold text *P*-values are those that are statistically significant

VU Model	Exponentiated coefficients* (if significant)	95% Confidence interval*	*P*-value
Personnel factors			
Anaesthesia attending			
Overall effect of anaesthetist			**0.000**
Most liberal attending	2.421	1.311–4.471	**0.005**
Most restrictive attending	0.699	0.456–0.9261	**0.016**
Anaesthesia in-room provider			
Overall effect of anaesthesia staff			**0.000**
Most liberal staff	1.906	1.235–2.942	**0.000**
Most restrictive staff	0.406	0.504–0.171	**0.000**
Staff type (CRNA *vs* resident)	1.126	1.103–1.149	**0.000**
Surgeon			
Overall effect of surgeon			**0.000**
Surgeon with most liberal care	–	0.997–2.053	0.052
Surgeon with most restrictive care	0.287	0.149–0.552	**0.000**
Patient factors			
Age (yrs)	0.999	0.998–1.000	**0.041**
ASA Class	–	0.970–1.040	0.317
CVP median (mm Hg)	–	1.000–1.082	0.052
CVP minimum (mm Hg)	–	0.995–1.003	0.637
Gender (female)	–	0.921–1.046	0.568
Height (kg)	1.001	1.000–1.002	**0.008**
Hb median (g dl^{-1})	–	0.960–1.010	0.288
Hb minimum (g dl^{-1})	–	0.979–1.009	0.464
Hb preoperative (g dl^{-1})	1.009	1.004–1.014	**0.000**
HR median (beats min^{-1})	1.002	1.001–1.002	**0.000**
MAP median (mm Hg)	0.998	0.998–0.999	**0.000**
MAP minimum (mm Hg)	0.999	0.998–0.999	**0.004**
Nothing *per os* time (h)	–	0.993–1.003	0.536
Temperature median (°C)	0.986	0.973–0.998	**0.024**
Temperature minimum (°C)	–	0.997–1.002	0.861
Urine output (ml)	1.000	1.000–1.000	**0.000**
Weight (kg)	1.001	1.000–1.001	**0.000**
Procedural factors			
Arterial line used (yes)	1.050	1.026–1.074	**0.000**
Central venous line used (yes)	–	0.933–1.033	0.483
Duration (min)	1.002	1.002–1.002	**0.000**
Epidural used (yes)	1.055	1.006–1.106	**0.027**
Estimated blood loss (ml)	1.000	1.000–1.000	**0.000**
Non-laparscopic	–	0.936–1.015	0.218
surgery type (compared with prostatectomy)			
Overall effect of surgery type			**0.000**
Appendectomy	–	0.966–1.06	0.562
Cholecystectomy	–	0.893–1.008	0.088
Colectomy	1.061	1.008–1.118	**0.025**
Hysterectomy	1.057	1.014–1.103	**0.010**
Nephrectomy	1.194	1.160–1.229	**0.000**
Pancreatectomy	1.194	1.124–1.269	**0.000**
University (VU)	–	0.806–2.452	0.231

consistent in their administration, with cCOV's <40%, probably a reasonable level given all the variances in procedures and patients, both institutions have providers with cCOV's >100% (interquartile ranges as wide as 15 ml kg^{-1} h^{-1}). For this range (assuming 0–15 ml kg^{-1} h^{-1} absolute volume), a patient weighing 75 kg who has a 4 h procedure with 400 ml blood loss and 1 ml kg^{-1} h^{-1} urine output will receive anything between 700 and 5400 ml of crystalloid. Some patients received as much as 20–30 ml kg^{-1} h^{-1}, representing 6.7–9.7 litres for the example patient. Ignoring absolute values of the volumes, if a provider is applying a consistent methodology for fluid administration, we should expect a narrower range of corrected volumes administered, especially as this data set was restricted to low-blood-loss, uncomplicated procedures that did not require colloids or blood products. The wide ranges seen indicate that most providers are in fact fairly inconsistent in their individual approaches. Moreover, as most intraoperative haemodynamic and patient variables were either non-significant in the model or had very weak effects, it is difficult to argue that the fluid differences result from haemodynamic differences during surgery.

In the total crystalloid model, the strongest effect types are those related to personnel (attending, in-room provider, and surgeon), while patient-specific factors or surgery-specific factors, such as blood loss, duration, ASA status, and haemodynamics, had very low strengths, even when significant. For example, the most liberal to most restrictive anesthesia attendings have effect sizes from 2.42 to 0.70, respectively (Table 3), indicating that a patient would receive on average four times more fluid from the liberal attending compared with the restrictive attending. The effect of blood loss, however, is <1.0005 per millilitre lost, meaning that even a 500 ml difference in blood loss between two patients would result in no more than a 1.2–1.3 factor difference in fluid administration. This suggests that crystalloid administration volume is a result of the persons giving the fluid as opposed to patient and procedural factors. Alternatively, if practice is indeed based on specific patient factors, there is so little consistency between providers in how haemodynamics and other patient and procedural variables are used to guide fluid management that these effects appear to be random elements in the model. Either way, it appears that there is a great deal of inconsistency in how these variables are managed in terms of fluid resuscitation.

Despite having eliminated procedures <60 min in duration, the argument could be made that there is a risk of bias from 'frontloading', in which shorter procedures appear to receive more volume because of the fluids typically given during the induction period and immediately thereafter. Moreover, there is a trend in the data towards higher infusion volumes (in millilitres per kilogram per hour) in short *vs* long procedures (Fig. 2), which supports this argument. This is an unsatisfactory explanation of the total variability, however. First, the existence of frontloading alone does not negate the existence of variability. In looking at Figure 2, while there is a decrease in total millilitres per kilogram per hour and in variability as procedures grow longer, it is also immediately apparent that there is a huge range of fluid volumes given to patients in procedures of virtually all durations, and in particular, procedures <300 min in duration (the majority) show the greatest variability. Moreover, while 'frontloading' seems readily accepted by many providers *a priori*, it is obvious from the data in Figure 2 that there is no consistency in the application of this practice.

Unwarranted variation in practice has been identified as a major driver of both waste and suboptimal outcomes in healthcare systems.[2 3 19–23] Part of the recent National Health Service reform focus has been reduction of unwarranted variation[24] in order to ensure equivalent care across hospitals and providers. The results of this retrospective analysis suggest that there is a high degree of unwarranted variation in the volume of intraoperative crystalloids. This might be especially relevant given the evolving literature on perioperative fluid administration. Moreover, fluid administration studies are made all the more complicated by the fact that administration (both volume and type) remains more or less ad-lib.

Even the most recent 'state-of-the-art' literature on the topic shows significant variability in the way that baseline crystalloid infusion is administered. For example, the study by Challand and colleagues[25] focusing on fluid management in major surgery used a baseline crystalloid infusion of 10 ml kg^{-1} h^{-1}, while the OPTIMIZE study by Pearse and colleagues[26] used a crystalloid administration of 1 ml kg^{-1} h^{-1}. Both studies were conducted in the UK and in similar surgeries but used dramatically different fluid regimens. Thus, the variability in practice observed in our study from practitioner to practitioner is also observed from study to study and probably from institution to institution.

Interestingly, prostatectomy patients at UCI do have a specific fluid administration protocol dictated by the surgeons that restricts fluids intraoperatively and then requires more liberal fluid administration after re-anastamosis of the urethra through the postoperative period. It might not be coincidence that this procedural subgroup had the lowest cCOV of any procedure (34%). This was reflected in the surgical comparisons (Fig. 3), where the UCI prostatectomies had the lowest corrected crystalloid infusion rate and the smallest range of variation among procedures at either institution. This suggests that specific protocols can be effective in clinical practice in reducing variation between providers. It is likely that implementation of guidelines such as crystalloid restriction and goal-directed therapy would help to standardize the way in which fluid is administered.

Limitations

First, we attempted to control for procedural and patient factors as best as possible, but it is still possible that one or more significant factors that might explain the observed variability was not taken into accounted. Second, some sources recommend replacement of blood lost at a ratio of 3:1 with crystalloid, whereas in the present study we used a 1:1 ratio for the corrected crystalloid calculation. The low coefficient for blood loss from the modelling, however (<1.0005), suggests that blood loss is weakly linked to crystalloid administration and that using a 3:1 model would not have changed

findings significantly. It is also possible that one or more combinations of variables were missed during model building that might have had more explanatory power than the resultant models in this study. Vasopressor use, for example, was not included but could have played a role in some anaesthetists' approaches to resuscitation. The types of crystalloid administered were not taken into account in the present study. In general, the vast majority of the fluid administration in the operating rooms is Ringer's lactate, normal saline, or Plasmalyte (Baxter healthcare, Australia). As specific solutions and respective volumes were not analysed, however, it is possible that there is some unrecognized contribution of these factors to our analysis. Finally, we did not link the variability observed in the present study to any postoperative outcomes. While this is of interest for future studies, we believe that the fact that such variability exists is in itself an important issue to tackle in order to improve quality of care.

Conclusion

Despite recommendations in the literature for fluid management in abdominal operations, we find a large patient-to-patient variability in fluid administration practices between and within anaesthesia providers and surgical procedures at both the University of California Irvine and Vanderbilt University Medical Center. The regression model analysis showed that the strongest predictor for corrected crystalloid infusion rate for a specific patient was the anaesthesia provider and surgeon. Further studies are needed to assess change in patient outcomes with implementation of specific fluid management protocols on a large scale.

Authors' contributions

M.L.: study design, data collection and analysis, and manuscript preparation. J.M.E.: data collection and manuscript preparation. C.L.: data collection and analysis, and manuscript preparation. B.H.: data collection and analysis. M.C.: study design, data analysis, and manuscript preparation. J.R.: study design, data analysis, and manuscript preparation.

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Declaration of interest

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References

1 Wijeysundera DN, Austin PC, Beattie WS, Hux JE, Laupacis A. Variation in the practice of preoperative medical consultation for major elective noncardiac surgery: a population-based study. *Anesthesiology* 2012; **116**: 25–34

2 Pravinkumar SE. Physician practice variation in critical care: a stumbling block. *Crit Care Med* 2009; **37**: 1178–9

3 Wennberg JE. Time to tackle unwarranted variations in practice. *Br Med J* 2011; **342**: d1513

4 Medicine IO. *Crossing the Quality Chasm: A New Health System for the 21st Century*. Washington, DC: National Academy of Sciences, ed., 2001

5 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

6 Westert GP, Faber M. Commentary: the Dutch approach to unwarranted medical practice variation. *Br Med J* 2011; **342**: d1429

7 QIPP/Right Care. *The NHS Atlas of Variation in Healthcare*, 2010. Available from http://www.rightcare.nhs.uk/index.php/atlas/atlas-of-variation-2010 (accessed 9 December 2014)

8 Corcoran T, Rhodes JE, Clarke S, Myles PS, Ho KM. Perioperative fluid management strategies in major surgery: a stratified meta-analysis. *Anesth Analg* 2012; **114**: 640–51

9 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**: 191–9

10 Joshi GP. Intraoperative fluid restriction improves outcome after major elective gastrointestinal surgery. *Anesth Analg* 2005; **101**: 601–5

11 Forget P, Lois F, de Kock M. Goal-directed fluid management based on the pulse oximeter-derived pleth variability index reduces lactate levels and improves fluid management. *Anesth Analg* 2010; **111**: 910–4

12 Chappell D, Jacob M, Hofmann-Kiefer K, Conzen P, Rehm M. A rational approach to perioperative fluid management. *Anesthesiology* 2008; **109**: 723–40

13 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**: 331–41

14 Cecconi M, Corredor C, Arulkumaran N, *et al.* Clinical review: Goal-directed therapy - what is the evidence in surgical patients? The effect on different risk groups. *Crit Care* 2013; **17**: 209

15 Claeskens G, Hjort NL. *Model Selection and Model Averaging. Cambridge Series in Statistical and Probabilistic Mathematics*. Cambridge and New York: Cambridge University Press, 2008. xvii, 312 p

16 Tian L. Inferences on the common coefficient of variation. *Stat Med* 2005; **24**: 2213–20

17 Scheeren TW, Wiesenack C, Gerlach H, Marx G. Goal-directed intraoperative fluid therapy guided by stroke volume and its variation in high-risk surgical patients: a prospective randomized multicentre study. *J Clin Monit Comput* 2013; **27**: 225–33

18 Futier E, Constantin JM, Petit A, *et al.* Conservative vs restrictive individualized goal-directed fluid replacement strategy in major abdominal surgery: a prospective randomized trial. *Arch Surg* 2010; **145**: 1193–200

19 Byrnes J. 7 tactics to reduce variation in clinical practice. *Healthc Financ Manage* 2012; **66**: 146, 148

20 Dudley N. Tackling practice variation. Threats and opportunities of the NHS reforms. Br Med J 2011; **342**: d2269

21 Mays N. Reducing unwarranted variations in healthcare in the English NHS. *Br Med J* 2011; **342**: d1849

22 Miller MG, Miller LS, Fireman B, Black SB. Variation in practice for discretionary admissions. Impact on estimates of quality of hospital care. *JAMA* 1994; **271**: 1493–8

23 Stiefel M, Feigenbaum P, Fisher ES. The Dartmouth Atlas applied to Kaiser Permanente: analysis of variation in care at the end of life. *Perm J* 2008; **12**: 4–9

24 Richards RG. Tackling practice variation. How to do it. *Br Med J* 2011; **342**: d2285

25 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**: 53–62

26 Pearse RM, Harrison DA, MacDonald N, *et al.* Effect of a perioperative, cardiac output-guided haemodynamic therapy algorithm on outcomes following major gastrointestinal surgery: a randomized clinical trial and systematic review. *JAMA* 2014; **311**: 2181–90

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