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ORIGINAL ARTICLE

Intermittent boluses of balanced salt solution for post-operative intravenous hydration following elective major abdominal and thoracic surgery in children

William R. Johnston[1,2] · **Rosa Hwang**[1] · **Peter Mattei**[1]

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Abstract

Purpose Maintenance fluids following major operations in children are typically administered with a continuous rate. We hypothesized that administering fluids as intermittent boluses is more physiologic and could limit post-operative fluid volume, thereby avoiding harmful effects of excess fluid.

Methods We retrospectively reviewed children aged 1–21 admitted after an elective major abdominal or thoracic operation from 2015 to 2021. We excluded non-elective operations and patients receiving peri-operative enteral or parenteral nutrition. We analyzed total fluid volume at 0–24, 24–48, 48–72, and 72–96 h, time to regular diet and discharge, and end-organ complications.

Results We identified 363 patients, of which 108 received intermittent boluses and 255 continuous fluids. Bolus group patients received significantly less fluid up to 72 h post-operatively with average rates of 0.49 mL/kg/h vs 0.86 mL/kg/h at 0–24 h ($p << 0.01$), 0.57 mL/kg/h vs 1.46 mL/kg/h at 24–48 h ($p << 0.01$), and 0.50 vs 0.92 mL/kg/h at 48–72 h ($p << 0.01$). Additionally, the bolus group maintained adequate urine output, tolerated a regular diet sooner (2.08 days vs 2.51 days; $p = 0.0023$) and averaged a shorter hospital stay (3.12 vs 4.14 days; $p = 0.004$). There was no difference in adverse effects between the two groups.

Conclusion Utilizing intermittent boluses reduces the volume of maintenance fluids administered and may lead to a faster time to regular diet and discharge.

Level of evidence IV.

Type of study Retrospective review.

Keywords Maintenance fluids · Intermittent bolus · Perioperative fluid management · Postoperative ileus · Lactated ringers · Normal saline

Introduction

Traditional protocols for maintenance intravenous fluids (mIVF) following major abdominal or thoracic operations in children emphasize continuous fluid administration, total volume based on the 4:2:1 rule, hypotonic solutions, and the inclusion of 5% dextrose [1, 2]. These protocols aim to replenish insensible losses, maintain metabolism, and prevent protein catabolism. Recent studies questioned these tenets and argue that isotonic, balanced salt solutions with lower doses of dextrose better maintain homeostasis [3, 4]. In particular, these reports demonstrate that balanced isotonic electrolyte solutions adequately protect against the risks of hyponatremia and hyperchloremic acidosis, while

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✉ Peter Mattei
mattei@chop.edu

William R. Johnston
William.Johnston@pennmedicine.upenn.edu

Rosa Hwang
hwangr2@chop.edu

[1] General, Thoracic, and Fetal Surgery, Department of Surgery, Wood 5, Children's Hospital of Philadelphia, 34th St. and Civic Center Blvd., Philadelphia, PA 19104, USA

[2] Hospital of the University of Pennsylvania, Philadelphia, PA, USA

the addition of 1–2% glucose is sufficient to avoid hypoglycemia, lipolysis, or hyperglycemia [5].

There are limited data, however, to justify the administration of maintenance fluids in a continuous manner. The use of a continuous rate is largely historical and there are no prospective trials demonstrating it to be the optimal mode of administration. When continuous fluids are started, the initial rate relies on estimates such as the 4:2:1 rule rather than clinical parameters. Consequently, patients often receive fluid volumes higher than needed for end-organ function. The detriments of such excess fluid administration are well documented and include electrolyte and acid–base imbalances, pulmonary dysfunction, and bowel wall edema [6, 7]. As such, multiple clinical guidelines now argue that maintenance fluids should be prescribed with the same care as any other drug and every effort should be made to avoid their unnecessary administration [5, 8, 9]. Thus, it stands to reason that post-operative maintenance fluids should be administered in a manner that limits their infusion to only that which is physiologically necessary until patients are able to take in adequate enteral fluid.

We believe that administering maintenance fluids in the form of intermittent boluses of balanced salt solution is more physiologic and could limit the volume of post-operative fluids, thereby avoiding harmful effects of maintenance fluids on electrolyte homeostasis, glucose metabolism, and organ function. Several years ago, we began implementing a strategy at our institution in which the vitals, urine output, volume status, and enteral tolerance of post-operative patients are assessed every four hours by inpatient providers, with boluses of balanced salt solution administered as clinically indicated until patients can support themselves with enteral nutrition. Concurrently, several physicians in our institution continued to use continuous fluids due to their preference. In this study, we sought to compare patients managed with intermittent boluses to those still managed with continuous fluids. We hypothesized that fluid management would reduce the volume of fluid patients received and accelerate time to discharge by limiting the side effects of excess fluids, such as ileus and oxygen requirement.

Methods

Study design and population

We included children aged 1–21 admitted to a regular hospital bed after an elective major abdominal or thoracic operation from 2015 to 2021. A full search of patients treated at our institution was performed using our internal Children's Hospital of Philadelphia registry and CPT codes for nephrectomy, J pouch, neuroblastoma resection, mass resection/biopsy, total colectomy, lap-assisted bowel resection, ileocecectomy, liver resection, lung resection, thoracotomy excision/biopsy, and mediastinal mass resection. These operations were chosen as they represented the bulk of the practice for our providers utilizing the intermittent bolus protocol. The operations were subsequently grouped as tumor resection, tumor biopsy, small or large bowel resection, J pouch creation, and nephrectomy. The patients in the continuous fluid group consisted of patients of providers who still preferred the use of continuous fluids, as well as patients who received continuous fluids while the new practice pattern was still being implemented. To minimize confounding factors, we excluded patients undergoing non-elective operations and those who received peri-operative enteral or parenteral nutrition.

Protocols for fluid administration

Under our current protocol, all patients are not allowed solid food the night before surgery but are allowed clear liquids up until 2 h before the procedure to minimize any pre-operative fluid deficit. Post-operatively, a standardized protocol is utilized to determine when boluses are administered for patients managed with the bolus strategy. Per unit protocol, urine output and vital signs are recorded every four hours by nursing staff. If urine output is below 1 cc/kg/h, a 10 cc/kg bolus of lactated ringers solution is administered and the covering provider is notified. Additionally, if the patient's heart rate is greater than 110, the covering provider is notified and a bedside assessment of their volume status is performed to determine if a bolus is warranted.

For patients managed with continuous fluids, the initial rate and type of fluid are left to the discretion of the fellow or resident covering the operation. In our study population, the types of continuous fluids included 0.45% normal saline with 5% dextrose (75.3% of patients), normal saline (9.0%), 0.9% normal saline with 5% dextrose (7.1%), 16 with lactated ringers (6.3%), lactated ringers with 5% dextrose (2.0%), and 0.2% normal saline with 10% dextrose (0.004%). Providers are then notified if urine output is below 1 cc/kg/h or heart rate is greater than 110 and a 10 cc/kg and a bolus of lactated ringers is administered if indicated.

Key to our protocol is buy-in from all relevant stakeholders including anesthesia, nursing staff, and support staff. Extensive education ensures that fluid intake and output are accurately recorded before, during, and after surgery. Additionally, clinical indicators of fluid status, such as lower extremity edema, capillary refill, and chest auscultation, are routinely assessed to ensure patients are not under- or over-resuscitated if intake and output are recorded inaccurately. Given our practice of limiting

post-operative labs, measures, such as Cr, BUN/Cr ratio, and lactate, are only utilized when volume status is unable to be ascertained on physical exam. When potassium repletion is necessary, our practice is to supplement orally to avoid additional fluids. Additionally, for all patients, the presence of nausea and toleration of liquids are ascertained on daily morning and afternoon rounds with diet advancement as tolerated.

Measures and statistical analysis

We analyzed intra-operative fluid volume, total volume of fluid at 0–24, 24–48, 48–72, and 72–96 h, urine output, time to regular diet and discharge, and end-organ complications. Time to regular diet was defined as the time at which the patient was switched to a regular diet. End-organ complications included pulmonary dysfunction requiring oxygen supplementation, symptoms of hypoglycemia, and seizures. Once patients were discharged, they were excluded from analysis of future time periods. Patients discharged in the middle of a time period had their mL/kg/h adjusted based on the timing of discharge.

Comparisons for both primary analysis and subgroups were made using Student's *t* test for continuous variables and chi-squared test for categorical variables. Given the number of comparisons, a more conservative *p* value of < 0.01 was selected to determine significance. Patients managed primarily with continuous therapy who received additional boluses, as well as patients managed initially with bolus therapy that were switched to continuous therapy, were included in their initial group for data analysis. Institutional IRB approval was obtained for the study (No. 20-018170).

Results

We identified 401 patients with our search criteria, of which 38 were excluded for an urgent/emergent operation or peri-operative enteral or parenteral nutrition. Our final analysis included 363 patients, 108 of whom were initially treated with bolus maintenance fluids and 255 with continuous maintenance fluids. There were no baseline differences in age, weight, or intra-operative fluids received between groups. There was a slightly greater proportion of female patients in the continuous fluid group. Each operation was well represented in each group. In the continuous group, 192 patients were managed with 0.45% normal saline with 5% dextrose, 23 with normal saline, 18 with 0.9% normal saline with 5% dextrose, 16 with lactated ringers, 5 with lactated ringers and 5% dextrose, and 1 with 0.2% normal saline with 10% dextrose. Nine patients from the bolus group crossed over the continuous group during the entire 96-h period. In each instance, this was due to provider unfamiliarity with the protocol. In the continuous fluid group, 21 patients received boluses in the 0–24 h period, 65 in 24–48 h, 25 in 48–72 h, and 20 in 72–96 h (Table 1 and Fig. 1).

Patients who received bolus maintenance fluids received significantly less fluid up to 72 h post-operatively than those who received continuous maintenance fluids with average rates of 0.49 mL/kg/h vs 0.86 mL/kg/h at 0–24 h ($p << 0.01$), 0.57 mL/kg/h vs 1.46 mL/kg/h at 24–48 h ($p << 0.01$), and 0.50 vs 0.92 mL/kg/h at 48–72 h ($p << 0.01$). This difference largely held true on subgroup analysis of each operation as well, though comparisons for late time periods were limited once many patients had been discharged. Comparing abdominal and open surgery irrespective of maintenance fluid type, there was no difference in fluid rate at any time point. However, patients who underwent abdominal surgery and received bolus fluids had significantly less fluid at all time points up to 72 h (0.53 mL/kg/h vs 0.82 mL/kg/h with $p = 0.003$ at 0–24 h; 0.62 mL/kg/h vs 1.51 mL/kg/h with $p < 0.001$ at 24–48 h; 0.44 mL/kg/h vs 1.18 mL/kg/h with $p = 0.001$). Patients who underwent chest surgery and received bolus fluids had significantly less fluid at 24–48 h (0.42 mL/kg/h vs 1.13 mL/kg/h with $p = 0.006$) and non-significantly less at 0–24 and 48–72 h. Comparing laparoscopic and open surgery irrespective of fluid type, those who underwent laparoscopic surgery received significantly less fluid at 0–24 h (0.60 mL/kg/h vs 0.86 mL/kg/h with $p = 0.003$) and 48–72 h (0.58 mL/kg/h vs 0.94 mL/kg/h with $p = 0.004$). Patients who underwent laparoscopic surgery and received bolus fluids had significantly less fluid at 0–24 h (0.36 mL/kg/h vs 0.71 mL/kg/h with $p = 0.0025$) and non-significantly less at 24–96 h. Those who underwent open surgery and received bolus fluids had significantly less fluid at 0–24 h (0.59 mL/kg/h and 0.85 mL/kg/h with $p = 0.005$) and 24–48 h (0.62 mL/kg/h vs 1.64 mL/kg/h with $p < 0.001$ and non-significantly less at 48–96 h.

The bolus group also tolerated a regular diet significantly sooner than the continuous group (2.07 days vs 2.51 days with 95% CI [1.79–2.36] vs [2.28–2.74] with $p = 0.0018$) and averaged a shorter hospital stay (3.10 days vs 4.13 days with 95% CI [2.56–3.64] vs [3.39–4.87] with $p = 0.004$).

Table 1 Patient demographics and baseline characteristics

	Bolus ($n = 108$)	Continuous ($n = 255$)	
Age (year)	11.22	11.55	$p = 0.62$
Gender (male, %)	52, 48%	109, 42%	$p = 0.019$
Weight (kg)	40.72	42.48	$p = 0.50$
Intra-operative fluids (mL/kg/h)	8.78	9.56	$p = 0.26$

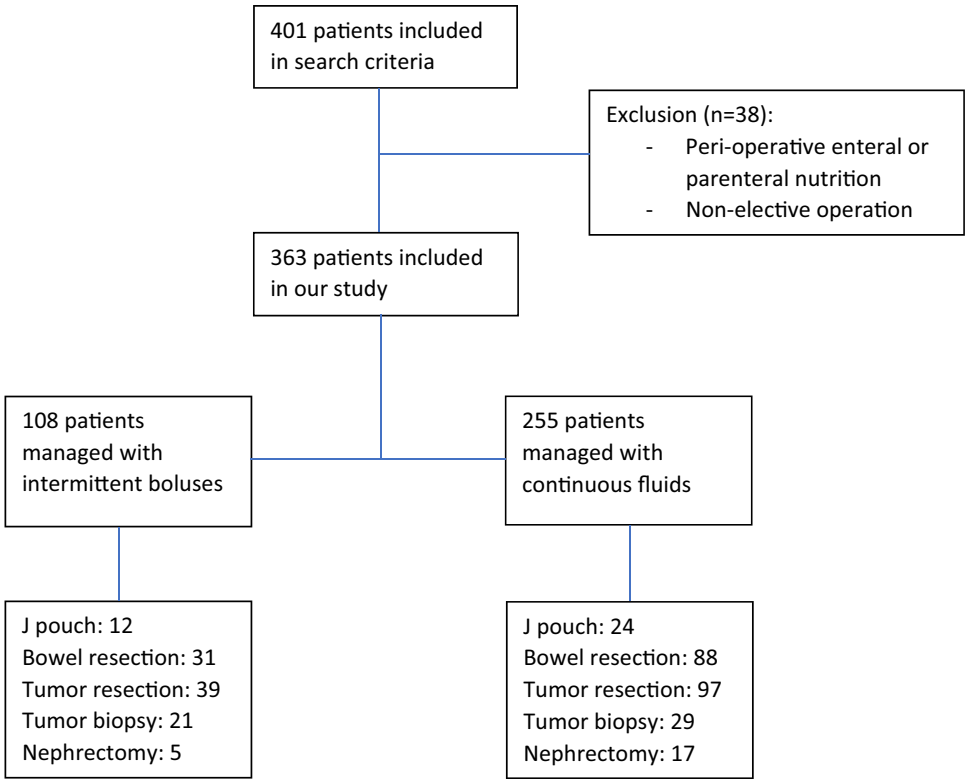

Fig. 1 Flowchart of selection of patients

Patients in the bolus group had a lower urine output 0–24 h and 72–96 h, though hourly rates remained above 1 mL/kg/h aside from 0 to 24 h when both groups were narrowly below that value (Figs. 2, 3 and Table 2).

Six patients in the continuous mIVF group required temporary supplemental oxygen, compared to two in the bolus group ($p = 0.75$). Given our practice of limiting post-operative labs, there were insufficient data to compare creatinine, sodium, and glucose values between groups, but only one patient in each group required free water restriction and diuretic therapy for clinically evident fluid retention and no patients developed seizures or symptoms of hypoglycemia.

The administration of maintenance fluids following major abdominal or thoracic operations aims to replenish urinary and insensible losses and maintain metabolism. The manner of administration has substantially evolved over the past several decades with a shift from the hypotonic dextrose saline initially advocated by Holliday and Segar to the use of balanced crystalloids and lower concentrations of glucose. Such protocols reduce post-operative hyponatremic encephalopathy, cerebral edema, renal dysfunction, and respiratory insufficiency while maintaining glucose levels [1, 2, 10–15]. Additionally, clinicians have recognized that over-resuscitation and excess maintenance fluids cause increased cumulative doses of sodium and water, which in turn lead to pulmonary dysfunction and ileus [7, 16–20]. As such,

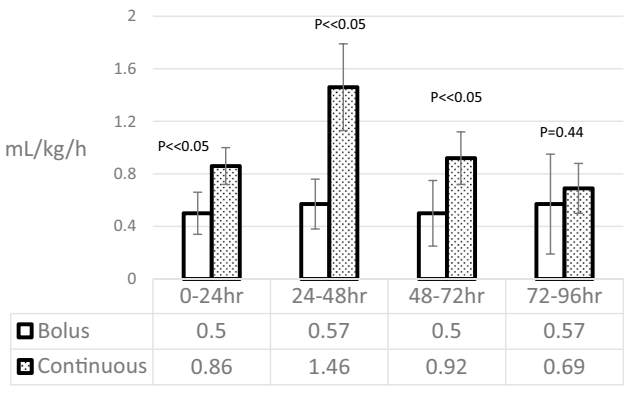

Fig. 2 Maintenance fluids per group in each time period. *Brackets represent confidence intervals

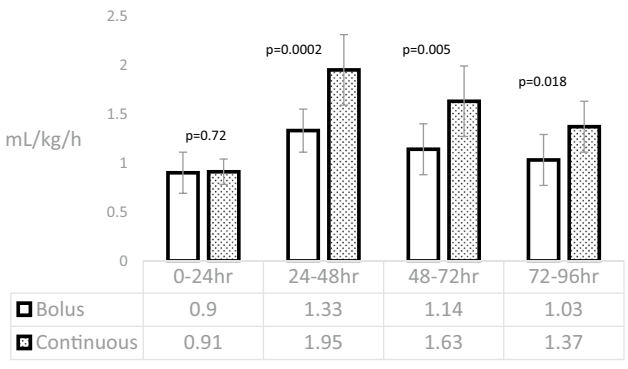

Fig. 3 Urine output per group in each time period. *Brackets represent confidence intervals

Table 2 Maintenance fluids per operation in each time period

Period	Bolus		Continuous		
	n	mL/kg/h	*n*	mL/kg/h	
Tumor resection					
0–24	39	0.49 [95% CI 0.14–0.84]	97	1.01 [95% CI 0.75–1.28]	$p=0.003$
24–48	33	0.36 [95% CI 0.07–0.65]	93	1.38 [95% CI 1.01–1.74]	$p<0.005$
48–72	23	0.31 [95% CI − 0.13 to 0.75]	69	0.89 [95% CI 0.64–1.15]	$p=0.01$
72–96	8	0.52 [95% CI − 0.78 to 1.82]	45	0.73 [95% CI 0.37–1.12]	$p=0.71$
J pouch					
0–24	12	0.58 [95% CI 0.30–0.87]	24	0.61 [95% CI 0.31–0.91]	$p=0.86$
24–48	12	0.94 [95% CI 0.49–1.39]	24	1.52 [95% CI 1.09–1.95]	$p=0.02$
48–72	12	1.03 [95% CI 0.71–1.36]	24	1.30 [95% CI 0.86–1.74]	$p=0.22$
72–96	12	1.02 [95% CI 0.36–1.69]	24	1.14 [95% CI 0.76–1.51]	$p=0.70$
Bowel resection					
0–24	31	0.48 [95% CI 0.26–0.70]	88	0.73 [95% CI 0.53–0.93]	$p=0.03$
24–48	31	0.64 [95% CI 0.32–0.96]	87	1.36 [95% CI 0.55–2.16]	$p=0.04$
48–72	29	0.32 [95% CI 0.05–0.59]	84	0.66 [95% CI 0.36–0.96]	$p=0.03$
72–96	20	0.34 [95% CI − 0.1 to 0.77]	63	0.44 [95% CI 0.18–0.71]	$p=0.59$
Biopsy					
0–24	21	0.39 [95% CI 0.11–0.66]	29	0.76 [95% CI 0.41–1.11]	$p=0.02$
24–48	19	0.34 [95% CI − 0.01 to 0.69]	27	1.14 [95% CI 0.52–1.75]	$p=0.01$
48–72	5	0.08 [95% CI − 0.13 to 0.30]	15	1.10 [95% CI 0.45–1.75]	$p=0.001$
72–96	0	N/a	5	1.28 [95% CI 0.58–1.97]	N/a
Nephrectomy					
0–24	5	0.89 [95% CI − 0.2 to 2.0]	17	1.21 [95% CI 0.66–1.76]	$p=0.54$
24–48	2	1.57 [95% CI − 1.4 to 4.55]	17	2.92 [95% CI 2.11–3.72]	$p=0.46$
48–72	2	1.88 [95% CI − 0.77 to 4.55]	17	1.60 [95% CI 0.78–2.41]	$p=0.83$
72–96	0	N/a	14	0.80 [95% CI 0.11–1.49]	N/a

practice committees now advocate for "fluid stewardship" and treating maintenance fluids as clinicians would other drugs, with a clear appreciation of their side effects [8, 9].

Several years ago, we developed a protocol to limit postoperative maintenance fluids to that which is physiologically necessary to limit the negative impacts of excess fluid administration. As described in the methods section, the key aspect of our protocol is the administration of maintenance fluids as intermittent boluses of balanced salt solution based on urine output, vital signs, and assessment of volume status. We began implementing this protocol several years ago and, in this article, we report the results of patients managed with the new bolus fluid protocol compared to those managed with traditional continuous fluid protocols.

At every time point up to 72 h, patients managed with the bolus maintenance fluid protocol received significantly less fluid than the continuous fluid group. These results generally held true for subgroup analysis by operation as well, particularly for tumor resections, biopsies, and bowel resections. There was no difference in amount of fluid for abdominal versus chest surgery, though differences in resuscitation rate held true when each compartment was subdivided by bolus and continuous fluid. Patients who underwent laparoscopic surgery did receive less fluid on average than those undergoing open surgery, which is likely due to the larger physiologic impact of open compared to laparoscopic surgery. Furthermore, when controlling for type of surgery, patients receiving bolus therapy still received less fluid. The main reason for this difference is that patients receiving intermittent boluses only receive fluids when clinically indicated. In contrast, patients on continuous fluids receive a baseline rate that may or may not match their physiologic requirements. The rate is based on an estimate of fluids needs rather clinical parameters. The main concern is that patients receiving bolus fluids will receive insufficient fluids, whereas patients receiving continuous fluids will receive excess fluids. However, measures of inadequate fluids are clear, while measures of excess fluids are often slow to manifest and harder to detect. For example, nursing staff can easily notify a provider when urine output has dipped below 1 mL/kg/kr or heart rate has risen > 110 bpm, but detecting the slow accumulation of excess pulmonary and gastrointestinal edema typically requires bedside evaluation by a more senior member of the team on rounds.

Review of hourly urine output and patient complications indicates that intermittent bolus administration is safe as

well. A primary concern of bolus therapy is that the lower rate of fluid administration could lead to inadequate fluid administration and acute kidney injury. While patients managed with continuous fluids maintained a higher rate of urine output from 24 to 96 h post-operatively, the bolus fluid patients still averaged a rate > 1 mL/kg/h. This indicates the bolus fluid patients received sufficient fluids for kidney perfusion and metabolite clearance. The higher rate of urine output in the continuous group reflects an appropriate response to the higher rate of fluids they received, but does not indicate any clinical benefit. Additionally, there were no notable differences in the need for supplemental oxygen and no reports of patients requiring glucose supplementation for symptoms of hypoglycemia.

Patients managed with bolus fluids also achieved a regular diet and discharge faster than the continuous group, despite both groups being equally encouraged to take in liquids as tolerated. This difference is likely explained by the bowel wall edema and ileus that results from excess fluid administration. The underlying mediators of edema-induced ileus are well defined and include alterations in tissue architecture and interstitial pressures that lead to a decrease in intestinal contractility [16]. Limiting maintenance fluids to only that which patients cannot take in by mouth has the potential to limit these derangements. While intermittent boluses can easily be titrated to patient need, clinicians are often hesitant to discontinue continuous fluids until patients are fully tolerating a liquid diet, leading to excess maintenance fluid and bowel wall edema. Additionally, when patients do not require continuous fluids, they do not have to be attached to an IV pole. This likely leads to improved post-operative mobility and early ambulation, as well as improved sleep due to fewer machine alarms. Administering fluids as intermittent boluses thus serves as an excellent complement to current ERAS protocols.

The omission of dextrose did not have any appreciable negative clinical impact in the bolus group. Prior studies indicate that 1–2% dextrose solutions adequately protect against hypoglycemia and ketogenic acidosis compared to 5% dextrose solutions while leading to fewer hypoglycemic events. Studies that insist on the inclusion of at least 1% dextrose note that its omission could lead to lipolysis and acidotic ketosis [14]. However, the evidence for such an approach is largely restricted to neonates and very young infants who have a greater demand for exogenous glucose, limited glycogen reserves, and relatively immature fat stores and lipolytic pathways. Children older than one year of age are better equipped to tolerate brief periods of starvation. In fact, multiple studies demonstrate that patients receiving lactated ringers without dextrose do not routinely suffer hypoglycemic events [21–23]. Given these studies, we chose to omit dextrose in our protocol. While lab values were not available for review, no patients in our report demonstrated clinical symptoms of hypoglycemia or ketosis. This is likely referable to our practice of ensuring adequate pre-operative nutrition and encouraging the early intake of enteral fluids. As a matter of course, patients should be routinely assessed pre-operatively for evidence of malnutrition so that appropriate nutritional optimization can occur. If a prolonged period without enteral access is anticipated, then parenteral nutrition can be considered. Early enteral fluids minimizes the period in which patients are dependent on IV supplementation, provides a source of carbohydrates, and reduces the overall need for maintenance fluids.

In summary, the use of intermittent boluses of balanced salt solution to satisfy post-operative maintenance fluid requirements safely resulted in lower rates of fluid administration and a faster time to regular diet and discharge. Our study is limited in that it is a retrospective, single-center, non-randomized study. Providers less familiar with the bolus protocol could have reflexively placed certain patients who underwent prolonged and difficult operations on continuous fluids, creating the potential for selection bias. This was combated with thorough education of covering providers and regular review by attending providers. Of note, patients in the bolus fluid group consistently received lactated ringers, while those in the continuous group received a mix of different fluids. In particular, most patients in the continuous group received hypotonic solutions with additive glucose, while a smaller subset received isotonic solutions without glucose. Given that the fluid types between the continuous and bolus groups are different, direct comparisons may be limited. However, the heterogeneity seen in our continuous group likely represents broader patterns across institutions. As such, our data would indicate that administering intermittent boluses of isotonic fluids tends to limit overall fluid volume as compared to prevailing models that traditionally emphasize hypotonic solutions. Future prospective trials can standardize the fluids administered to further quantify the relative contribution of form of administration compared to type of fluid administered. Additionally, an insufficient number of patients had labs drawn to assess for evidence of acute kidney injury, hyponatremia or hypoglycemia, though review of actual clinical manifestations indicates no clinical differences. Given our inclusion of various degrees of operative complexity and well-balanced groups, our results are generalizable to other institutions. However, our results should not be taken to justify the use of bolus fluids in patients undergoing urgent or emergent operations as they were excluded in this study. We intend to address these limitations with a subsequent randomized, prospective trial, for which this study provides an effective proof of concept.

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Declarations

Conflict of interest Statement of competing interests: the authors have no competing interests to declare. No financial support has been provided for this research.

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