Estimation of Postoperative Fluid Requirements in Infants and Children

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A quadrant scheme is presented for estimating postoperative fluid volumes for replacement of internal fluid shifts (third space losses) in pediatric surgical patients undergoing major intra-abdominal surgery. The benefits derived from using a prescribed postoperative fluid management program that includes this quadrant scheme are determined by analyzing a series of 50 consecutive patients managed by five senior general and thoracic surgical house officers. Although the program tended to overestimate the fluid needs of the patients relative to a predetermined optimal urine output level, all but two patients with septic complications were hemodynamically stable and none had complications due to the fluid administration program.

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INFANTS AND CHILDREN present especially difficult challenges in fluid and electrolyte management because their great range of size and age compound the often already clouded understanding of their fluid needs. The tiny premature weighing 600 g differs markedly in volume requirements from the 16-year-old who may weigh 70 kg. Nevertheless, the insensible losses and physiologic derangements are similar in kind; only the volume requirements differ.

Because every physician has some knowledge of fluid and electrolyte requirements, it is difficult to achieve any degree of consistency or standardization in fluid and electrolyte management. This lack of consistency often leads to poor communication among physicians and relegates to the nursing staff the adjustment of intravenous fluid rates, with little understanding of the overall goals and requirements of the fluid program. One of the more significant aspects of the patient's management, intravenous fluid administration, is thus provided in a haphazard fashion, and the patient is denied the opportunity for constant intelligent monitoring that could be provided by a knowledgeable nursing staff.

For many years, one of the authors (HCF) has taught a comprehensive, practical program for the management of fluids in pediatric surgical patients, which includes a "quadrant scheme" for estimating intraoperative and postoperative internal fluid shifts (third space shifts).[1,2] This is similar in purpose to the "Rule of Nines,"[3] long used to estimate body surface area in burn patients, providing an initial "estimate" that then allows accurate adjustments based on output monitoring. The program has been useful not only as a didactic device for teaching fluid management to medical students, nurses, physician associates, and house officers in surgery, pediatrics, and anesthesia, but also as a practical aid in providing a foundation for the patient's fluid program and in enhancing communication among the health care team.

This paper presents the results obtained in analyzing the performance of five consecutive senior surgical house officers using a highly structured program in providing intravenous fluid management for a wide range of postoperative patients on a pediatric surgical service.

Materials and Methods

Patients

Fifty consecutive patients, ranging in age from 1-day-old premature newborns to 15-year-old teenagers and ranging in weight from 1180 g to 47.9 kg undergoing major surgery on the pediatric surgical service, were selected for a preplanned program of fluid and electrolyte administration. Over one half of the patients were under 5 kg and almost one half were under one month of age (Table 1).

One of the 50 patients was not completely managed by the prescribed program, and three others had procedures that were felt not to require third space replacement fluids. Thus, 46 patients were actually managed by the full program.

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Residents

Five consecutive senior residents in the General/Thoracic Program at Duke University Medical Center applied the program. They were taught the basics of the program initially and invited to participate in the study, but were then allowed to manage the patients independently without an outline or checklist and with only routine attending surveillance on daily rounds. None had significant prior experience in managing children after major surgery.

Fluid Program

The patients daily fluid requirements consisted of the following three categories:

a. *Maintenance fluid.* These fluids replaced insensible losses from the lungs and body surface and provided a volume of free water solvent to dissolve and excrete daily solute waste as an *obligatory* urine volume. In adults this requires a volume of approximately 1000 ml/m^2 or roughly 1500–2000 ml/day.[4,5] In children this volume is determined by one of several formulas, the most widely used being[6,7]: M (maintenance) = 100 ml/kg to 10 kg + 50 ml/kg from 10–20 kg + 20 ml/kg above 20 kg. An alternative formula initially presented by Wallace, has been the senior author's preferred formula for years[8]: M = (100 ml − 3 × age in years) × weight in kg.

Most of the residents used the first formula, but regardless, the guideline called for limiting maintenance fluid to a maximum of 1500 ml/day, the minimum figure for adults. To the free water volume are added the day's requirements for minimum calories, maintenance electrolytes, and vitamins.

1. Calories: Provided as a minimum of 5% dextrose in all solutions.
2. Electrolytes: Na^+ = 3 meq/kg/day; Cl^- = 3 meq/kg/day; K^+ = 2–3 meq/kg/day.
3. Vitamins: 0.5–1.0 ml multivitamin injection.

A solution of 5% dextrose in ⅕ or ¼ normal saline (30–38 meq NaCl/liter) to which 20–30 meq K^+ is added per liter, thus provides the proper ingredients for a maintenance solution.

b. *Measured losses.* These volumes were usually from the gastrointestinal tract and were most commonly gastric secretions evacuated by tube. It was assumed that gastric juice contained approximately 60 meq/L sodium, 5–30 meq/L potassium, and 105–140 meq/L chloride.[9] A solution of D_5%/½ normal saline with 30 meq/L KCl added provided: Na^+ = 75 meq/L; Cl = 105 meq/L; K^+ = 30 meq/L.

This solution replaced all prepyloric losses volume for volume. Losses clearly postpyloric in origin were considered to be comparable to extracellular fluid in character and were replaced with lactated Ringer's solution (D_5%/LR) volume for volume.

TABLE 1. *Age and Weight Distribution of 50 Consecutive Patients*

	Number
Age of patients	
Less than 48 hours	11
48 hours–1 week	7
1 week–1 month	6
1–12 months	8
1–5 years	7
5–10 years	6
Over 10 years	5
Weight of patients	
Less than 2000 grams	3
2000–3000 grams	13
3000–5000 grams	11
5–10 kg	5
10–20 kg	7
20–40 kg	7
Over 40 kg	4

c. *Internal fluid shifts (third space losses).* These fluids are sequestered within the body but are generally *temporarily* beyond osmotic equilibrium with the vascular space. They include such fluids as edema, ascites, pleural effusions, shifts into the intestinal lumen accompanying ileus or mechanical obstruction, inflammatory reactions, and fluid shifting into the interstitial space as a result of loss of capillary membrane integrity from sepsis, endotoxin, hypoxia, or toxins. These fluids are generally comparable to extracellular fluid in their make-up and were replaced by D_5%/LR volume for volume in this program.

Direct measurement of the volumes required is generally impossible because the fluids remain within the body, but are functionally lost from the vascular space. Past efforts to gauge these volumes with isotope labels have been unsuccessful generally. The clinician must, therefore, *guess* at the volumes initially and then adjust the amounts based on careful monitoring of urine output, the most accurate guide to the adequacy of fluid replacement.

d. *The quadrant scheme.* To enhance the accuracy of the *initial* guess, a quadrant scheme was used. This scheme relates the extent of intra-abdominal inflammatory or obstructive diseases and the amount of surgical trauma to the patient's weight through the maintenance formula, and thereby allows a more reasoned estimate of the volumes of D_5%/LR required for internal fluid shifts. The quadrant scheme called for an additional one fourth of the maintenance volume for each quadrant of the abdominal cavity involved with an inflammatory or obstructive disease and an additional one fourth of the maintenance volume for each quadrant of the abdominal cavity significantly traumatized by the surgical procedure. The physician must use his judgement in deciding the degrees of involvement just as is true for the "Rule of Nines" in burn therapy. A patient could thus receive as little as one fourth additional maintenance volume for an appendectomy without appendicitis to $^8/_4$ or 2× additional maintenance volume for a generalized exploratory laparotomy and bowel resection for bowel necrosis due to malrotation and volvulus or a strangulating obstruction secondary to adhesions.

It is important to emphasize that the use of the maintenance volume here is only to relate the replacement volumes to body weight. The fluid used for replacement volumes was not maintenance quality fluids (*e.g.*, D_5%/one fourth normal saline) but deficit replacement type fluids (D_5%/LR).

The maintenance, measured loss, and internal fluid volumes were then totaled and divided by 24 hours to give an hourly administration rate. Fluid was initially administered at this hourly rate giving D_5%/LR until the urine output was well established. The urine output was monitored carefully, and the rate of fluid administration was increased or decreased to achieve a urine volume of 1.5–2 ml/kg/hr, approximating 40 ml/kg/day, an amount shown to be optimal by Wallace.[8] Increasing the rate required adding more D_5%/LR to complete the 24 hours; decreasing the rate eliminated some of the prior estimated D_5%/LR from the total volume, thus providing the "fine tuning" adjustment to the gross estimates of the quadrant scheme. After the 26th patient, the replacement volumes given by the anesthesia team intraoperatively were subtracted from the replacement volumes estimated by the quadrant scheme.

It was suggested to each house officer that his postoperative orders be written so as to allow the nurses to adjust the hourly fluid administration rate within a prescribed range to attempt to correct the urine output toward the optimal level. A limited number of corrections or a defined time period was to be included in these orders.

Illustrative Examples of the Quadrant Application

Example 1. A 3-day-old 2 kg newborn developed abdominal distention, blood streaked stools, and bilious aspirates. Radiographic evidence of pneumatosis confirmed necrotizing enterocolitis. Twelve hours after initiating medical therapy, pneumoperitoneum was noted.

At surgery, generalized peritoneal soilage and necrosis of much of the colon were encountered. An ileostomy and sigmoid mucous fistula were performed after subtotal colectomy. Nasogastric losses recorded before and during surgery equaled 50 ml.

Postoperative fluid orders (24 hours):

a. Maintenance: 100 ml − 3 × age in years × weight in kg = 100 ml/kg × 2 kg = 200 ml D_5/¼ NS + 6 meq KCl.
b. Measured losses: 50 ml D_5/½ NS + 1.5 meq KCl.
c. Internal shifts: generalized peritonitis: 4 quads; general exploratory laparotomy and subtotal colectomy: 4 quads = $^8/_4$ × M = 2 × M = 400 ml D_5%/LR.

Total fluid volume: 650 ml; hourly rate: 650 ml divided by 24 = 27 ml/hr.

Initially, urine output was 3.8 ml/hr; it rose in the second 12 hours to 5.5 ml/hr. The intravenous rate was decreased to 23 ml/hr, and the urine output decreased to 4.2 ml/hr (2.1 ml/kg/hr).

Example 2. A 6-year-old 20 kg white girl presented with a two-day history of crampy abdominal pain, repeated emesis becoming brownish-green in color, and decreased stools. Fourteen months previously she underwent an appendectomy and three-week hospitalization for appendicitis with perforation and generalized peritonitis. Abdominal radiographs confirmed complete small bowel obstruction, and at exploration, multiple adhesions were lysed including a band completely obstructing the mid ileum.

Postoperative fluid orders (24 hours):

a. Maintenance: 100 ml/kg to 10 kg = 1000 ml; 50 ml/kg between 10–20 kg = 500 ml. Total = 1500 ml or (100 − 3 × age in years × weight in kg = 100 ml − 18 years × 20 kg = 82 ml × 20 = 1640 ml D_5%/¼ NS; this is limited to 1500 ml maximum by the guidelines.
b. Measured losses: None during intraoperative period.
c. Internal shifts: (quadrant scheme); disease: Mid-small bowel obstruction with moderate adhesions *estimated* at 2 quadrants = $^2/_4$ × M = 750 ml; Surgery: exploratory laparotomy, lysis of adhesions involves 4 quadrants = $^4/_4$ × M = 1500 ml.

Total fluid estimated for internal shifts = 2250 ml D_5%/LR; total estimated postoperative fluids: 3750 ml = 156 ml/hr administration rate.

The initial urine output averaged 50 ml/hr so the intravenous rate was decreased to 140 ml/hr after the first 6 hours. Urine output decreased to 40 ml/hr (2 ml/kg/hr), and the total fluid received in 24 hours was 3424 ml.

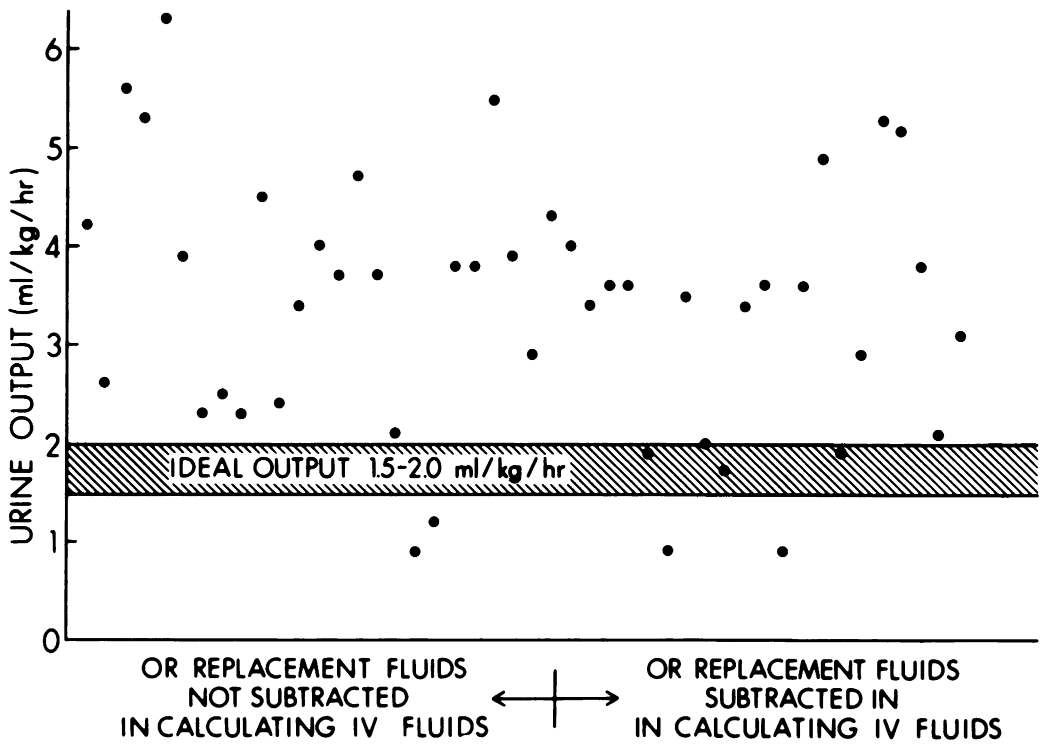

FIG. 1. Urine output (ml/kg/hr) in first 24 hours for 46 patients in study.

Results

A urine volume of 40 ml/kg/day or approximately 1.5–2.0 ml/kg/hr was considered optimal for all patients.[8] Figure 1 shows the distribution of 46 patients. The urine output fell below the optimal level in four patients and was within or higher than the optimal level in 42 patients.

Analysis

When the patient's urine output was within the optimal range, the fluid given averaged 97% of predicted values. One received less than predicted, two almost exactly as predicted, and one received slightly more than predicted.

When the urine output was less than the optimal level (four patients) the fluids given averaged 107% of predicted values. Two received more; one less; one exactly the predicted amounts.

When the urine output was over the optimal range, the fluids given averaged 94% of predicted values. Twenty-seven received less than predicted; three exactly the predicted amount; and eight more than the amount predicted by the program.

Only two patients required pharmacologic manipulation for diuresis (Furosemide, 1 mg/kg intravenously). One patient with sepsis from enterocolitis due to Hirschsprung's disease required Furosemide to achieve a urine output in a reasonable range. During the first 12 hours after operation, the amount of fluid given exceeded that predicted by the quadrant scheme by 142%. The patient's central venous pressure (CVP) was 5 cm of water and after one dose of Furosemide, the patient's urine output averaged 2 ml/kg/hr in the second 12 hours.

A second patient with ileal volvulus and sepsis urinated well the first 12 hours after operation (2.88 ml/kg/hr), but then the urine output decreased and despite a decrease in fluid administration to less than the predicted volume, the CVP increased above 10 cm of water and Furosemide was required. The patient responded appropriately to this. Thus, neither patient received excess fluid due to the predictions of the quadrant scheme.

All other patients were perfectly stable as far as cardiovascular and respiratory functions were concerned and underwent normal postoperative diuresis without pharmacologic diuretic therapy. Central venous pressures were available in only five other patients. In two, the levels were less than 5 cm of water, and in three they were between 5–10 cm of water.

Discussion

Fluid management in postoperative patients can be an extremely haphazard undertaking with little understanding and communication among members of the patient care team. When faced with managing postoperative fluids in pediatric patients ranging widely in ages and weights, most physicians have little idea how to convert the standard approaches they use in adult patients to pediatric patients, especially newborns and infants. This study shows that a simple scheme can greatly aid in the management of these patients by giving the inexperienced physician a guideline for judging the fluid needs in the 24 hours after operation.

That the program did not unerringly achieve urine outputs within the predetermined optimal range was predictable; the program, and particularly the quadrant scheme, is only meant to be a guideline for *initiating* fluid administration. The only quantifiable element of this study is the actual urine output compared to preselected optimal values. What cannot be quantified is the ease with which residents, previously unskilled in managing fluids in pediatric patients, were able to manage a large number of patients within a wide range of age, weight, and complexity of physiologic upsets, maintaining excellent vascular volume replacement. In addition, the program taught the residents a great deal about the variability of response of the patients and the need for careful observation and frequent readjustments of the fluid administration program. The most consistent advantage is that the entire patient care team, nurses and physicians, understand the method and the goals of postoperative fluid management.

Some observations can be made, nevertheless, regarding the propensity for the program to over-replace the patient in this study. Random evaluations of the scheme in the previous ten years showed it to be rather accurate in predicting fluid needs and to give urine outputs more nearly within the optimal range. Several factors may have contributed to improved preoperative and intraoperative hydration as elements of the program became more widely used within our institution. First, realization by the pediatric and surgical house staffs of the sizable volumes required for postoperative replacement has led them to use the quadrant scheme to estimate the patient's postoperative fluid needs *before operation* and use this estimate in deciding how much *preoperative* hydration the patient needs. Second, our pediatric anesthesia service has adopted the scheme for estimating *intraoperative* fluid requirements. They calculate maintenance and replacement volumes using the quadrant scheme to estimate the latter volume, and use this data to determine an hourly intraoperative fluid administration rate. These two factors result in a patient who is better hydrated at the conclusion of the procedure and, thus, requires somewhat less fluid than the scheme indicates for him. However, we consider this a positive factor in evaluating the efficacy of the program as a whole. In fact, after the 26th patient, the program was modified by subtracting the replacement fluids administered in the operating room from the postoperative replacement volumes estimated by the quadrant scheme. This improved, but did not completely eliminate the tendency toward predicting too much fluid.

Another factor was the tendency of the residents to be very concerned and attentive to achieving an adequate urine output in the initial few postoperative hours, but once a good urine output was achieved and the patient was well stabilized, they tended not to reduce volumes immediately when above preselected optimal urine output levels were occurring. Thus, several hours often elapsed during which the patients were stable, but putting out more than the optimal 2 ml/kg/hr urine volumes. This period often was late at night. Most residents tended not to incorporate into their orders the suggestion that they allow the nurses to adjust the hourly fluid rates based on urine outputs. By the time the residents ordered adjustments in the fluid administration rates, the output was often too excessive to allow complete correction within the remaining hours of the 24-hour postoperative period. This proved to have no ill effect on any patient, but obviously a more exact control of fluid input would have resulted in more often achieving outputs within the optimal range.

Finally, the resident was not "coached" in the application of the quadrant scheme beyond the simple guidelines set forth in this paper. It was up to each resident to decide how many quadrants of the peritoneal cavity were *significantly* involved by the disease process and the surgical trauma. The scheme tended to lead to initial overestimates until some experience was gained with it.

Conclusion

A scheme that provides a guideline for estimating fluid requirements in postoperative pediatric surgical patients has proven to be an excellent means of enabling previously inexperienced pediatric and surgical house officers to manage infants and children with a wide variety of surgical illnesses of the abdomen intelligently. Careful attention to the guidelines can achieve optimal urine output in all patients, but average attention leaves the typical patient well replaced but passing urine above preselected optimal levels. None of these patients had any complications of fluid overload, however.

In addition, knowledge of the program led to improved preoperative fluid replacement and optimal intraoperative fluid management by the anesthesia team.

Finally, education of the nursing staff in the principles of fluid management using the program and quadrant scheme improved their understanding of the patient's fluid needs and enabled them to understand more fully the importance of postoperative urine monitoring. Appropriate orders can be written so that the nurse may adjust fluid administration rates to correct for insufficient or excessive urine outputs. The house officer is then advised if the sought for correction fails to occur.

As is true of any "formula" for patient management, the scheme loses its efficacy if the physician fails to realize that it is only a guideline for initially estimating the patient's needs. Its successful use then depends on careful monitoring and re-evaluation of all the physiologic variables that an individual patient can exhibit, including especially changes in cardiovascular efficiency, the presence of inappropriate antidiuretic hormone, intrinsic renal malfunctioning, or the onset or persistence of the cardiovascular deficiencies caused by sepsis.

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