JPPT | Review

Management of Pediatric Parenteral Fluids

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Parenteral fluid therapy in children requires careful consideration of patient-specific factors such as weight, hydration status, and concomitant disease states. Recent literature has changed the standard of care for maintenance fluids for children in the past decade and brought to light more questions. Concentrations of electrolytes in fluids and the use of balanced fluids are still controversial. This article will review the use of parenteral fluids in children, including fluid content, maintenance fluid rate, treatment of dehydration, and the basics of parenteral fluid ingredients. All pediatric patients should have a plan for fluid therapy that includes careful consideration of hydration status and individual response to therapy.

ABBREVIATIONS D5NS, Dextrose 5% in normal saline; D5W, dextrose 5% in water; NICE, National Institute for Health and Care Excellence; NS, normal saline; SIADH, syndrome of inappropriate antidiuretic hormone

KEYWORDS dehydration; infusions, intravenous; isotonic solutions; osmolarity; parenteral infusions; pediatrics

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Introduction

Fluid needs in pediatric patients are dynamic and depend upon various patient-specific factors such as hydration status, renal function, and underlying illness. This paper will review concepts in parenteral fluid therapy for children, and serve as an update to the previously published article on this topic.[1] Fluid needs for neonates and premature infants as well as fluid therapy for specific diseases such as diabetic ketoacidosis, renal dysfunction, cardiac disease, burns, diabetes insipidus, syndrome of inappropriate antidiuretic hormone (SIADH), and sepsis will not be discussed.

It is important to remember that while the concepts reviewed in this article will provide general recommendations for fluid therapy, each patients' needs are unique, and this is especially true for hospitalized patients. Critical illness, as an example, can profoundly impact fluid requirements and these requirements can change throughout a given day. Some medications also require extra hydration in order to prevent adverse events: acyclovir and cyclophosphamide are classic examples. Continual assessment of hydration status, medications, and organ function (in particular renal function) is essential to appropriately managing fluid status.

Recent literature as well as maintenance fluid guidelines[2] have brought attention to the components of fluids used in pediatric patients and raised new questions about fluid and electrolyte requirements. While advancements have been made in our understanding of fluid and electrolyte needs for pediatric patients, remaining questions highlight the importance of close monitoring of these patients.

Fluid Therapy Categories

Fluid therapy can be divided into 3 main categories: 1) maintenance fluid, 2) deficit fluid, and 3) replacement fluid. Maintenance fluids are those used to compensate for normal losses due to metabolism, urine output, and other insensible losses. Every patient requires maintenance fluids, and the decision to administer it orally or intravenously is based on the patient's underlying disease state and clinical needs. Deficit fluids are those used to replace an acute loss of fluid from medical conditions such as blood loss or diarrhea. The term "replacement fluid" is generally used to describe fluids given to compensate for ongoing losses due to medical treatment such as drainage from an external ventricular drain or a chest tube.

Appropriate fluid therapy for children needs to include consideration of all 3 fluid categories—maintenance, plus any additional need for deficit and replacement fluid for some children. Each category of fluid will be discussed in detail.

Maintenance Fluids. Maintenance fluids are needed by all patients and should be provided by the parenteral route only if oral hydration is clinically inappropriate or the patient cannot tolerate oral intake. Maintenance fluids are meant to provide for ongoing sensible losses such as urine output and insensible losses from the skin and respiratory tract. Certain patient-specific factors can alter maintenance requirements such as body temperature, hypermetabolic states, and ongoing losses. Table 1 summarizes key points in pediatric maintenance fluid selection, and Table 2 lists ingredients of commonly available parenteral fluids.

Table 1. Key Points for Intravenous Fluid Selection in Children

- Osmolarity denotes the amount of solutes in a given volume and has a unit: Osm/L or mOsm/L
- Tonicity describes a behavior—the ability of a fluid to exert an osmotic force on a cell membrane; it is affected by the osmolarity but also the ability of a solute to cross a cell membrane
- Dextrose 5% in water and sodium chloride 0.9% are both isosmotic; when mixed together they become hyperosmotic
- Dextrose 5% in water is hypotonic because the dextrose quickly crosses cell membranes and is metabolized, leaving only water
- Sodium chloride 0.9% contains only sodium and chloride in similar concentrations to that in cells, thus the amounts crossing the cell membrane back and forth are roughly equal; thus sodium chloride 0.9% is isotonic
- The American Academy of Pediatrics Maintenance Fluid Guidelines recommend isotonic fluids—specifically 0.9% sodium chloride—with appropriate amounts of potassium and chloride for children greater than 28 days of age
- The appropriate fluid for children can quickly change given the child's underlying disease state and clinical condition; patients receiving intravenous fluids should be closely monitored

Table 2. Electrolyte Contents of Common Intravenous Fluids[25–28]

Electrolyte	0.9% Sodium Chloride	Lactated Ringer's Solution*	PlasmaLyte
Sodium	154 mEq/L	130 mEq/L	140 mEq/L
Chloride	154 mEq/L	109–110 mEq/L	98 mEq/L
Potassium	0	4 mEq/L	5 mEq/L
Calcium	0	2.7–3 mEq/L	0
Magnesium	0	0	3 mEq/L
Lactate	0	28 mEq/L	0
Acetate	0	0	27 mEq/L
Gluconate	0	0	23 mEq/L
Osmolarity	308 mOsmol/L	273 mOsmol/L	294 mOsmol/L

* Contents of Lactated Ringer's Solution vary by manufacturer; listed are the ingredients for the products from B. Braun[28] and Baxter.[26]

Maintenance Fluid Rate. Calculation of maintenance fluid rates for pediatric patients has been based on the Holliday Segar Equation (Table 3) for over 60 years. In their 1957 article,[3] Drs Holliday and Segar rationalized a simple equation for calculating maintenance fluids in children based on estimated metabolism and its changes as children grow. The equation recommends 100 mL/kg/day for each of the first 10 kg, 50 mL/kg/day for each of the second 10 kg, and 20 mL/kg/day for each kg thereafter. Since fluid rates are usually ordered as rate per hour, the simplified "4-2-1" method is a commonly used shortcut to quickly calculate a patient's fluid rate. It is an estimate based on 24 hours, and dividing each component of the Holliday Segar Equation by 24, thus recommending 4 mL/kg/hr for each of the first 10 kg, 2 mL/kg/hr for each of the second 10 kg, and 1 mL/kg/hr for each kg thereafter. The weight used to calculate maintenance fluid rates should usually be actual body weight, but in cases of fluid overload or dehydration, other weights such as dry weight may be clinically appropriate. See Table 3 for an example.

Maintenance Fluid Composition. *Osmolarity and Tonicity.* Maintenance fluids have 3 main ingredients: water, electrolytes, and dextrose. Infusing an appropriate balance of these ingredients is vital for safe fluid therapy. Crystalloid fluids, meaning aqueous solutions that contain mineral salts and glucose, are used as maintenance fluids; an understanding of tonicity and osmolarity is key to choosing the appropriate crystalloid fluid. Osmolarity is defined as the amount of solutes in a given volume and is given a unit of milliosmoles per liter (mOsm/L). Tonicity differs from osmolarity in that it is a *behavior* and has no unit. Tonicity is a description of what a fluid does to cells—gain water, lose water, or neither. Hypotonic fluids cause cells to gain volume and put them at risk of bursting. Hypertonic fluids cause cells to lose volume and shrink. Isotonic fluids do not cause cells to gain or lose volume. Ultimately, tonicity depends on both osmolarity and whether solutes from the solution can enter the cell or not. In a normal state, the osmolarity of plasma and the interior of red blood cells is 0.3 Osm. Fluids such as 0.9% sodium chloride ("normal saline" [NS]) and Dextrose 5% in water (D5W) also have an osmolarity of about 0.3 Osm, making them both isosmotic. Despite NS and D5W both being isosmotic, their *behavior* toward cells is very different. Normal saline is comprised of sodium and chloride in water. Both the sodium and chloride have concentrations similar to that in cells, and they are transported back and forth across the cell membrane in equal measure, meaning the cell volume remains the same—this makes normal saline isotonic. D5W, on the other hand, has dextrose, which crosses into the cell and is quickly metabolized, leaving only water behind. The water enters the cell due to its higher concentration in the extracellular environment, causing the cell to swell and potentially causing hemolysis. Thus, both NS and D5W are isosmotic but only NS is isotonic. The hypotonic nature of D5W makes it fundamentally dangerous to be infused

Table 3. Calculation of Maintenance Fluid Rate

	Holliday Segar Equation		Simplified "4-2-1" Method	
	Volume Required	**Example**	**Volume Required**	**Example**
1st 10 kg	100 mL/kg/day	8 kg 8 kg × 100 mL/kg/day = 800 mL/day = 33.3 mL/hr	4 mL/kg/hr	8 kg 8 kg × 4 mL/kg/hr = 32 mL/hr
2nd 10 kg	50 mL/kg/day	13 kg (10 kg × 100 mL/kg/day) + (3 kg × 50 mL/kg/day) = 1150 mL/day = 48 mL/hr	2 mL/kg/hr	13 kg (10 kg × 4 mL/kg/hr) + (3 kg × 2 mL/kg/hr) = 46 mL/hr
Every kg thereafter	20 mL/kg/day	38 kg (10 kg × 100 mL/kg/day) + (10 kg × 50 mL/kg/day) + (18 kg × 20 mL/kg/day) = 1860 mL/day = 77.5 mL/hr	1 mL/kg/hr	38 kg (10 kg × 4 mL/kg/hr) + (10 kg × 2 mL/kg/hr) + (18 kg × 1 mL/kg/hr) = 78 mL/hr

by itself as a maintenance fluid in most circumstances (extreme hypernatremia may make D5W infusions clinically appropriate), and it has proved fatal when used as a bolus fluid.[4]

Sodium. Historically maintenance fluids for children were hypotonic, usually Dextrose 5% with 0.45% normal saline. Holliday and Segar[3] recommended 3 mEq/kg/day of sodium for children. For a 10-kg child receiving 1 L of fluid per day as maintenance, if 0.45% sodium chloride is used, this will provide 77 mEq/day, or 7.7 mEq/kg/day, thus 0.45% sodium chloride provides more than double the original amount of sodium that Holliday and Segar thought necessary for children. One theory regarding the increased sodium needs has been that hospitalized children have a higher sodium requirement than otherwise healthy children. In addition, the need for the sodium content to influence the tonicity of the maintenance fluids generally outweighs the concern for providing more sodium than is thought to be needed.

Over time, data have accumulated that points to a risk of hyponatremia with the use of hypotonic fluids. In a study published in 2013 by Carandang et al,[5] hypotonic fluids were shown to increase the risk of hospital-acquired hyponatremia (serum sodium less than 135 mEq/L) in children. In a study from Neville et al[6] and published in 2010, 124 children admitted to a children's hospital for surgery were randomly assigned to 0.9% or 0.45% sodium chloride solutions at either a maintenance or half maintenance rate. The risk of hyponatremia (serum sodium less than 135 mEq/L) was found to be influenced only by sodium content and not the rate, with patients who received isotonic solutions being at a lower risk for hyponatremia. McNab et al[7] published a randomized controlled trial in 2015 that compared 319 pediatric patients who received maintenance fluids with 140 mmol/L of sodium (140 mEq/L, isotonic) with 322 pediatric patients who received maintenance fluids with 77 mmol/L of sodium (77 mEq/L, hypotonic). Patients received intravenous fluids for a variety of reasons, and just under 50% were surgical patients. The patients receiving isotonic fluids had a significantly lower risk of hyponatremia (serum sodium less than 135 mEq/L) ($p = 0.001$). Fewer patients in the isotonic fluid group had seizures (1) compared with the hypotonic group (7), although this finding was not statistically significant ($p = 0.07$).

In a meta-analysis published by Foster et al[8] in 2014, ten studies were identified that compared the use of hypotonic and isotonic fluids in hospitalized children. The study found that for patients in pediatric critical care units and postoperative settings, the use of hypotonic fluids increased the risk of hyponatremia (serum sodium less than 135 mEq/L) as well as moderate hyponatremia (serum sodium less than 130 mEq/L). This meta-analysis found insufficient data to reach a conclusion for patients on the general pediatrics ward. Another systematic review published in 2014 by McNab et al[9] that included 10 studies (8 of which were the same as the meta-analysis just mentioned[8]) found that isotonic solutions decreased the risk of hyponatremia, particularly in surgical patients; this conclusion applied to only the first 24 hours of therapy.

In 2018, Feld et al[2] published the first guidelines for maintenance fluids in pediatric patients. These guidelines apply to children aged 28 days to 18 years in surgical and medical acute care settings, including critical care units. The guidelines recommend isotonic fluids, specifically 0.9% sodium chloride, with appropriate dextrose and potassium. Isotonic fluids are defined by the guidelines as those containing a sodium concentration close to that of plasma (135–144 mEq/L). Since the concentration of sodium in the aqueous phase of plasma is 154 mEq/L, normal saline is considered to be isotonic. PlasmaLyte, with a sodium concentration of 131 mEq/L, is also considered isotonic by the guidelines. While lactated ringers has a sodium concentration of 130 mEq/L, it was not included in any of the studies evaluated as part of the guidelines and thus it is not included in the recommendations.

Similarly, the United Kingdom's National Institute for Health and Care Excellence (NICE) Guidelines from 2020[10] also recommend starting fluid therapy for children with isotonic crystalloid fluids. Notably the NICE Guidelines also recommend monitoring blood glucose and plasma electrolyte concentrations at the start of therapy and at least every 24 hours.

Chloride. Holliday and Segar[3] recommended 2 mEq/kg/day of chloride, and similar to sodium, the amount that both hypotonic and isotonic fluids provide far exceed this. Additionally, the concentration of chloride in 0.9% sodium chloride is the same as that of sodium—154 mEq/L, which far exceeds the normal concentration in the plasma of about 100 mEq/L. By infusing an excess of negative ions, the body excretes bicarbonate in an attempt to maintain the cation and anion balance.[11] This loss of bicarbonate can result in metabolic acidosis, and is often referred to as hyperchloremic metabolic acidosis. It should be noted that the converse situation—a loss of sodium—would produce a similar effect. This has been described in the literature,[12–14] though most of these data are from the anesthesia literature from case series of patients in the intraoperative period; its clinical significance outside of the operating room is not clear. Some practitioners prefer lactated ringers solution or other balanced crystalloids since they provide less chloride while remaining isotonic. This is discussed further below.

Potassium. Potassium is an electrolyte required for normal homeostasis and cardiac function. Normal requirements for potassium are estimated to be 2 mEq/kg/day by Holliday and Seger.[3] Generally it should not be added to fluids until the patient has urinated and proved their ability to excrete it. For patients who are not able to take anything orally, especially those with vomiting and diarrhea, a lack of potassium can cause significant hypokalemia. Often patients are started on intravenous fluids without potassium when they are first admitted since they may not have urinated yet; it is important to remember to add potassium to the intravenous fluids once the patient has urinated and as long as the renal function is normal—omitting potassium may cause hypokalemia. Generally 20 mEq/L in maintenance fluids will provide the requirements suggested by Holliday and Segar. Patients with ongoing losses may require additional potassium, and up to 40 mEq/L may be necessary. Those with hypokalemia at presentation may require additional potassium boluses.

Dextrose. Dextrose is often added to maintenance fluids in order to provide a source of glucose to prevent hypoglycemia and ketosis. Dextrose affects the osmolarity of fluids; however, it has no effect on tonicity, as previously described. Of note this makes the bag of intravenous fluid such as D5NS hyperosmolar prior to administration but once it is administered the bag becomes either isotonic or hypotonic. While it will not provide the patient's full caloric needs, it is often an easy way to provide some calories, especially in those patients who are not able to take anything orally. For example, in a 10-kg patient, 1 L of fluid per day is the maintenance fluid requirement. If using D5NS as the maintenance fluid, this will provide 50 g per day of dextrose, which is 170 kilocalories, or 17 kcal/kg. Patients of this weight are usually around 1 year of age and generally require about 80 to 100 kcal/kg/day, thus the dextrose in maintenance fluids provides about 20% of daily caloric needs. The concentrations of dextrose most commonly studied are 2.5% and 5%, and there is not enough data to conclude which is most appropriate.

Normal Saline vs Balanced Fluids. Due to concerns over hyperchloremic metabolic acidosis and hyperchloremia in general, some practitioners favor "balanced" fluids, which are defined as those which have sodium, chloride, and potassium contents closer to that of plasma and include fluids such as Lactated Ringer's and PlasmaLyte. In a study by Semler et al[15] comparing balanced fluids with normal saline in critically ill adults, there was no statistically significant difference in the primary outcome of the incidence of a major kidney adverse event, which was a composite of death, new receipt of renal-replacement therapy, or persistent renal dysfunction (final inpatient creatinine value of ≥200% of the baseline value); however, more patients in the normal saline group had new renal replacement therapy. In a similar study in non-critically ill adults from Self et al,[16] no difference was found in hospital-free days between patients who received normal saline and those who received balanced crystalloids in the emergency department setting. The "BaSICS" trial, published by Zampieri et al,[17] randomly assigned critically ill adults to normal saline or PlasmaLyte 148. There was no difference in the primary outcome of 90-day survival. A more recent study from Finfer et al[18] comparing normal saline and PlasmaLyte in critically ill adults found no differences in death or acute kidney injury.

There is much less data in children on this topic. A recent single center study by Raman et al[19] randomly assigned 516 patients to receive normal saline, gluconate/acetate-buffered solution, or lactate-buffered solution. Patients younger than 16 years who were admitted to the pediatric intensive care unit at a single center in Australia were eligible for randomization. The median age was 3.8 years (IQR, 1.0–10.4 years). A statistically significant difference was found in the primary outcome of the incidence of a rise in serum chloride of 5 mEq/L or more in the first 48 hours after randomization, with more patients in the normal saline group reaching this endpoint. Notable associations of a lower incidence of the primary outcome were found in the subgroups of infants younger than 6 months and those with non-elective admissions treated with gluconate/acetate-buffered solutions and lactate-buffered solutions compared with normal saline. There were no differences in the secondary endpoints including new-onset acute kidney injury, and length of hospital or pediatric intensive care unit stay. The clinical implications of a rise of serum chloride 5 mEq/L are unclear; incidence of metabolic acidosis and serum bicarbonate concentrations were not reported. A meta-analysis of studies by Lehr et al[20] comparing balanced and un-balanced fluids used as boluses in children found some improvements in blood pH and bicarbonate in children who received boluses with balanced fluids; however, the clinical significance of this is unclear given the limited patient populations of the studies. Secondary endpoints such as serum chloride levels, acute kidney injury, need for renal replacement therapy, vasopressor requirements, and mortality did not demonstrate statistically significant differences between groups. Data from adults seems to indicate some benefit of balanced fluids in critically ill adults but the clinical differences of balanced solutions and normal saline in children remain unclear. Additionally, their known drug incompatibilities (e.g., ceftriaxone) in addition to the paucity of data studying their compatibility with intravenous medications currently limit their practical use.

Deficit Fluids. Dehydration is a common occurrence in pediatric patients; it can range from mild cases that can be treated at home to severe cases that require hospitalization. To begin, the patient's hydration status must be determined, as this will guide the amount of fluid needed as well as the timeframe over which it should be delivered. Finally, serum sodium will also need to be assessed so that the appropriate fluid and rate can be chosen for rehydration. Generally speaking, the fluids used in dehydration are the same as those for maintenance fluid therapy, that is, isotonic with dextrose and potassium when appropriate, although electrolytes should be checked in order to screen for any disturbances that would affect fluid choice.

Determining Degree of Dehydration in Pediatric Patients. Hydration status of children can be difficult to quantify, and no true guidelines exist, though several review articles suggest various methods. Given that 1 L of water is equal to 1 kg of weight, if the amount of weight loss is known, the fluid deficit can easily be determined; for example, if a patient has lost 0.8 kg, the fluid deficit is 800 mL. Unfortunately, caregivers are often unaware of a current pre-illness weight (the weight prior to the current illness), thus the deficit must be estimated based on clinical signs and symptoms. Table 4 lists common signs and symptoms of dehydration and their estimated effects on hydration status.[21] It is important to remember that these are only estimates, that many of these signs and symptoms are affected by other medical conditions, and

Table 4. Signs and Symptoms of Dehydration[29]*

	Mild Dehydration	Moderate Dehydration	Severe Dehydration
Estimated corresponding weight loss	3%–5%	6%–9%	10% or more
Mental status	Normal	Normal, fatigued, restless, or irritable	Apathetic, lethargic, or unconscious
Urine output	Normal – decreased	Decreased	Minimal
Vital signs			
Heart rate	Normal	Normal – increased	Tachycardic; bradycardic if severe
Pulse quality	Normal	Normal – decreased	Weak, thready, or difficult to palpate
Systolic blood pressure	Normal	Normal or low	Low
Physical exam findings			
Anterior fontanelle	Normal	Sunken	Very sunken
Mucous membranes	Normal	Dry	Parched
Eyes	Normal	Slightly sunken	Very sunken
Tears	Present	Decreased	Absent
Skin elasticity	Normal – instant recoil with pinching	Recoil in <2 sec	Recoil in >2 sec
Capillary refill	Normal	Prolonged	Prolonged, minimal
Extremities	Warm	Cool	Cool, mottled, cyanotic

* Adapted from Santillanes G, Rose E. Evaluation and management of dehydration in children. *Emerg Med Clin N Am.* 2018;36:259–273.

that the patient's clinical status must be continually reassessed to determine appropriateness of fluid therapy. Using clinical signs and symptoms, the percent dehydration can be estimated and this can be used to determine the deficit using the equation below. For the equation below, the "pre-illness weight" refers to the patient's weight prior to the current illness, and the "illness weight" refers to the patient's current weight, during their illness.

Deficit Calculations. Pre-illness weight is known: Fluid deficit (mL) = Pre-illness weight (kg) – Illness weight (kg) × 1000

Clinical signs and symptoms: Fluid deficit (mL) = %dehydration × weight (kg) × 10

Once the volume of the deficit is determined, rehydration is usually divided into 3, and sometimes 4, phases.[22,23] During phase 1, a bolus of fluid is administered with the goal of maintaining blood pressure and perfusion to vital organs. In children the volume of the bolus should be 10 to 20 mL/kg per dose; repeat doses may be required depending on the patient's response. Patients whose dehydration is severe or those in septic shock are likely to require multiple boluses. Generally phase 1 happens in the emergency department, but may occur on an inpatient unit based on a patient's clinical condition. Once the bolus has been administered, the total bolus volume should be subtracted from the deficit; the remaining deficit will be given during phases 2 and 3.

Phases 2 and 3 of the child's rehydration plan include replacement of the remaining fluid deficit over a 24-hour period once phase 1 boluses have been administered. The total volume remaining is divided equally between phase 2 (8-hour phase) and phase 3 (16-hour phase), which means the deficit is replaced more rapidly in phase 2 compared with phase 3. The half remaining deficit given during phase 2 is administered over 8 hours while the half remaining deficit for phase 3 is administered over 16 hours. Therefore, when calculating the total fluid rate provided during phase 2 and phase 3 one would add the patient's usual maintenance fluid rate per hour plus the deficit fluid rate calculated per hour. Equations for the volumes of these fluids are as follows:

Phase 1 = 10–20 mL/kg/dose (may be repeated) administered over 10–30 minutes
Phase 2 = 1/3 of 24-hour maintenance volume (mL) + [(deficit (mL) – (bolus volume (mL)/2)]/8 hours
Phase 3 = 2/3 of 24-hour maintenance volume (mL) + [(deficit (mL) – (bolus volume (mL)/2)]/16 hours

An example dehydration plan is included in Table 5.

Sometimes a fourth phase is used where patients are weaned off of maintenance fluids.[22] This can be especially useful in children who are recovering from viral gastroenteritis or abdominal surgery, where they have not been able to tolerate anything by mouth for a period of time. By cutting the fluid rate to half of maintenance, the thirst mechanism will be stimulated and may help to encourage the patient to begin drinking on their own, without completely eliminating intravenous fluid support.

Assessment of Serum Sodium in Dehydration. Most pediatric patients with dehydration are isonatremic, however hypernatremia and hyponatremia do occur, and when this happens, rehydration should be handled differently. In both scenarios, overly rapid rehydration can result in rapid changes in serum sodium, which can lead to osmotic demyelination of neurons, seizures, and cerebral edema. Frequent checks of serum sodium—every 1 to 4 hours depending on the patients' clinical status—after initial fluid resuscitation and during phases

Table 5. Dehydration Plan Example for a 15-kg Patient With 10% Dehydration

	Equation	Calculation
Deficit	10% dehydrated × 15 kg × 10 = 1500 mL	
Phase 1 Resuscitation	10–20 mL/kg/dose, 2 doses given	15 kg × 20 mL/kg = 300 mL 300 mL × 2 doses = 600 mL
Phase 2 First 8 hr	1/3 of 24-hr maintenance volume + (deficit – phase 1 volume)/2	• Maintenance = (1250 mL)/3 = 417 mL • ½ of deficit = (1500–600)/2 = 450 mL • 417 + 450 = 867 mL Divided over 8 hr = 108 mL/hr
Phase 3 Next 16 hr	2/3 of 24-hr maintenance volume + (deficit – phase 1 volume)/2	• Maintenance = (1250 mL) × 2/3 = 833 mL • ½ of deficit = (1500–600)/2 = 450 mL • 833 + 450 = 1283 mL Divided over 16 hr = 80 mL/hr
Phase 4 Weaning (patient may require regular maintenance fluid rate after phase 3 and prior to phase 4)	½ maintenance	(if needed) 1250 mL/2 = 625 mL Hourly rate = 625/24 = 26 mL/hr

2 and 3 should be undertaken in order to ensure a slow normalization of sodium and return of adequate hydration status. In general, it is advisable to correct by no more than 12 mmol/L in the first 24 hours.[24]

Replacement Fluids. Occasionally medical treatment requires drains to be placed, as in the case of thoracostomy tubes and external ventricular drains. In this case, the volume of fluid draining should be monitored and depending on the patient's clinical condition, may warrant being replaced. The volume being replaced may be equal to the volume lost (1:1 replacement) but depending on the patient, sometimes other volume ratios such as 1:1/2 replacement are chosen. This can be replaced by adding volume to the maintenance fluid volume or as a separate infusion. The type of fluid used may vary based on the drain. Often tubes such as thoracostomy tubes that drain fluid with higher protein content are replaced with colloid fluids such as albumin, while fluid from external ventricular drains is often replaced with normal saline.

Conclusion

Intravenous fluid therapy in children should be evaluated just as carefully as any medication treatment, with the dose, rate, and fluid contents calculated and chosen considering the individual patient. A thorough understanding of the need for each fluid component, including the difference between tonicity and osmolarity is important for pharmacists and other healthcare practitioners, in order to provide safe parenteral fluid therapy. While more research is needed in pediatric patients, isotonic crystalloid fluids remain the preferred fluid over balanced fluids due to their low cost, availability, and data supporting co-infusion with medications. Finally, treating the dehydrated patient according to their calculated deficit and maintenance fluids provides an individualistic approach to rehydration. Fluid therapy for hospitalized patients is a complex science that involves consideration of individual patient factors, and proper monitoring of response to therapy.

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