A review of past and current thinking in pediatric fluid therapy

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The author presents an approach to pediatric fluid therapy, comparing the fluid compartments in pediatric and adult patients, differences in the renal systems, and various facets of preoperative assessment. Also included are workable formulae for intra- and post-operative fluid management. Stress is placed on maintaining the continuity of care by informing the postanesthesia care team of the planned fluid therapy.

Fluid requirements for pediatric patients may vary considerably, depending on the child's age and stage of development. This article will focus on the newborn, infant, and the child less than 13-years-old because the major differences from routine adult fluid therapy are more clearly seen in these age groups.

The incidence of cardiac arrest during anesthesia is four times as common in pediatric patients than in adults. A major contributing factor in these arrests is an inadequate estimation of fluid loss and inadequate replacement of these fluids. A rational approach to fluid therapy may help reduce the incidence of cardiac arrest and other untoward responses to anesthesia in pediatric patients. Areas relevant to fluid therapy in children include the following topics.

1. Knowledge of the differences and similarities in the fluid compartments of the newborn, child and adult.
2. The degree of renal maturity in the newborn.
4. Intraoperative fluid management of the newborn and the child.
5. Postoperative, follow-up fluid therapy.

Fluid compartments in the newborn, child and adult

For the sake of clarity we will consider the newborn less than 72-hours-old, the infant less than one-month-old, and the child less than 13-years-of-age. Differences exist in these three groups which warrant our attention. First, it is well understood that newborns and infants have a greater amount of water in their extracellular fluid compartments. This condition persists until they are approximately two-years-old and begin to reach adult proportions of 20% extracellular and 40% intracellular water. The newborn has up to 400 ml/kg extracellular fluid, twice the amount proportionally found in the adult. This allows the newborn to withstand wide ranges of fluid manipulation proportionate to his body size. However, one must keep in mind that this total body water is only $2\frac{1}{2}$ L compared to the adult's 40 L.

A second difference to be noted is that the newborn has less albumin and globulin than the
adult. In addition, because much of the newborn's albumin is extracellular, his plasma colloid osmotic pressure is lower. Thirdly, the newborn has more sodium, chloride, potassium and phosphate ions per kilogram than does the adult. This is important to keep in mind during evaluations of laboratory data.

A fourth difference is seen when comparing the total circulating blood volume of the newborn, child and adult. The blood volume of the newborn varies between 60-130 ml/kg, depending on the position of the baby in relation to the placenta and perineum during delivery and whether the obstetrician "milked" the cord toward or away from the newborn prior to clamping it. Figures generally accepted are 80-85 ml/kg for the infant and 70 ml/kg for the adult. The total circulating blood volume of a child lies somewhere between the two, approaching the adult blood volume as he reaches his teen years. Adult females have a blood volume of approximately 65 ml/kg and males have 70 ml/kg.

The renal system in the newborn, child and adult

Next, we must consider the renal system of the newborn in comparison to that of the adult. The newborn has fewer functional nephrons, loops of Henle, distal convoluted tubules and collecting ducts than the adult. Thus, he is less able to concentrate urine and has a tendency toward increased diuresis. This results in twice the daily water turnover relative to the body water in the infant compared to the adult.

By the end of the first month, the renal system has reached 80-90% complete maturity. Because of the comparatively larger extracellular fluid volume, the larger ratio of surface area to body weight and the proportionately greater amount of insensible water loss, the newborn will lose approximately 4% of his body weight if maintained intravenously for eight hours before surgery. This is compared to an approximate 1⅛% loss in body weight measured in the adult.8

The renal system of the newborn and infant is capable of compensating for decreases in circulating plasma volume and interstitial fluid volume by way of the renin-angiotensin and aldosterone mechanisms, which may result in hypotension if the fluid replacement contains inadequate amounts of sodium.

Preoperative assessment of pediatric patients

Let us turn our attention to the preoperative assessment of pediatric patients. What specifically should the anesthetist look for during the preoperative evaluation? Before we see the child, we can obtain a great deal of information from the patient's record. The doctor's order sheets and progress notes tell us what the fluid regimen has been up to this time. The record can also warn us as to possible gastric fluid losses should we see orders for the care of drainage tubes. Remember, the child who is having gastric suction can lose a great deal of acid and may have concomitant alkalosis.

Take note of the caloric supply in either intravenous fluids or dietary orders. The order sheet will tell the anesthetist if blood has been typed for the proposed surgery, thereby giving an idea of how extensive the surgeon anticipates the procedure to be. Be careful, however, not to be led into complacency if little or no blood is ordered.

If there are orders for antidiarrheal medications, we can suspect fluid loss from diarrhea, which can be extensive and debilitating in itself. If several laboratory tests have been done, it is conceivable that the child may have lost a fair amount of blood. Blood urine nitrogen (BUN) and creatinine are increased in dehydration as are hemoglobin and hematocrit. Also to be considered is the order for diuretics for the child with renal or cardiovascular disease. Antipyretics would indicate the presence of fever with considerable accompanying fluid loss.

Other things that may affect fluid balance are treatments the patient is presently receiving, such as laxatives, steroids, tube feedings and wound irrigation. Other documents, including the vital sign records, nurses' notes and intake and output records, contain a wealth of information concerning around-the-clock patient responses.

After reviewing the patient's chart, take the opportunity to talk to the child's parents. They can relate a great deal of information concerning the child's state of hydration, activity and general health.

Our next step is direct observation of the child. In the newborn and infant, one can determine the state of hydration by observing the fontanelles, eyes, tongue, and the skin of the forehead and abdomen. Sunken fontanelles and eyes, skin that retracts slowly, a dry, furrowed tongue and a tearless cry are signs that the child has some degree of dehydration. Drago offers a rule which can be applied clinically as follows: Mild dehydration represents a 5% weight loss; moderate dehydration represents a 7⅛% weight loss; and severe dehydration represents a 10-15% weight loss.1

With dehydration in mind, the anesthetist
must then consider preoperative orders for giving and withholding fluids. The child older than four should be given liquids at bedtime, 2-4 year-olds should receive fluids six hours prior to surgery, and children under two should be awakened four hours prior to scheduled surgery and given a sweet, clear liquid. In each case, a notation must be made to the time, quantity and type of fluid given.4

Opinions vary concerning premedications. Some practitioners advocate the use of sedatives, hypnotics, and antisialagogues 45 min-1 hr prior to surgery. Others feel that there is little justification in traumatizing the child with from one to three injections prior to surgery.5 They would rather give the premedication intravenously just before induction of anesthesia.

Ideally, fluid deficits should be replaced prior to the child's arrival in surgery. If they have not, the deficits can be calculated by one of several formulae which follow. To replace the fluids, 50% of the calculated volume is administered during the first hour of surgery, 25% during the second hour, and the remaining 25% during the third hour.

**Intraoperative fluid management of the newborn and the child**

Once the preoperative state of hydration is assessed and the blood volume, hematocrit and anticipated blood loss during surgery are estimated, we can next turn to the intraoperative fluid management. There are three methods commonly used for calculating maintenance fluid requirements.

The first, based on studies done by Swenson and Egan in 1969, uses body size in square meters.6 This requires either a complex formulation of body surface area based on height and weight, or the use of a surface area nomogram. Another method, based on body weight as described somewhat simply by Kelsey, states that intraoperative fluid maintenance can be achieved by administering 4 ml of fluid per kilogram of body weight per hour.

The third method was developed by Holliday and Egan in 1956.7 This technique is based on the caloric energy needs since water losses are a function of energy expenditure. The authors found that 50 ml of water utilized for each 100 calories of energy used is an approximation of insensible water loss. Based on these findings they recommend the following formula for maintenance fluid requirements:

<table>
<thead>
<tr>
<th>Fluid Requirement</th>
<th>Usage</th>
</tr>
</thead>
<tbody>
<tr>
<td>100 ml/kg</td>
<td>First 10 kg body weight</td>
</tr>
<tr>
<td>50 ml/kg</td>
<td>Second 10 kg body weight</td>
</tr>
<tr>
<td>20 ml/kg</td>
<td>Remainder of body weight above 20 kg</td>
</tr>
</tbody>
</table>

These figures represent the daily water requirement necessary to meet normal losses through the lungs, skin, urine and feces. From this, one can determine the hourly rate of administration; and, by knowing the hours of fluid restriction, one can calculate the fluid deficit and fluid needs.

Obviously, the amount of fluid lost during surgery varies with the extent of the surgery. Ahlgren and Furman both offer workable formulae for fluid replacement with various degrees of surgical manipulation.4 In addition to the maintenance requirements for fluids, the anesthetist should add 1, 2 or 4 ml/kg body weight for each hour of surgery for minimal, moderate and extensive surgical manipulation, respectively. If two body cavities are open, as occurs occasionally with congenital thoracicoabdominal defects, one should add 6 ml/kg per hour of surgical manipulation to the maintenance dose of fluids.

Also, if a non-humidified, non-rebreathing system is used to administer the anesthetic, an additional 2 ml/kg of fluids should be added for each hour of anesthesia. This, of course, is added to the fluid deficits calculated above from the preoperative period. Other considerations requiring additional intraoperative fluid include fever, which increases water loss at a rate of 10 ml/100 calories per degree Celsius rise over normal,8 and the expertise of surgical staff. An inexperienced staff may take longer, and therefore, add to the fluid loss because of an increased surgical time and less efficient manipulation of tissue which can cause additional fluid loss.

As blood loss occurs, it should be replaced immediately by use of a balanced salt solution in addition to the calculated hourly fluid maintenance requirement. When the allowable loss has occurred, steps must be taken to replace cellular components since plasma and balanced salt solutions carry little oxygen and carbon dioxide.

To determine acceptable whole blood loss, first determine the estimated red cell mass. To do this, Furman recommends estimating the blood volume and multiplying it by the patient's hematocrit.9 If we use a minimally acceptable hematocrit of 30, we can then calculate the estimated red cell mass which is the lowest acceptable volume.

Next, subtract this lowest acceptable red cell mass from the estimated red cell mass. This is the acceptable red cell loss. By multiplying this by 3, we get a figure representing the acceptable whole blood loss. Keep in mind that whole blood administered through a needle smaller than 20 gauge will suffer considerable red cell destruction.

During surgery, patient monitoring should in-
clude: (1) urine output, specific gravity and osmolality; (2) temperature; (3) ECG, blood pressure, and pulse; and (4) hydration of mucosa.

What type of crystalloid fluids should we give the patient? The child needs glucose. During periods of stress and starvation, hepatic glucose depletion occurs, which can lead to ketoacidosis. By supplying glucose we can also prevent the utilization of proteins to meet caloric needs, and therefore, reduce the risk of negative nitrogen balance and mobilization of free fatty acids. In the process of oxidation of glucose, there is the liberation of water which aids in replacing insensible loss.

Is a lactate solution of any specific value? A lactated solution will aid in maintaining renal hemodynamics and postoperatively, will help avoid acute renal shutdown, acute water retention and hypotension. However, it lacks the capacity to exert oncotic pressures comparable to plasma. To meet this need, administer a 5% solution of albumin with the lactated solution, especially if albumin levels drop below 4 gm.

Various methods of fluid administration are available today. Some considerations to keep in mind are as follows:

1. The fluid can be given by an in-dwelling catheter or straight needle.
2. Various constant infusion pumps are desirable, and volume measuring devices are important.
3. Not more than one-third of the day’s maintenance intravenous fluid volume should be bottled and hung at any given time to prevent inadvertent over-hydration.

Postoperative follow-up fluid therapy

Maintaining the continuity of patient care by informing the recovery room staff of the fluid therapy protocol which was carried on during surgery is of major importance. It is understood that the translocation of fluids and fluid losses associated with surgery do not stop with the end of the operation.

Ideally, the anticipated losses and fluid replacement regimen should be discussed by the surgeon, pediatrician, anesthetist and recovery nurses. The observation of vital signs and urinary output will play a major part in the postoperative assessment of fluid replacement and renal function.

REFERENCES


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