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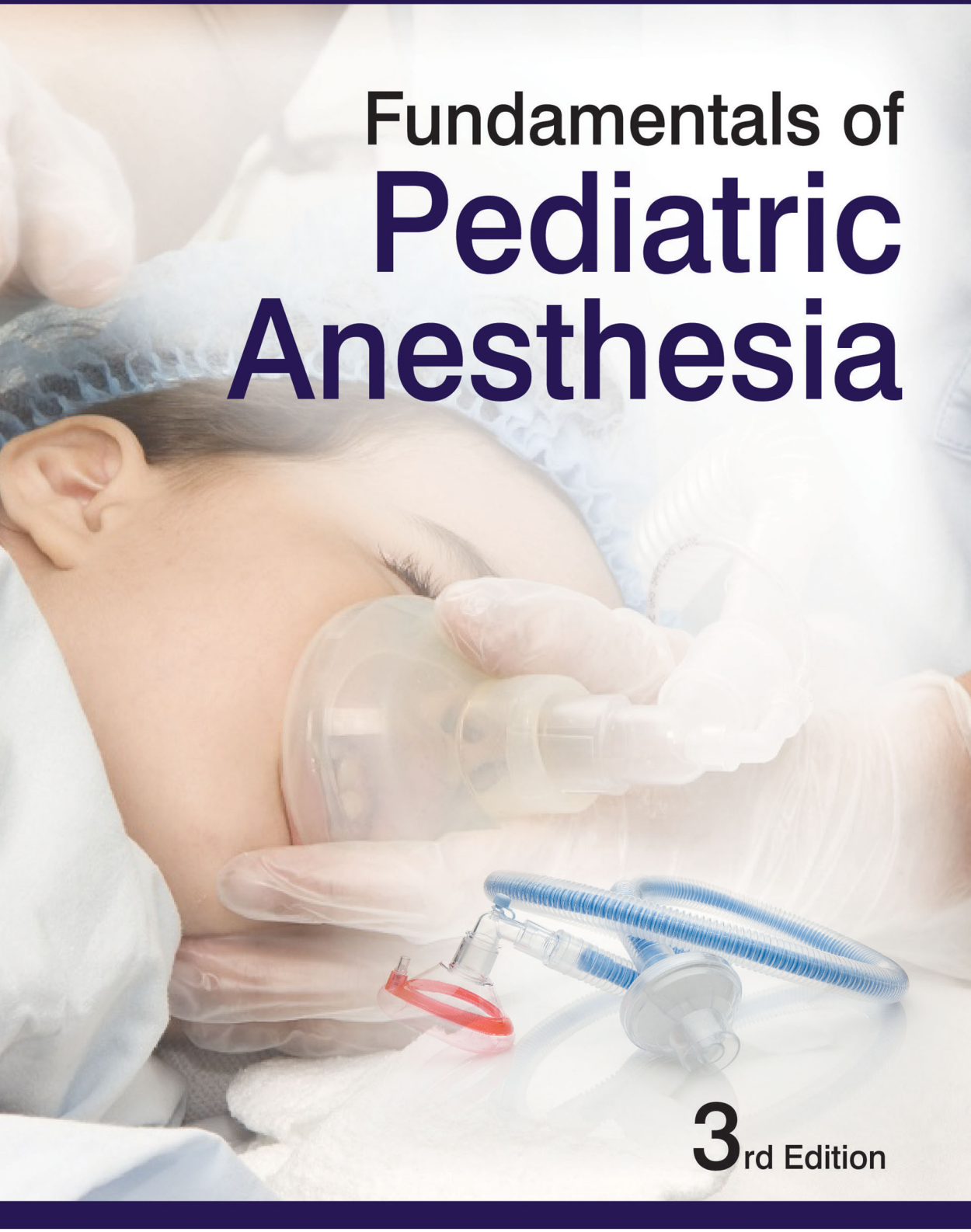
Fundamentals of Pediatric Anesthesia



3rd Edition

Arun Kumar Paul

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CHAPTER

4

Renal Function and Fluid Balance

RENAL FUNCTION

The kidneys are immature at birth and both glomerular filtration and tubular reabsorption are somewhat reduced until the age of 6 to 8 months. Initially, the number of cells increases and then the size. Until about 4 months of age, there is low cortical blood flow and relatively high intrarenal vascular resistance. Eventually, 80 to 90% of renal blood flow occurs in the cortex and 10 to 20% in the medulla. The autoregulatory abilities of the infant kidney are not known. This possible lack of autoregulatory mechanism may be a contributing factor to acute renal failure in premature infants. In fetal life, the kidney is essential as it excretes copious amounts of dilute urine which maintains the amniotic fluid volume during pregnancy. During gestation, the fetal kidneys receive 3 to 7% of the cardiac output while mature kidneys receive roughly 20% of the cardiac output. This level is usually achieved by about 2 years of age.

In the fetus, glomerular filtration is usually less than 1 ml/minute, but in the full term baby glomerular filtration rate is 2 to 4 ml/minute, within the first few days it is 8 to 20 ml/minute and is said to be mature by 1 year of age. This rapid increase in glomerular function is mostly due to increase in systemic blood pressure and decrease in renal vascular resistance. The pores of glomerulus of an infant kidney are about half the size of those in adults. However, for normal functions, the immature kidneys are usually adequate for the infants, but under abnormal stress the baby may be adversely affected. Thus, the neonates are more susceptible to nephrotoxic drugs like aminoglycosides. The doses of filtered drugs like digoxin, tubocurarine, etc. should be adjusted accordingly in neonates and infants.

Tubular function in newborn is depressed in comparison to that in adults. Small-for-date babies have decreased tubular reabsorptive capacity for glucose and may have glycosuria with osmotic diuresis and dehydration. Albuminuria is also common in premature infants. On the whole, in

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infants the capacity to excrete water and retain sodium or to concentrate urine is somewhat restricted. The maximum urine osmolarity is about half compared to that of adult. The permeability of the tubular membrane and the colloidal osmotic pressure are usually low in the early weeks of life.

In view of all these factors, there is inability to handle excessive water loads, and over infusion or over transfusion may lead to edema and cardiac failure. Abrupt increase of sodium, as in cases with administration of sodium bicarbonate, is also handled poorly. Urinary obstruction, hypothermia, excess catecholamines, high arterial oxygen tension, etc. increase the disability to handle abnormal loads. Infant has a low threshold for bicarbonates and does not rapidly excrete acids or ammonia; thus, a mild acidosis and raised blood urea nitrogen are normal. Infants have persistent metabolic acidosis though the urine is alkaline, the pH being 5 to 7. Urine excretion in newborn is about 15 to 60 ml/day, at 6 months 250 to 450 ml/day, at 1 year 500 to 600 ml/day, at 5 year 650 to 1000 ml/day, and at 12 years 700 to 1500 ml/day. In this connection, it should be borne in mind that the full bladder rises higher out of the pelvis in infants and children than in adults.

Renal insufficiency is not uncommon in children. Acute renal failure in children as in adults is divided into prerenal, renal and postrenal causes. Prerenal causes are mostly due to low circulating blood volume, low cardiac output, hypotension, hypoxia and serious infection. The most common causes of intrinsic renal failure are acute glomerulonephritis following bacterial, viral, mycoplasmal, fungal, protozoal, helminthic or spirochetal infections, and nephrotoxic drugs and chemicals. Glomerulonephropathy may also occur in Henoch-Schonlein purpura where there is vasculitis attacking joints, kidneys and the gastrointestinal system. In children, acute tubular necrosis may occur due to renal ischemia and from nephrotoxic drugs. Postrenal failure usually occurs as a result of bilateral obstruction of the kidneys, obstruction at the bladder level, urethral obstruction or in unilateral obstruction in presence of evere hypofunctioning of one or both kidneys. Chronic renal failure may occur above the age of 5 years and is mostly due to obstructive uropathies, or congenital malformations of the urinary tract.

FLUID AND ELECTROLYTE BALANCE

At birth, total body water in a full term baby is about 80% of his body weight. It decreases to about 70% of body weight by the age of 3 months and then to adult levels of 60 to 65% at the age of 1 year. The extracellular fluid in the

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case of neonate is about 40% of total body fluid. It decreases to 30% of total body fluid by 3 to 6 months and then gradually decreases to adult levels of about 20%. Fluid status in the neonates, infants, and children is mainly governed by the kidney. The infant kidney readily excretes dilute urine but there is limitation of its power to concentrate and/or to conserve water. Infants have also limited ability to cope with excess water and sodium.

The rapid rate of fluid turnover in infants and children is mostly due to their high metabolic rate and high oxygen consumption. On the weight basis, an infant may lose water at about twice the rate of an adult and thus rapidly becomes dehydrated. It is said that in an adult if there is no intake by mouth for a day, there is weight loss of about 4%, but in an infant it may be about 10% of his body weight. Fluid imbalance in neonates, infants and children may cause more immediate and adverse reactions than in adults and this has important implications for perioperative fluid therapy.

Blood volume in relation to weight in neonates and infants is always greater than that in adults, but it remains a similar proportion of total body fluid. Blood volume in newborn is 90 to 100 ml/kg body weight and within 1 to 2 years it decreases to about 80 ml/kg and then gradually attains the adults level of 75 ml/kg at the age of 2 to 3 years. It is said that a moderate loss of blood volume of about 10% indicates blood replacement in pediatric patients and when 15% of blood volume is lost the infant is potentially in danger.

Blood components change mostly in the first week; fetal hemoglobin is rapidly lost with relatively slow replacement by the adult type. Protein level is usually low in infants, which may lead to reduced plasma osmolarity. Thus, the extracellular fluid easily collects in interstitial space and there is increased possibility of edema in case of excessive extracellular fluid accumulation.

Water Balance

Water balance is maintained through a delicate balance between water loss and gain in the body. Water loss usually occurs by evaporation through lungs and skin, in the form of urine and from alimentary tract. Water loss in infants is most variable depending on metabolic rate, insensible loss through lungs and skin, ambient temperature and so on. At a temperature of 34°C with relative humidity of 45%, infant loses water at the rate of about 20 ml/kg body weight per 24 hours by evaporation. It is gradually reduced with advancing age. The amount of water lost through alimentary tract is usually about 10 ml/kg/24 hours. In growing children, there is some retention of water for growth. It is very small, amounting to about 5 ml/kg/24 hours. There is also loss of water through urine. The infants are

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mostly on fluid diet. Infants excrete very dilute urine as the infant kidney is less able to concentrate urine. Absolute minimum water output to allow excretion of urea and electrolytes is usually 35 ml/kg/24 hours in case of infants upto 4 weeks of age, about 25 ml/kg/24 hours in infants and about 10 ml/kg/24 hours in older children.

Water intake is usually by mouth and alimentary tract, through infusion and by oxidative metabolism of the body. Input should always be well in excess to cover for insensible loss, urinary loss and alimentary tract loss and also retention for growth. Allowances should also be made for water produced in metabolism. In infants, it is about less than 1 ml/kg/24 hours. Minimum water requirement for healthy children is about 60 ml/kg/24 hours in cases of infants upto 1 month of age, 50 ml/kg/24 hours in infants of 1 to 3 months of age. In older children, it steadily falls to 25 ml/kg/24 hours. The input of water should be maintained as follows: upto 10 kg, 100 to 130 ml/kg/hours; 10 kg to 20 kg, 75 to 100 ml/kg/24 hours, and over 20 kg 25 to 50 ml/kg/24 hours.

Electrolyte Balance

Electrolytes are essential for life and for adequate growth. The excretion of electrolytes through urine and insensible water loss, should always be replaced. In children as in adults, the kidney does not recover all the potassium content of the glomerular filtrate, thus urinary loss is usually substantial. In malnutrition, tissue catabolism further increases potassium loss.

Minimum requirements of electrolytes are as follows: Sodium 2 mmol/kg/24 hours, potassium 1 mmol/kg/24 hours and calcium 1 mmol/kg/24 hours.

FLUID MANAGEMENT DURING PEDIATRIC SURGERY

Fluid management during pediatric surgery is most vital and many times it dictates the outcome of surgical procedure and reduces the incidence of mortality and morbidity of surgical patients. Infants and children tolerate blood loss very badly, particularly during anesthesia and surgery. Acute and/or inadequately treated blood loss causes cardiovascular insufficiency very easily in children. The distribution of blood in the child body differs from that in adults and there is much less amount in peripheral venous pools in upper and lower extremities.

During surgery, the child may have a deficiency of extracellular fluid due to various reasons such as prolonged preoperative fasting, evaporative fluid loss from skin, gut, pleura, peritoneum, dry anesthetic gases and so on. Major surgery is associated with an apparent reduction in functional

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extracellular fluid volume because of sequestration. Any operation which may result in blood loss exceeding 5% of estimated blood volume should have intravenous fluid therapy. Blood loss above 10% of blood volume should indicate blood transfusion.

Stress of surgery and anesthesia has its implications on fluid balance. Surgery and anesthesia may cause acute reduction in renal function and urinary output. In the postoperative period, there is usually retention of sodium and water as a consequence of metabolic response to injury. Oliguria is mostly due to reduction and redistribution in renal blood flow caused by increased sympathetic activity and catecholamine release, and partly due to an increase in plasma antidiuretic activity due to ADH, adrenocortical hormones and hormones liberated in the kidney.

Anesthesia may influence the fluid and electrolyte balance. Vasodilatation caused by most volatile anesthetics maintains the renal blood flow and provides renal excretion of excess water and electrolytes, provided no severe hypotension occurs. Some volatile anesthetic agents may reduce renal blood flow by causing renal vasoconstriction. Hypocarbia from any cause may also reduce renal blood flow by causing vasoconstriction. Narcotic analgesics in large doses may depress catecholamine, plasma cortisol and growth hormone response to surgery. It may also reduce ADH release.

Excessive fluid therapy should always be avoided; otherwise, pulmonary congestion and even edema may occur. However, the kidneys of children are able to excrete excess amount and thus embarrassment of the child may not be a problem. On the other hand, active diuresis may protect against renal shut down resulting from shock or trauma.

OBJECTIVES OF INTRAVENOUS FLUID THERAPY

a. To provide adequate fluid volume in presence of dehydration.
b. To replace the predicted loss of fluid (blood).
c. To provide an excess fluid volume to act as protection buffer against blood loss.
d. To prevent hypotension caused by vasodilatation of various drugs used in anesthesia like halothane.
e. To provide nutrition.

Fluid Therapy

During fluid management, the volume of the fluid should be calculated and the type of the fluid should be selected carefully considering preoperative dehydration either by usual fasting or abnormal losses as in pyloric stenosis, burns, etc. maintenance requirements, surgical trauma and body temperature.

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Preoperative dehydration

It may be due to prolonged period of fasting or secondary to increased losses due to vomiting, diarrhea, pyrexia, etc. The amount of deficit can be assessed by physical examination, body weight loss and hematocrit. The percentage of the normal body weight in kg can be converted to ml.

Clinical assessment of dehydration

- Mild dehydration: 5% loss of body weight. Child is pale, dry mouth and tongue, skin and subcutaneous tissue are less elastic, fontanelle is less tense, pulse—normal, blood pressure—Normal, urine output becoming less, specific gravity 1010 (normal1006 in infants).
- Moderate dehydration: 10% loss of body weight. General condition becoming worse, pyrexia, mucous membrane and tongue are dry, sunken fontanelle, tachycardia and hypotension. Urine volume is scanty, specific gravity is 1010 to 1015.
- Severe dehydration: Over 15% loss of body weight, child in shock, hypovolemic, skin is gray, mottled, lax and inelastic. Slow capillary refilling, eyes are sunken, fontanelle are depressed, veins collapsed, marked tachycardia and hypotension, pulse is feeble, anuria or severe oliguria and respiratory distress.

Some investigations should help in the diagnosis and these are hemoglobin concentration, hematocrit, urea and creatinine estimation, electrolytes, urine and blood osmolality. Blood pressure, central venous pressure and urine output should be monitored during replacement of losses. Physiological saline, dextrose saline or even blood may be needed depending upon the type of fluid loss.

Maintenance fluids

These are the fluid losses occurring normally through the kidney, bowel, skin and lungs. The simplest way to calculate the maintenance fluid of average child is approximately 4 ml/kg/hour for the first 10 kg body weight, adding 2 ml/kg/hour for the next 10 kg and then 1 ml/kg/hour for body weight above 20 kg. Dextrose 4%/saline 0.18% is used normally, except in neonatal period where one-third to one-fifth dextrose saline can be used. In addition, potassium 2 mmol/100 ml may be given provided urinary output is adequate.

Replacement of losses (other than blood loss)

This is due to abnormal losses not covered by maintenance fluids and during operation it accounts for the evaporative losses from the operating

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site, *third spacing* and respiratory water loss due to dry anesthetic gases and lack of humidification in the ventilator circuit. Fluid may also be lost by evaporation if overhead radiant heaters are used. For minor surgery, it is 1 to 3 ml/kg/hour, for moderate surgery it is 3 to 5 ml/kg/hour and for major surgery it is 5 to 7 ml/kg/hour. Respiratory water loss due to dry gases may be 2 ml/hour. A rise of body temperature by 1°C can increase fluid loss by 12%.

Blood loss replacement

When more than 10% of the estimated blood volume is lost, blood should be replaced. If crystalloid solution is used to replace the blood loss, the replacement volume is 3 to 4 times the blood loss. When blood is given, it should be replaced milliliter for milliliter. In case of blood loss, hypotension indicates a loss of more than 20% blood volume. Following return to normal blood pressure, urine output should be at least 1 ml/kg/hour.

The following may be considered as another useful guide: In the first hour of operation 15 ml/kg. Subsequently, basic 2 ml/kg/hour + for mild surgery 2 ml/kg/hour or for moderate surgery 4 ml/kg/hour or for major surgery 6 ml/kg/hour + blood replacement.

An alternative regime may also be taken into account as follows: Initially Hartmann solution should be given at the rate of 20 ml/kg/hour in the first hour or so of the operation. This solution closely approximates the composition of interstitial fluid. Hartmann solution is Ringer lactate solution and its one liter contains sodium 130 mEq, potassium 4 mEq, calcium 4 mEq, chlorides 100 mEq and lactate 28 mEq. Infusion is then to be continued according to the need of the child. Prolonged preoperative starvation may cause hypoglycemia and it is recommended to administer 5% dextrose solution. It may be continued for 24 hours to make up the rest of normal requirement of water of the child. Potassium may also be added to fulfil maintenance need for which serum potassium concentration should be measured often. In presence of significant trauma, blood loss, and prolonged surgery additional Hartmann solution, 20 ml/kg/hour, may prove useful.

Half-strength Hartmann solution in 5% dextrose solution can also be given intraoperatively. Blood losses of 10 to 20% of blood volume can reasonably be replaced by plasma substitutes like dextran, hemaccel, etc. without restoring to blood transfusion. Some anesthesiologists prefer to maintain the hematocrit at 30%. Routine blood loss measurement is essential as it dictates the need of blood transfusion and many times it avoids unnecessary blood transfusions. Blood loss can be easily monitored

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by weighing the swabs, measuring the suction volumes and by visual evidence.

Blood loss below 5% of estimated blood volume can be ignored and usual infusion can be maintained. Losses from 5 to 10% of blood volume should be adequately replaced by an additional equivalent volume of Hartmann solution. Blood loss of 10 to 15% of blood volume may need but 70,000 molecular weight dextran or hemaccel can be replaced satisfactorily. Blood loss above 15% should always be replaced by blood. But for all practical purposes, in case of above 10% blood loss, blood transfusion is indicated.

During intravenous therapy, following measures should be adopted:

i. All infusions should be well-recorded particularly the type of fluid and its volume. Intake and output chart must be maintained. Blood group should be noted and well-checked before transfusion.
ii. Full aseptic measures should be adopted.
iii. Careful monitoring of vital signs such as pulse, respiration, blood pressure and body temperature is essential.
iv. Blood loss should be assessed carefully.
v. Dehydration, if present, should be clinically assessed.
vi. Central venous pressure monitoring, urine volume, plasma electrolytes, hemoglobin estimation, hematocrit, blood gas analysis and so on may be helpful in selected cases. Blood glucose estimation may have to be done in some cases. Dextrose solution in excess of 10 ml/kg/minute may lead to hyperglycemia and osmotic diuresis. Hyperglycemia is usually associated with hypertonic dehydration.
vii. Progress of therapy should be carefully judged by clinical findings and laboratory investigations.
viii. Whenever children are given intravenous fluids, it is essential to have a burette system available. In setting up a drip, meticulous care is needed to avoid the entry of any air bubbles into the bloodstream.
ix. Catheterization of any vein particularly the cut-down technique should be done with full aseptic measures. Intravenous infusions may lead to phlebitis, if kept for prolonged period.
x. The drip rate should be well-controlled even to very small volumes. Drip controllers of either mechanical or electrical type may help in the administration of small volumes.
xi. Drugs used in infants are usually given well diluted. Overdilution should be avoided, since excessive fluid intake or overload may result. The drug and dilution should be well recorded.

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Some basal fluid volumes in neonates and adults on average or range		
	Neonate	Adult
Urine volume, m//kg/hour	1–4	1–4
Urine osmolality, mOsmol/liter	100–600	50–1600
Extracellular volume, % body weight	35	20
Intracellular fluid volume, % body weight	40	40
Plasma, % body weight	5	5
Total fluid volume, % body weight	80	65
Blood volume, ml/kg	80–90	65–70

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