PAEDIATRIC PERIOPERATIVE FLUID THERAPY- CURRENT PERSPECTIVE

Mohanchandra Mandal[1], Dipanjan Bagchi[2], Susanta Sarkar[3], Piyali Chakrabarti[4], Mrinal Saha[5], Suchitra Pal[6]

[1]Associate Professor, Department of Anaesthesiology, NBMC, West Bengal.
[2]Consultant Anaesthesiologist, Department of Anaesthesiology, Howrah District Hospital, Howrah, West Bengal.
[3]Associate Professor, Department of Anaesthesiology, NBMC, West Bengal.
[4]Postgraduate Trainee, Department of Physiology, NBMC, West Bengal.
[5]Postgraduate Trainee, Department of Anaesthesiology, NBMC, West Bengal.
[6]Nursing Sister, MSc Nursing (Psychiatry), Central Hospital, SE Railway, Kolkata, West Bengal.

ABSTRACT

BACKGROUND

Hypotonic fluid containing sodium less than 130 mEq/L with high (4 - 5%) glucose is no longer tenable in paediatric patients in the perioperative atmosphere where ADH response is high. Hypovolaemia should be treated promptly to minimise the ADH response. Dextrose containing fluids in the perioperative setting should be reserved only for certain groups of paediatric patients who are at high risk of hypoglycaemia. The tonicity of the fluid should be as close to plasma as possible. There is some gray zone about the status of the commonly available isotonic and near-isotonic fluids regarding the superiority of one over another.

KEYWORDS

Hyponatraemia, Hyponatraemic Encephalopathy, Paediatric, Perioperative Encephalopathy.

HOW TO CITE THIS ARTICLE: Mandal M, Bagchi D, Sarkar S, et al. Paediatric perioperative fluid therapy- current perspective. Journal of Research in Anaesthesiology and Pain Medicine 2017; Vol. 3, Issue 1, Jan-June 2017; Page:11-15.

BACKGROUND

Perioperative fluid therapy is a prescription which should be adapted to the patient's status, the extensiveness of surgery and the expected course of events in the perioperative period. Fluid therapy is aimed at correcting the fluid deficit, providing maintenance fluid requirement, replacing ongoing losses and ultimately providing the volume of fluid needed to maintain adequate tissue perfusion. Literature search was done using relevant keywords such as paediatric fluid therapy, perioperative fluid therapy, hyponatraemia, hyponatraemic encephalopathy, etc. Only full text articles in English language were considered. The search was mainly confined from 2000 to recent date except a few older seminal articles.

Why Infants and Children need a Special Prescription?

Infants and children are not simply small adults,[1] rather they are special population with their unique physiology, therefore need delicate balancing.

Special physiological features in this age group are- Infants and children are vulnerable to both hypovolaemia and hypervolaemia. Neonates and infants are more vulnerable to fluid loss via urine, even in fluid deficit state. They have poor ability to concentrate urine owing to their immature distal nephron with an anatomically shortened loop of Henle. Young infants are also vulnerable to greater insensible fluid loss due to higher skin permeability, higher basal metabolic rate and larger surface area. This insensible water loss is further increased in preterm infants due to use of radiant warmer and phototherapy.

Financial or Other, Competing Interest: None.
Submission 26-04-2017, Peer Review 10-06-2017,
Acceptance 17-06-2017, Published 29-06-2017.
Corresponding Author:
Mohanchandra Mandal,
A-5, M. O. Qtrs.,
NBMC Campus,
P. O. Sushrutanagar District,
Darjeeling-734012.
E-mail: drmcmandal@gmail.com

Neonates have relatively larger water content (around 80% of body weight) as compared to 60% in adolescents and adults.[2] Extracellular Fluid (ECF) volume is equal to Intracellular Fluid (ICF) volume in neonates. Infant exchanges 50% of ECF volume daily as compared to about 15% daily in adults. In this background of larger turnover of ECF, we are administering a proportionately larger volume of fluid (daily requirement of 100 mL/kg for body weight of 10 kg or less) in a smaller capacity of circulating volume (80 mL/kg). Hence, fluid overload can occur easily in young children.[1,3]

Underhydration and overhydration, both are poorly tolerated by preterm babies, sick neonates and children with renal failure. Neonates and young infants are more sensitive to hypovolaemia, because of incomplete myocardial development and immature sympathetic nervous system. Infants and children are less able to increase cardiac output by increasing the stroke volume. Hypotension is a late and ominous sign of hypovolaemia, which requires immediate treatment. Due to poor ventricular compliance, biventricular heart failure can occur easily with fluid overload.[1] The Glomerular Filtration Rate (GFR) in a term neonate is 25% of an adult due to smaller surface area available for filtration. The GFR rises rapidly during the first week of life and maturation is achieved by the end of the first month of life. The distribution of body fluid undergoes a gradual change during the first two years of life.[1]

Increased propensity for oedema (esp. in lungs and brain): The plasma protein level is low in this population resulting in a low plasma oncotic pressure. The blood-brain barrier is also immature. A low plasma oncotic pressure and higher permeability of the capillary wall in preterm babies compared to term infants and adults enhances the shift of water from the intravascular to the interstitial compartment increasing risk of oedema.

This population is also susceptible to both hyponatraemia and hypernatraemia. The ability of infant's kidney to eliminate excess sodium is limited. Exceeding this amount in the absence of loss results in hypernatraemia. The higher propensity of choosing hypotonic fluids in the atmosphere of increased Antidiuretic Hormone (ADH) due to a multitude of factors along with lack of routine electrolyte monitoring makes the children prone to hyponatraemia.[1]

Higher brain-to-skull ratio in children renders them prone to cerebral oedema compared to adults.[4,5] The brain of a child outgrows growth of its skull (reaches adult size by 6 years and 16 years respectively). In children, the Cerebrospinal Fluid (CSF) is proportionately less than the other components of cranium. So the capacity of CSF to buffer the brain expansion is relatively lesser. The intracellular concentration of sodium in child's brain is about 25% higher than in adults. Early in hyponatraemia, the brain extrudes the intracellular sodium to the extracellular space with limited function of Na^+K^+ATPase. However, the paediatric kidney is unable to excrete the excess free water load. This leads to osmotic movement of fluid into a brain with a high brain-to-skull ratio resulting in relatively rapid cerebral oedema, which is seen with hyponatraemia in paediatric patients.

Much of the practice of perioperative fluid therapy in paediatric patients is based on the landmark article of Holliday and Segar.[6] Daily sodium and potassium requirements in children amount to 3 and 2 mmol/kg respectively. This combination of maintenance fluid and electrolyte requirements results in a hypotonic electrolyte solution. The postoperative period is at risk for nonosmotic secretion of ADH, which reduces the ability of the kidneys to excrete free water. In the context of ADH release, the associated low urine output makes maintenance volume requirement decrease to 50% of the calculated hourly rate. Isotonic fluids are suitable during intraoperative period. Controversies still exist on the nature of maintenance fluid in the postoperative period.[4,7-9]

Glucose during Perioperative Period- Is it Necessary at all?

Since the original publication of Holliday and Segar,[6] one-fourth to one-half strength saline with 5% dextrose have been used as intravenous maintenance fluid in children. The dextrose is added with an intention to prevent hypoglycaemia. Hypoglycaemia (symptomatic with blood glucose level < 45 mg/dL) can produce devastating effects on CNS, especially in neonates with an increase in morbidity and mortality in paediatric ICU patients. Neonates have a higher metabolic rate with an increased risk of perioperative hypoglycaemia and lipolysis. However, during anaesthesia, oxygen consumption and metabolic rate are decreased in neonates as well, reducing intraoperative glucose requirement.

The actual risk of perioperative hypoglycaemia has been demonstrated to be low in normal healthy infants and children (1% - 2%) despite prolonged fasting periods.[7] In a recent study,[10] it was concluded that 2 - 4% dextrose-containing fluid is more suitable for use during major neonatal surgeries requiring average fluid infusion rate of 10 mL/kg/hour.

Hyperglycaemia, on the other hand induces osmotic diuresis, dehydration and electrolyte disturbances and increases the risk of hypoxic-ischaemic insult to brain and spinal cord. In the presence of ischaemia or hypoxia, impaired metabolism of excess glucose leads to accumulation of lactate, intracellular acidosis, compromised cellular function and cell death.[4] Also, dextrose containing solutions do not properly replace perioperative fluid losses via drain or nasogastric tube and frank blood loss.

There is a growing consensus to selectively administer intraoperative dextrose only in patients at great risk for hypoglycaemia such as neonates (in the first 48 hours of life), preterm neonates and term neonates already receiving dextrose containing solutions and children of low birth weight (less than 3rd percentile). Also, children receiving hyperalimentation or parenteral nutrition, those with endocrinopathies, children born to diabetic mothers, those having prolonged surgery or undergoing extensive regional anaesthesia with a reduced stress response should receive a dextrose containing maintenance solution (1 - 2.5% dextrose) or have their glucose monitored during surgery.[10-14]

Why Hyponatraemia in Perioperative Settings?

In the perioperative environment, D5 - 0.45% saline and D4 - 0.18% saline solutions are hypotonic. There is low sodium content (only around ≤ 70 mmol/L of sodium) in these solutions to maintain isotonicity. Such solutions remain isotonic only in vitro.[8] Once they enter blood, glucose is metabolised and the solutions become effectively hypotonic. This predisposes the paediatric patients to dangerously low levels of sodium.[8] Recent studies draw attention to the postoperative hyponatraemia and associated morbidity and mortality rates demanding a consensus regarding the nature and the quantity of fluids to be used.[15,16]

Besides hypotonic fluid therapy, other causes of hyponatraemia may co-exist in the perioperative setting like brain injury, brain tumours and other causes of inappropriate secretion of ADH. Plasma ADH is often increased in postoperative period owing to hypovolaemia, stress, pain or traction of dura mater.[7] Exacerbated ADH response attributes to impaired ability to excrete free water. Dilutional and hypotonic hyponatraemia ensues from a rapid infusion of large volume of electrolyte-poor (hypotonic) fluid exceeding the Kidney's capacity of free water excretion.[13,17] The resultant hyponatraemia causes osmotic movement of free water across cell membrane from extracellular to intracellular compartment and cellular oedema. The brain is the most seriously damaged organ with potential threat of brain herniation. This occurrence of iatrogenic hyponatraemia has led to a critical reappraisal of the validity of the Holliday-Segar method for calculating maintenance fluid requirements and also the choice of solution in older infants perioperatively. The emphasis is on the prevention of hyponatraemia, which is the most common electrolyte disorder in hospitalised patients (incidence of approximately 1% - 4%).[1,4,7,8]

Rapid expansion of ECF may suppress ADH response in acutely ill children with subtle hypovolaemia. After expansion of ECF, IV maintenance can be achieved safely using recommended amount of hypotonic saline. In other words, ECF must be restored (thus ADH response be curtailed) before the start of maintenance therapy.[18]

How much Sodium is Enough?

Only isotonic solutions should be used in clinical situations known to be associated with increased ADH secretion. No single fluid can be used safely in all situations. In patients suffering from significant renal impairment or congestive cardiac failure, ECF overload could result if excess amount of 0.9% NaCl is administered. Likewise, 0.9% NaCl could result in hypernatraemia if administered to a patient with renal or extrarenal free water losses as is seen in nephrogenic diabetes insipidus or excess nasogastric drainage. Further use of normal saline can lead to hyperchloraemic acidosis in a dose-dependent fashion.[19]

Lactated Ringer's solution does have an advantage over 0.9% NaCl. The former contains lactate which can be converted to bicarbonate by the body, but unfortunately it is hypotonic. Lactated Ringer's solution would be more suitable if the manufacturers increase the sodium concentration to 150 mEq/L.

Postoperative Hyponatraemia or Hypernatraemia: A Diagnostic Dilemma

Postoperative hyponatraemic encephalopathy can be difficult to diagnose due to nonspecific features such as headache, nausea and vomiting which are common occurrences in many medical illnesses and postoperative period.[5] Females, children, patients with hypoxaemia or underlying CNS disease are at highest risk for developing this type of encephalopathy even at mildly hyponatraemic values. Neurological symptoms of hyponatraemic and hypernatraemic dehydration are often difficult to distinguish. Hyponatraemic dehydration manifests clinically with symptoms of volume depletion plus non-specific symptoms like irritability, headache and weakness, and may progress to cerebral oedema with confusion, convulsion and coma.[4,5,7]

On the other hand, hypernatraemic dehydration may also present with restlessness, lethargy, hyperreflexia, seizures and coma. Thus, an irritable, restless, lethargic child who suffers seizures and progresses to coma may put clinicians in a diagnostic dilemma, unless facility of estimation of sodium concentration is not available readily. Often respiratory arrest is the first manifestation of such electrolyte imbalance, because hyponatraemia progresses unnoticed until too late. The mortality rate of hyponatraemia in hospitalised patients is reported to be 7- to 60-folds more frequent compared with normonatraemic controls.[20] Anaesthesiologists should maintain a high index of suspicion for hyponatraemia in patients with neurologic symptoms during the perioperative period.

Acute symptomatic hyponatraemia is a medical emergency, which needs immediate intervention. The risk of seizure increases when sodium level is below 125 mmol/L. As such, hypertonic saline should be infused to raise plasma sodium to at least this serum level. A suspected case of hyponatraemic encephalopathy, even if only mildly symptomatic should be treated with a 2 mL/kg bolus of 3% NaCl before proceeding with radiologic investigations. Each 2 mL/kg bolus usually results in a 2 mEq/L increase in serum sodium at the maximum and may be repeated up to 2 - 3 times if needed. This will result in an increase in serum sodium of 4 - 6 mEq/L, which falls within the safe range of even the most conservative approach. This increase in serum sodium is likely to decrease brain oedema. A patient not responding to such a therapy most likely does not have hyponatraemic encephalopathy. It needs mention that postoperative patients are at lower risk of developing cerebral demyelination, as hyponatraemia in the perioperative setting is of acute onset and is unlikely to be overcorrected with this therapy.[5,6,12,21]

Controversies

Two opposite views have emerged regarding both the volume and composition of postoperative fluids.[7] Holliday and Segar have modified their previous recommendation regarding maintenance fluid therapy for surgical patients. They advise correction of fluid deficit at first with 20 - 40 mL/kg of isotonic saline, followed by 'half of the average' maintenance fluid for the first 24 hours along with the monitoring of plasma sodium. Isotonic saline is to be used for countering any hypovolaemia (called it as 'measured expansion'), followed by a 'keep open' rate which is to be modified according to the events during surgery and immediate recovery. They uphold the notion that isotonic saline infused as the sole maintenance fluid may impose a sodium load, which may be harmful similar to free water.[22]

The other school promotes using isotonic saline in 5% dextrose in hospitalised children except in those with plasma sodium above 140 mmol/L. When the plasma sodium is < 138 mmol/L and there is risk of non-osmotic secretion of ADH, the maintenance rate should be reduced. In children with plasma sodium more than 160 mmol/L, isotonic solutions have been recommended to reduce chances of neurological injury due to rapid fall in plasma sodium. The rate of reduction of plasma sodium should not exceed 0.5 mmol/L/hour if hypernatraemia has prevailed for more than 5 days.[12,23] There are two potential problems when using only isotonic fluids to avoid hyponatraemia. The first is the desalination process. Clinical evaluation of the magnitude of ECF contraction often overestimates the gravity of problem, resulting in large volume of isotonic fluid administration. This leads to production of hypertonic urine and fall in plasma sodium level- a process termed as 'desalination.'[21,24,25] The extracellular space is expanded by isotonic solutions; at the same time the loss of hypertonic urine and retention of free water caused by ADH creates a net increase in hypotonic fluids. This 'desalination process' leads to postoperative hyponatraemia. Although, the potential for significant hyponatraemia is lower with isotonic fluids than with hypotonic fluids, large volumes of any IV fluid which may accumulate in the extracellular space can increase the risk for low serum sodium. Second, there is a concern that patients who receive isotonic fluid may develop hypernatraemia.

Recommendations

Recent guidelines provide following general recommendations about fluid therapy for children and young people:

For resuscitation: A glucose-free crystalloids containing sodium in the range of 131 - 154 mmol/L (e.g. RL, RS, NS) should be used with a bolus of 20 mL/kg over less than 10 minutes. In pre-existing co-morbid conditions such as cardiac and/or kidney disease, small fluid volumes may be needed.[26]

For routine maintenance: Initially isotonic crystalloid containing sodium in the range of 131 - 154 mmol/L should be used. Plasma electrolyte and blood glucose should be measured at the start of infusion and at least every 24 hours thereafter. If there is a risk of water retention, the volume should be restricted to 50 - 80% of routine maintenance needs.[26]

For replacement of abnormal loss and to counteract the effect of redistribution: NICE guideline recommends to consider isotonic crystalloids containing sodium in the range of 131 - 154 mmol/L for replenishment of abnormal losses and to correct the relative hypovolaemia of redistribution.[26]

(a) Intraoperative Fluids: Glucose-free isotonic solutions should be used intraoperatively in children over 4 - 5 years of age. In infants and young children, dextrose 5% solution should be avoided; instead lactated Ringer's solution with 1 - 2% dextrose is appropriate.[7] Recent European consensus states that intraoperative fluid should be closer to plasma regarding the osmolarity and sodium content. It should have a glucose concentration around 1 - 2.5% and should contain metabolic anions as bicarbonate precursors to prevent hyperchloraemic acidosis.[13] An intravenous fluid containing a sodium content less than 75 mmol/L is being considered as 'poison' for children.[27]

(b) Postoperative Fluid Therapy: For minor surgical procedures, intraoperative administration of large volumes of crystalloids (superhydration) is associated with a reduced incidence of postoperative nausea and vomiting after anaesthesia in both paediatric and adult patients.[7] Hyponatraemia is the most frequent electrolyte disorder in the postoperative period. When hypotonic fluids are infused in this setting of raised ADH, dilutional hyponatraemia and cerebral oedema may result. This risk of hyponatraemia could be lessened with isotonic fluids regardless of the volume status.

The increased ADH response can justify to curtail the volume of postoperative fluid by approximately 33 - 50% of calculated amount.[7,28, 29] Boluses of isotonic saline should only be administered when there is clear haemodynamic indications. This is to avoid unnecessary infusion of large amount of isotonic saline to minimise chances of desalination process. On the other hand, hypotonic fluids should not be used routinely in the intraoperative or postoperative period when ADH response is at its peak. It should also be avoided in a patient with low-normal sodium level or having a clear-cut hyponatraemia.[28-30]

CONCLUSION

Administration of dextrose containing fluids in paediatric patients in the perioperative setting needs to be strongly discouraged. It should be reserved only for certain groups of patients at high risk of hypoglycaemia. Blood glucose should preferably be monitored perioperatively, and the patient should be followed up closely during recovery. Hypovolaemia should be treated rapidly to curtail the magnitude of ADH level. The daily maintenance fluids are to be reduced by 30 - 50% of the calculated hourly rate during the first postoperative day after major surgery in children at risk of high ADH secretion, provided they are normovolaemic. Further investigation is warranted for the consolidation of supremacy of isotonic fluid in perioperative situation.

Declaration

The first author delivered an invited lecture on 'Perioperative fluid therapy in paediatric patients' in the 23rd Joint Annual Conference (East Zone), hosted by Indian Society of Anaesthesiologists, West Bengal State Branch and Kolkata Metro City Branch, held at Kolkata on 27th to 29th September, 2013. A write-up containing some portion of text, sufficiently different from this article has been circulated as limited copy booklet exclusively among the attendees (approximately 400) of the said conference. Subsequently with the advent of medicine, new information has been gathered and the topic has been revised. Also it has been extended with current views incorporated. The present article in its present shape has not been submitted or published in any journal. This article sufficiently distinct from the texts in the aforementioned booklet is submitted to this esteemed journal for wide dissemination of current information to a greater number of readers.

REFERENCES

[1] Murat I, Humblot A, Girault L, et al. Neonatal fluid management. Best Practice & Research Clinical Anaesthesiology 2010;24(3):365-74.
[2] Arya VK. Basics of fluid and blood transfusion therapy in paediatric surgical patients. Indian J Anaesth 2012;56(5):454-62.
[3] Pandya SN. Fluid therapy in children. In: Pandya SN (edr). Practical guidelines on fluid therapy. 2nd edn. Chapter 8. Bhalani Medical Book House, Mumbai, India 2005:231-59.
[4] Bailey AG, McNaull PP, Jooste E, et al. Perioperative crystalloid and colloid fluid management in children: where are we and how did we get here? Anesth Analg 2010;110(2):375-90.
[5] Moritz ML, Ayus JC. Water water everywhere: standardizing postoperative fluid therapy with 0.9% normal saline. Anesth Analg 2010;110(2):293-5.
[6] Holliday MA, Segar WE. The maintenance need for water in parenteral fluid therapy. Pediatrics 1957;19(5):823-32.
[7] Murat I, Dubois MC. Perioperative fluid therapy in pediatrics. Pediatr Anesth 2008;18(5):363-70.
[8] Lonnqvist PE. Inappropriate perioperative fluid management in children: time for a solution? Pediatr Anesth 2007;17(3):203-5.
[9] Rajesh MC. Current thinking in pediatric peri-operative fluid therapy. BMH Medical Journal 2016;3(3):72-5.
[10] Datta PK, Aravindan A, Pawar DK. Peri-operative glucose supplementation in children: a review of the latest literature & rationalisation recommendations. Insights in Medical Science 2016;1(1):1-4.
[11] Lander A. Paediatric fluid and electrolyte therapy guidelines. Surgery 2010;28(8):369-72.
[12] APA consensus guideline on perioperative fluid management in children 2007. APAGBI review date 2010. Available at: http://-www.apagbi.org.uk/sites/default/files/Perioperative_Fluid_Management_2007.Accessed on 9th April, 2017.
[13] Sümpelmann R, Becke K, Crean P, et al. European consensus statement for intraoperative fluid therapy in children. Eur J Anaesthesiol 2011;28(9):637-9.
[14] Sümpelmann R, Mader T, Dennhardt N, et al. A novel isotonic balanced electrolyte solution with 1% glucose for intraoperative fluid therapy in neonates: results of a prospective multicentre observational postauthorisation safety study (PASS). Paediatr Anaesth 2011;21(11):1114-8.
[15] Fernández AR, Ariza MA, Casielles JL, et al. Postoperative hyponatremia in pediatric patients. Rev Esp Anestesiol Reanim 2009;56(8):507-10.

[16] Way C, Dhamrait R, Wade A, et al. Perioperative fluid therapy in children: a survey of current prescribing practice. Br J Anaesth 2006;97(3):371-9.
[17] Arieff AI, Ayus JC, Fraser CL. Hyponatraemia and death or permanent brain damage in healthy children. BMJ 1992;304(6836):1218-22.
[18] Holliday MA. Isotonic saline expands extracellular fluid and is inappropriate for maintenance therapy. Pediatrics 2005;115(1):193-4.
[19] Steurer MA, Berger TM. Infusion therapy for neonates, infants and children. Anaesthesist 2011;60(1):10-22.
[20] Bhananker SM, Paek R, Vavilala MS. Water intoxication and symptomatic hyponatremia after outpatient surgery. Anesth Analg 2004;98(5):1294-6.
[21] Paut O, Lacroix F. Recent developments in the perioperative fluid management for the paediatric patient. Current Opinion in Anaesthesiology 2006;19(3):268-77.
[22] Holliday MA, Ray PE, Friedman AL. Fluid therapy for children: facts, fashions and questions. Arch Dis Child 2007;92(6):546-50.
[23] Patient safety alert 22. Available at: http://www.nrls.npsa.nhs.uk/alerts/?entryid45=59809&p=3.
[24] Steele A, Gowrishankar M, Abrahamson S, et al. Postoperative hyponatremia despite near-isotonic saline infusion: a phenomenon of desalination. Ann Intern Med 1997;126(1):20-5.
[25] Choong K, Bohn D. Maintenance parenteral fluids in the critically ill child. J Pediatr (Rio J) 2007;83(2 Suppl): S3-10.
[26] NICE guideline-2015. Intravenous fluid therapy in children and young people in hospital 2017. Available at: nice.org.uk/guidance/ng29.
[27] Kempthorne PM. The European consensus statement on intraoperative fluid therapy in children: a step in the right direction. Eur J Anaesthesiol 2011;28(9):618-9.
[28] Holliday MA, Friedman AL, Segar WE, et al. Acute hospital-induced hyponatremia in children: a physiologic approach. J Pediatr 2004;145(5):584-7.
[29] Hoorn EJ, Halperin ML, Bohn D. Isotonic saline expands extracellular fluid and is inappropriate for maintenance therapy. Pediatrics 2005;115(1):194.