# Perioperative fluid and electrolyte management in surgical neonates

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**ABSTRACT**

Neonates with surgical conditions may experience significant electrolyte abnormalities and dehydration of varying degrees. Increased awareness of perioperative hyponatremia and its associated morbidity has led to a shift in Pediatric fluid guidelines favoring the use of isotonic fluids. However, there is a lack of evidence-based guidelines for neonatal perioperative fluid administration, resulting in the extrapolation of fluid management principles from adults and children. This article reviews perioperative neonatal fluid management.

## INTRODUCTION

Perioperative fluid management of neonates can be challenging due to several factors. Neonates are predisposed to both hypo and hypervolemia. Overzealous fluid resuscitation can lead to increased mortality whereas hypovolemia can increase the risk of hypotension and its sequelae, such as acute kidney injury. [1,2] Surgical neonates are a separate group, requiring specialized management in the perioperative period. Fluid resuscitation essentially follows pathways to approach normal physiology. The physiology of surgical neonates is vastly different and requires a tailored approach to specific conditions. During surgery, the neuroendocrine stress response characterized by a rapid increase in ADH occurs, therefore administration of effectively hypotonic solutions can lead to hyponatremia. [3] Hypotonic dextrose saline solutions continue to be the preferred intravenous fluid in the perioperative period despite the inherent risk of this hyponatremia. [4]

Nuanced perioperative fluid management, targets to maintain homeostasis, which includes requisite tissue perfusion, metabolic, electrolyte, and acid-base status. [5] This critical perioperative period is known to increase stress response in neonates. Balanced fluid and electrolyte administration be achieved to improve surgical outcomes. A vigilant, clinical response is the cornerstone of prescribing intraoperative fluid and electrolytes. Glucose and acid-base monitoring also form an essential part of this equation. Herein, we reviewed perioperative fluid and electrolyte management.

### Renal physiology and postnatal adaptation in neonates

Many physiological changes occur soon after birth. There is a dramatic rise in glomerular filtration rate during the first few days of life. As the neonate grows, there is a fall in the renal vascular resistance with an inversely associated rise in the mean arterial pressure. [6] This in turn increases the ECF volumes, and results in salt and water diuresis by the end of the second to third day of life.

Various aspects of neonatal physiology warrant a cautious approach towards the fluid management of neonates. Neonatal kidneys have a relatively diminished capacity to concentrate urine, due to the decreased osmotic gradient in the renal interstitium. [7] An increased surface area with immature skin causes rapid insensible water loss, predisposing neonates to become water-depleted if fluid administration is inadequate. Normally adequate breastfeeding would take care of this aspect (in the early neonatal period), however, surgical neonates depend on extraneous fluid administration. On the contrary, neonates are also prone to developing fluid

overload because of the inability of the neonatal kidney to excrete diluted urine efficiently.

Sodium excretion and conservation are limited by the immaturity of the neonatal kidney. The low GFR in the neonate is the limiting step in handling a high sodium load, and becomes a challenge, if excess free water is administered, in the intraoperative period. Associated Syndrome of inappropriate antidiuretic hormone (SIADH) may add to the challenges in this precarious period. Neonates also have limited capacity to excrete potassium, this may be attributed to the partial aldosterone resistance seen in neonates. [8] Surgeons anesthesiologists and intensivists must evaluate the neonate on a dynamic scale. A minimum of 6-8 hourly assessment of fluid and electrolyte orders is essential in critically ill surgical

**Neonatal fluid and electrolyte requirement**

Fluid therapy is initiated at 60-80 ml/kg/d with D10W and increased over the next few days (Table 1). [9] Premature neonates have a much higher fluid requirement because of high insensible losses. In the first 24 hours of life, the fluid administered can be sodium-free, and Potassium may be added after the establishment of diuresis. After 48 hours 3-5 mEq/kg/d of Sodium and KCl (2-3 mEq/kg/d) is added along with urine output monitoring. Sick infants are more prone to symptomatic hypocalcemia and calcium administration should be considered (40 mg/kg/day Elemental Calcium viz 4mL/kg/day 10% Calcium Gluconate). Neonatal fluid and electrolyte balance is a dynamic process, evolving throughout the neonatal period, and may pose considerable challenges in critically ill and surgical neonates.

Table 1: Fluid requirement in term and preterm neonates

| Birth weight | Day 1 | Day 2 | Day 3 | Day 4 | Day 5 | Day 6 | Day 7 |
|---|---|---|---|---|---|---|---|
| <1000g | 80 | 100 | 120 | 130 | 140 | 150 | 160 |
| 1000 to 1500 g | 85 | 95 | 110 | 120 | 130 | 140 | 150 |
| >1500g | 60 | 75 | 90 | 105 | 120 | 135 | 150 |

**Fluid and electrolyte abnormalities in the perioperative period in neonates**

Neonates with surgical conditions are exposed to the risk of dehydration due to reduced intake, increase in requirement or losses, and inadequate replacement. These babies are usually nursed in open care systems and repeatedly exposed for periodic reassessments. Surgical drains and dressings assess insensible losses as challenging. Infants with stomas and abdominal wall defects commonly suffer from dehydration and sodium depletion. [11] Repeated handling and transportation to units such as radiology and the operation theatre (OT) also pose an important challenge when calculating the fluid requirement. On the other hand, these neonates are also predisposed to overload if unmonitored fluid is administered.

Despite administration of isotonic fluids, children undergoing surgery are at a higher risk for developing hyponatremia. [10] Sodium wasting and hyperkalemia in neonates may be attributed to partial and transient unresponsiveness to Aldosterone. Hyperkalemia may occur in the postoperative period due to various reasons like blood transfusion, tissue handling and tissue cutting, and acute kidney insults. Metabolic acidosis also is an important cause of postoperative hyperkalemia. It is essential to closely monitor urinary output and add potassium only after diuresis has begun.

**Type of fluids**

Dextrose content

As hyperglycemia is a physiological response to surgery, healthy infants and children do not require intraoperative glucose administration. Owing to the improved knowledge of perioperative physiology, there has been a paradigm shift in the decreased usage of glucose-enriched fluids in the intraoperative period in children. However, the same is not true in neonates, as they are more prone to hypoglycemia in response to surgical stress. This can be attributed to low glycogen/fat stores in this population.

There needs to be a balanced approach to the use of perioperative glucose-enriched fluids, as even hyperglycemia is associated with increased mortality and morbidity. [12] The challenge in glucose administration is to provide the adequate amount, sufficient to suppress gluconeogenesis and fat mobilization. [13,14] A 1-2.5% dextrose solution provides the best balance between the risk for hyperglycemia and hypoglycemia. This fluid is not available commercially, however can be easily prepared in the unit. Glucose monitoring should be strictly done in the perioperative period to maintain blood sugar in the euglycemic range.

Hypotonic vs Isotonic fluids

The fluid of choice varies and can be decided as per the underlying pathophysiology in the surgical neonate. In a normal neonate, hypotonic maintenance fluid is recommended. On the contrary most pediatric guidelines now recommend giving Isotonic/Balanced fluids to sick children. [15] One of the important causes of postoperative hyponatremia is the routine use of hypotonic solutions, which has been rightly questioned. [16] To maintain perioperative homeostasis, especially in neonates and preterm infants, it is essential to calculate and replenish the pre-operative fasting deficit with a balanced isotonic solution with 1-2.5% glucose enrichment. [17] For preoperative resuscitation, in term neonates, the

recommended fluid is isotonic crystalloids, as a bolus of 10-20 ml/kg over a short span of 10-15 minutes. This may be repeated with 2-3 aliquots as determined by hemodynamics and urine output. [18]

Colloids

Crystalloids are easily available at a low cost and are therefore the favored therapeutic option. [19] There is a paucity of literature on the use of colloids in neonates. Intraoperative hypovolemia in children can be managed with colloids after a reasonable trial of crystalloid infusion. They may increase the oncotic pressure in conditions where blood products are not indicated. In children with hypovolemia, colloids can be used intraoperatively where crystalloids alone are not sufficiently effective and blood products are not indicated. [20] In neonates, 5% albumin is used preferentially. Albumin is widely used as it is iso-osmotic to plasma and effective in maintaining blood pressure and plasma colloid perfusion pressure. [21] The deleterious effects of albumin infusion may be in conditions with increased capillary permeability like prematurity, sepsis, respiratory distress syndrome, and the immediate postoperative period. Albumin administration may be counterproductive in increasing tissue edema, which may occur when albumin quickly leaks from the leaky capillaries and causes an increase in oncotic pressure in the interstitial space.

Fresh frozen plasma is commonly used in surgical units, without much evidence as a volume expander or a nutritional source. In neonates and infants, it is essential to use it only in neonates with coagulopathy. There is limited data on its use as volume replacement in symptomatic infants. [22] A Cochrane review evaluated the effect of early prophylactic volume expansion with FFP in premature infants. They concluded that the routine use of FFP for volume expansion is not beneficial as no improvement in mortality or severe disability was seen. [23]

**Fluid volume**

The Holiday Segar method of fluid calculation does not apply to the neonatal population as the neonatal physiology and requirements are different for older children and adults. So most neonatal guidelines recommend a significantly higher fluid administration. [24]

Hyponatremia is commonly caused due to increased administration of water. These infants are more prone to develop SIADH. This higher peak fluid balance due to liberal fluid during the first seven days of life has been autonomously linked to prolonged mechanical ventilation in critically ill neonates. [25] If there is a risk of water retention associated with non-osmotic antidiuretic hormone (ADH) secretion, restriction of fluid to 50-80% of the maintenance volume is

recommended as per the NICE guidelines. [26] Many neonatal surgical units follow the practice of restricting fluids in the postoperative period, especially in sick ventilated neonates. [27] A common element of modern enhanced recovery protocols is the limitation of excessive intravenous fluid, with a focus on the maintenance of normal volume. [28].

**Fluid monitoring**

Tachycardia, hypotension, delayed capillary refill, and increased core to peripheral temperature gradient are clinical signs of hypovolemia that should be monitored closely in the perioperative period. The rate of lactate rise in the postoperative period is a good marker to stratify neonates as low-risk or high-risk, in terms of morbidity and mortality. Serial Lactate values can be used for evaluating treatment response in the perioperative period. [29]

Monitoring tissue perfusion in neonates is more complex than in adults and children. Conventionally, hemodynamic volume status was measured by static parameters like the heart rate, arterial blood pressure, and central venous pressure (CVP). Clinical parameters of urine output were also an essential part of the monitory strategy. However, in the current scenario, several dynamic variables are being studied. Hemodynamic variables, like the Pulse pressure variation (PPV) and stroke volume variation (SVV), are well validated in the adult population but are not dependable markers in neonates. [31] The Pleth Variability Index (PVi) was precise in fluid status in two-thirds of the children undergoing non-cardiac surgery. Aortic flow velocity is one of the most suitable parameters to assess fluid responsiveness in neonates being ventilated. [32] A few studies have shown Transoesophageal Doppler (TED) derived indexed stroke volume (iSV) as a convenient guide to assess intraoperative fluid administration and targeted volume expansion in neonates and young infants. [33]

Electrolyte abnormalities are common in the perioperative period. Monitoring serum sodium levels is of utmost importance as these neonates are more vulnerable to hyponatremia. Neonates with special situations like stomas should undergo stringent sodium monitoring. Measuring urinary sodium values with adequate supplementation with a target of urinary sodium at > 30 mmol/l is beneficial in surgical neonates. [30]

**Specific neonatal surgical conditions**

Esophageal Atresia with Tracheoesophageal Fistula (EA with TEF)

Adequate optimization is essential in neonates planned for repair of EA/TEF. In the pre-operative period, these neonates can have dehydration and hyponatremia due to lack of oral intake and external salivary losses.

Hypovolemia correction is recommended using an isotonic fluid like normal saline in addition to the administration of maintenance fluids. [34]

Many units support the use of restrictive fluid in patients undergoing repair of EA/TEF as they are more prone to developing SIADH. This fluid policy is known to decrease the risk of hyponatremia in this population. [27] The maintenance fluid is restricted to 100 ml/kg/day irrespective of the day of life and further titration of fluid if required, is done based on the clinical hydration status of the neonate.

### Congenital Diaphragmatic Hernia (CDH)

There are several clinical determinants of prognosis in CDH. Early ventricular dysfunction is one such autonomous prognostic marker. [35] This postnatal Left Ventricular (LV) dysfunction which adds to the hemodynamic instability during transition in these CDH infants is multifactorial.

Central to the management of CDH are strategies targeting improved cardiac function and reducing pulmonary artery pressure. Cardiotropics like Dobutamine or Milrinone can be used to treat LV dysfunction and secondary systemic hypotension. Both these drugs can also be used to treat any parallel RV dysfunction. [36,37] Excessive fluid administration in the setting of poor left ventricular compliance in these babies, can cause an increased risk of developing pulmonary edema. Even fluid boluses, usually used for resuscitation should be judiciously used in this cohort.

Giving excessive fluids in neonates with CDH can prove detrimental. They need to be monitored for strict fluid intake and output, and they benefit from restricted fluid intake in the first few days of life (40–60 ml/kg/day) with additional saline volume top-up for intravascular filling in the case of inadequate tissue perfusion or hypotension. Diuretics should be given in persisting positive fluid balance without hypovolemia, aiming for diuresis of >1 ml/kg/h. [37]

In the postoperative period, Overzealous fluid administration can lead to worsening of Intra-Abdominal Hypertension (IAH) and venous hypertension, which significantly contributes to intestinal edema, leading to decreased contractility. Albumin along with diuretics may be utilized to channel third-space edema toward the intravascular space, in hemodynamically stable patients. This also helps improve abdominal wall compliance, thereby improving the problems associated with loss of organ domain. [38,39]

### Necrotizing Enterocolitis (NEC)

The medical management of NEC includes adequate rest of the bowel, along with appropriate antibiotics. Nasogastric and rectal decompression as indicated also aid in recovery.

Fluid restriction early in life is beneficial in preventing NEC, as evidenced by the Cochrane meta-analysis by Bell et al. (typical RR 0.43, 95% CI 0.21 to 0.87 and NNT=20 with restricted fluid intake). [40]

After establishing the probable diagnosis or definitive diagnosis of NEC, the treatment depends on dynamic fluid resuscitation, and transfusion of blood and blood products as clinically indicated. Xie et al. retrospectively analyzed a large cohort of 172 neonates with NEC and analyzed outcomes in two cohorts, of low versus high intraoperative fluid therapy. [41] The patients who received more intraoperative fluid, had lesser postoperative complications like surgical site infections and delayed healing, however had an increased overall mortality.

### Pyloric Stenosis

Infants present at 3-6 weeks of age with persistent non-bilious vomiting. [42] This vomiting is the cause of loss of sodium, potassium, chloride, and hydrogen ions, resulting in the classical metabolic abnormalities, associated with gastric outlet obstruction. The stimulation of the renin-angiotensin system causes the absorption of sodium and water secondarily to dehydration. [43] The kidneys conserve sodium and potassium at the expense of hydrogen ions, which are excreted in urine. This causes paradoxical aciduria in the setting of metabolic alkalosis. Correction of these metabolic derangements is the cornerstone of management before the patient is taken for surgery.

Severe volume depletion should be treated with a bolus of 10-20 ml/kg of normal saline, and the patient should be adequately hydrated before the operation. The chloride value at presentation can have high sensitivity and specificity, to predict the need for multiple boluses. [44] Adequate fluid resuscitation should be done using, isotonic crystalloids with 5% dextrose and 10-20mEq/l of potassium after establishing diuresis. [45] Subsequently, potassium should be adequately replaced as potassium ions are exchanged for hydrogen in the kidney to correct alkalosis and total body potassium is usually depleted in these patients. It may be better to wash the stomach with saline and remove the NG tube, to further stall the loss of gastric acids and electrolytes.

Optimization of pre-operative dehydration and restoration of electrolyte and acid-base balance is essential in patients with pyloric stenosis. Poorer perioperative outcomes are common in case of inadequate optimization

### Posterior Urethral Valve (PUV)

In infants with PUV, after the establishment of bladder drainage, there is a transient polyuria with an increased water and urinary sodium depletion. The

already immature nephrons are further stressed due to obstructive uropathy, incapacitating the urinary concentrating ability, and inability to absorb solutes as required. [46] Stringent fluid balance with strict input output monitoring, daily body weight, and electrolyte levels are critical in managing these patients. Some patients with PUV due to urinary obstruction may have type IV renal tubular acidosis. As a result, careful monitoring of serum electrolytes including serum bicarbonate and fluid status is required with timely replacement of fluid and electrolytes as needed. As many as 78% of PUV patients have polyuria due to irreversible renal tubular damage resulting in loss of the renal concentrating capacity. Desmopressin treatment has been shown to cause a significant reduction in 24-hour urine volumes and an increase in urine osmolarity. [47]

Secondary pseudohypoaldosteronism (PHA) is a rare condition seen in infants with obstructive uropathy which develops due to renal tubular unresponsiveness to aldosterone. Hyperkalemia, hyponatremia, and metabolic acidosis are seen in these infants. [48]

<u>Gastroschisis</u>

In gastroschisis, evaporative fluid losses through the exposed bowel can be very high. These excessive fluid losses can be decreased by covering the herniated bowel in warm, saline-soaked gauze, and covering it with a plastic wrap. Unfortunately, missed prenatal diagnoses and unplanned and unbooked deliveries catch the perinatal team by surprise. Early transport after establishing IV lines and avoiding insensible fluid loss is the key to better outcomes. A significant number of patients with gastroschisis are identified to have preoperative metabolic acidosis despite high fluid intake which is postulated to be a consequence of either prolonged intrauterine gut compromise or dehydration secondary to increased fluid loss. [49] Optimal pre-closure fluid resuscitation in gastroschisis should be achieved. [50] Though it is essential to maintain intestinal perfusion as well as adequate intravascular volume, routine aggressive fluid resuscitation should be avoided, and fluid boluses should be given only if there is clinical evidence of hypovolemia. A few studies have shown that overzealous fluid is associated with several adverse survival outcomes. Jansen et al. evaluated the effects of pre-closure intravenous fluid resuscitation on the outcome. There was a significant, direct relationship between resuscitative volume and days of post-closure ventilation, length of hospital stay, and sepsis. [51]

**5.7 Intestinal obstruction**

The neonates with intestinal obstruction may present with mild dehydration to septic shock. Third space sequestration of fluids in intestinal obstruction will lead to dehydration and depletion of intravascular fluid volume. Fluid requirements may be twice or three times the normal requirement. These infants may require 120-150 ml/kg/day in the immediate post-operative period as determined by hemodynamics and urine output monitoring. Isotonic saline also may be required because of the third spacing of fluid into tissues and bowel lumen. Recent literature in adults indicates that third space loss does not exist and that abdominal surgery outcomes are improved after a conservative fluid strategy than liberal fluid management; [52] however more studies are needed for the evidence. Strict input output recording should be done. Gastric drainage must be replaced volume by volume with isotonic saline. Vascular fluid volume should be restored adequately to maintain cardiovascular stability, organ perfusion, and adequate tissue oxygenation.

**CONCLUSION**

Standardized protocols for neonatal perioperative fluid management are lacking. Further trials are required to establish guidelines in this vulnerable population of neonates who are undergoing surgical stress in the period of transition from fetal to neonatal period.

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**REFERENCES**

1. Ewer AK, Tyler W, Francis A, Drinkall D, Gardosi JO. Excessive volume expansion and neonatal death in preterm infants born at 27–28 weeks gestation. Paediatr Perinat Epidemiol. 2003; 17:180–6.
2. Selewski DT, Charlton JR, Jetton JG, Guillet R, Mhanna MJ, Askenazi DJ, et al. Neonatal acute kidney injury. Pediatrics. 2015; 136: e463–73.
3. Burrows FA, Shutack JG, Crone RK. Inappropriate secretion of antidiuretic hormone in a postsurgical pediatric population. Crit Care Med. 1983; 11: 527–31.
4. Fluid choice during perioperative care in children: A survey of present-day proposing practice by anesthesiologists in a tertiary care hospital. Saudi J Anaesth. 2018; 12:42-5.
5. Bennett VA, Cecconi M. Perioperative fluid management: From physiology to improving clinical outcomes. Indian J Anaesth. 2017; 61:614-21.
6. Sulemanji M, Vakili K. Neonatal renal physiology. Semin Pediatr Surg. 2013; 22:195-8.
7. Quigley R. Developmental changes in renal function. Curr Opin Pediatr. 2012; 24:184-90.

8. Martinerie L, Pussard E, Foix-L'Hélias L, Petit F, Cosson C, Boileau P, et al. Physiological partial aldosterone resistance in human newborns. Pediatr Res. 2009; 66:323-8.

9. Aggarwal R, Deorari AK, Paul VK. Fluid and electrolyte management in term and preterm neonates. Indian J Pediatr. 2001; 68:1139-42.

10. Andersen C, Afshari A. Impact of perioperative hyponatremia in children: A narrative review. World J Crit Care Med. 2014; 3:95-101.

11. Butterworth SA, Lalari V, Dheensaw K. Evaluation of sodium deficit in infants undergoing intestinal surgery. J Pediatr Surg. 2014; 49:736-40.

12. Hall NJ, Peters M, Eaton S, Pierro A. Hyperglycemia is associated with increased morbidity and mortality rates in neonates with necrotizing enterocolitis. J Pediatr Surg. 2004; 39:898-901.

13. Milcic TL. Neonatal glucose homeostasis. Neonatal Netw. 2008; 27:203-7.

14. Pape L, Schreiber M, Strauss J, Weiss M. Perioperative intravenous fluid therapy in children: guidelines from the Association of the Scientific Medical Societies in Germany. Paediatr Anaesth. 2017; 27:10-8.

15. Feld LG, Neuspiel DR, Foster BA, Leu MG, Garber MD, Austin K, et al. Subcommittee on fluid and electrolyte therapy. Clinical Practice Guideline: Maintenance Intravenous Fluids in Children. Pediatrics. 2018; 142:e20183083.

16. Edjo Nkilly G, Michelet D, Hilly J, Diallo T, Greff B, Mangalsuren N, et al. Postoperative decrease in plasma sodium concentration after infusion of hypotonic intravenous solutions in neonatal surgery. Br J Anaesth. 2014; 112:540-5

17. Sümpelmann R, Becke K, Zander R, Witt L. Perioperative fluid management in children: can we sum it all up now? Curr Opin Anaesthesiol. 2019; 32:384-91.

18. Bhardwaj N. Perioperative fluid therapy and intraoperative blood loss in children. Indian J Anaesth. 2019; 63:729-36.

19. Medeiros DN, Ferranti JF, Delgado AF, de Carvalho WB. Colloids for the initial management of severe sepsis and septic shock in pediatric patients: A systematic review. Pediatr Emerg Care. 2015; 31:e11-6.

20. Sümpelmann R, Becke K, Brenner S, Breschan C, Eich C, Höhne C, et al. Perioperative intravenous fluid therapy in children: guidelines from the Association of the Scientific Medical Societies in Germany. Paediatr Anaesth. 2017; 27:10-18.

21. Oca MJ, Nelson M, Donn SM. Randomized trial of normal saline versus 5% albumin for the treatment of neonatal hypotension. J Perinatol. 2003; 23:473-6.

22. Northern Neonatal Nursing Initiative Trial Group. Randomised trial of prophylactic early fresh-frozen plasma or gelatin or glucose in preterm babies: outcome at 2 years. Lancet. 1996; 348:229–32.

23. Osborn DA, Evans N. Early volume expansion for prevention of morbidity and mortality in very preterm infants. Cochrane Database Syst Rev. 2004; 2004:CD002055.

24. Aggarwal R, Deorari AK, Paul VK. Fluid and electrolyte management in term and preterm neonates. Indian J Pediatr. 2001; 68:1139-42.

25. Selewski DT, Gist KM, Nathan AT, Goldstein SL, Boohaker LJ, Akcan-Arikan A, et al; Neonatal Kidney Collaborative. The impact of fluid balance on outcomes in premature neonates: a report from the AWAKEN study group. Pediatr Res. 2020; 87:550-7.

26. Neilson J, O'Neill F, Dawoud D, Crean P; Guideline Development Group. Intravenous fluids in children and young people: summary of NICE guidance. BMJ. 2015; 351.

27. Dogra S, Malik MA, Peters NJ, Samujh R. Postoperative hyponatremia in neonates with esophageal atresia and tracheoesophageal fistula receiving restricted hypotonic fluids. Ann Pediatr Surg. 2022; 18:72.

28. Adamina M, Kehlet H, Tomlinson GA, et al. Enhanced recovery pathways optimize health outcomes and resource utilization: a meta-analysis of randomized controlled trials in colorectal surgery. Surgery. 2011; 149:830–40.

29. Schumacher KR, Reichel RA, Vlasic JR, Yu S, Donohue J, Gajarski RJ, et al. Rate of increase in serum lactate level risk-stratifies infants after surgery for congenital heart disease. J Thorac Cardiovasc Surg. 2014; 148:589-95.

30. Mansour F, Petersen D, De Coppi P, Eaton S. Effect of sodium deficiency on growth of surgical infants: a retrospective observational study. Pediatr Surg Int. 2014; 30:1279-84.

31. Gan H, Cannesson M, Chandler JR, Ansermino JM. Predicting fluid responsiveness in children: a systematic review. Anesth Analg. 2013; 117:1380-92.

32. Oulego-Erroz I, Terroba-Seara S, Alonso-Quintela P, Rodríguez-Núñez A. Respiratory variation in aortic blood flow velocity in hemodynamically unstable, ventilated neonates: A pilot study of fluid responsiveness. Pediatr Crit Care Med. 2021; 22:380-91.

33. Raux O, Spencer A, Fesseau R, Mercier G, Rochette A, Bringuier S, et al. Intraoperative use of transoesophageal Doppler to predict response to volume expansion in infants and neonates. Br J Anaesth. 2012; 108:100-7.

34. Gayle JA, Gómez SL, Baluch A, Fox C, Lock S, Kaye AD. Anesthetic considerations for the neonate with tracheoesophageal fistula. Middle East J Anaesthesiol. 2008; 19:1241-54

35. Patel N, Lally PA, Kipfmueller F, Massolo AC, Luco M, Van Meurs KP, et al. Ventricular dysfunction is a critical determinant of mortality in congenital diaphragmatic hernia. Am J Respir Crit Care Med. 2019; 200:1522-30.

36. Massolo AC, Paria A, Hunter L, Finlay E, Davis CF, Patel N. Ventricular dysfunction, interdependence, and mechanical dispersion in newborn infants with congenital diaphragmatic hernia. Neonatology. 2019; 116:68-75.

37. Patel N, Kipfmueller F. Cardiac dysfunction in congenital diaphragmatic hernia: Pathophysiology, clinical assessment, and management. Semin Pediatr Surg. 2017; 26:154-8.

38. Carlotti AP, Carvalho WB. Abdominal compartment syndrome: A review. Pediatr Crit Care Med. 2009; 10:115-20.

39. Noek KG, Reiss IK, Greenough A, Capolupo I, Urlesberger B, Wessel L, et al. CDH EURO Consortium. Standardized Postnatal Management of Infants with Congenital Diaphragmatic Hernia in Europe: The CDH EURO Consortium Consensus - 2015 Update. Neonatology. 2016; 110:66-74.

40. Bell EF, Acarregui MJ. Restricted versus liberal water intake for preventing morbidity and mortality in preterm infants. Cochrane Database Syst Rev. 2014: 2014:Cd000503.

41. Xie X, Guo S, Deng C, Guo C. Postoperative outcomes based on crystalloid administration in pediatric patients with necrotizing enterocolitis undergoing laparotomy. Medicine (Baltimore). 2020; 99: e21987.

42. Galea R, Said E. Infantile hypertrophic pyloric stenosis: An epidemiological review. Neonatal Netw. 2018; 37:197-204.

43. Rich BS, Dolgin SE. Hypertrophic pyloric stenosis. Pediatr Rev. 2021; 42:539-45.

44. Dalton BG, Gonzalez KW, Boda SR, Thomas PG, Sherman AK, St Peter SD. Optimizing fluid resuscitation in hypertrophic pyloric stenosis. J Pediatr Surg. 2016; 51:1279-82.

45. van den Bunder FAIM, Hall NJ, van Heurn LWE, Derikx JPM. A Delphi analysis to reach consensus on preoperative care in infants with hypertrophic pyloric stenosis. Eur J Pediatr Surg. 2020; 30:497-504.

46. Dinneen MD, Duffy PG, Barratt TM, Ransley PG. Persistent polyuria after posterior urethral valves. Br J Urol. 1995; 75:236.

47. Naghizadeh S, Kefi A, Dogan HS, Burgu B, Akdogan B, Tekgul S. Effectiveness of oral desmopressin therapy in posterior urethral valve patients with polyuria and detection of factors affecting the therapy. Eur Urol. 2005; 48:819–25.

48. Delforge X, Kongolo G, Cauliez A, Braun K, Haraux E, Buisson P. Transient pseudohypoaldosteronism: a potentially severe condition affecting infants with urinary tract malformation. J Pediatr Urol. 2019; 15:265.

49. El-Naggar W, Al Mudeer A, Vincer M, Yanchar NL. Preoperative metabolic acidosis in infants with gastroschisis. J Neonatal Perinatal Med. 2017; 10:307-11.

50. Bhat V, Moront M, Bhandari V. Gastroschisis: A State-of-the-Art Review. Children (Basel). 2020; 7:302.

51. Jansen LA, Safavi A, Lin Y, MacNab YC, Skarsgard ED; Canadian Pediatric Surgery Network (CAPSNet). Preclosure fluid resuscitation influences outcome in gastroschisis. Am J Perinatol. 2012; 29:307-12.

52. Al-Ghamdi AA. Intraoperative fluid management: Past and future, where is the evidence? Saudi J Anaesth. 2018; 12:311-17.