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Perioperative Fluid Therapy

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Abstract: **In perioperative medicine, fluid management is a crucial role as it can lead to one of the causes of perioperative morbidity and mortality. The aim of fluid therapy is to maintain fluid homeostasis and it can provide adequate hydration, blood volume and oxygen delivery to tissues. Perioperative fluid therapy is a medical prescription which consists of three categories such as maintenance therapy, deficit therapy and replacement therapy. To achieve a correct fluid management plan, it is necessary to understand normal fluid distribution, features of commonly used intravenous fluids, hydration status of the patient and nature of surgery. As body fluid composition is different between adults and children, fluid therapy must be based on individual patients to avoid fluid overload or underload. Fluid losses can be replaced with crystalloids or colloids until transfusion point is reached and it also depends on individual patient. Based on different case scenarios, a well-structured fluid regime should be planned after taking into account physiology, preoperative losses, intraoperative and postoperative factors.**

Keywords: **fluid therapy; crystalloid; colloid; fluid physiology; hydration.**

1. INTRODUCTION

Fluid therapy is an important aspect in the perioperative period. Intravenous fluids are required to maintain adequate hydration, blood volume and oxygen delivery. If we manage incorrectly, it is a significant cause of morbidity and mortality. In this short review, normal fluid distribution, types of intravenous fluids, assessment of hydration status, perioperative fluid therapy in adults and children are discussed.

2. FLUID AND ELECTROLYTE PHYSIOLOGY

Water is present in a number of body fluid compartments such as extracellular fluid (ECF) and intracellular fluid (ICF). Total body water (TBW) constitutes 55-60% of body weight in men and 45-50% of body weight in women; a normally hydrated 70 kilogram man consists of approximately 42 litres of water.[9] TBW also depends on the patient's age (Table 1).

Table 1. TBW variation with age[8,11]

Age	TBW (% of total body weight)
Newborn	75-80
1 year	60
Adult	60
60 years	50

Two-thirds of TBW is within the cells of the body and is called intracellular fluid (ICF). One-third of TBW is outside the cells of the body and is called extracellular fluid (ECF). ECF is subdivided into other compartments such as interstitial fluid (ISF) and intravascular fluid (IVF). Normal osmolality (285-295 mosm/kg) is kept constant between all compartments by the movement of water by osmosis.

In ECF, sodium is the principal cation and chloride is the principal anion. Protein is a non-diffusible anion and is present in a higher concentration in plasma. In ICF, potassium is the principal cation and phosphate is the principal anion.[1]There is a high protein content in ICF (Table 2).

Based on that information, solution of 5% glucose will be distributed throughout the total body water after glucose is metabolized. Less than 10% of the infused volume remains in the plasma. After infusion of 0.9% saline, there is no change in ECF osmolality as this is an isotonic solution and no water movement occurs. Thus, around one-third of infused volume remains in the intravascular volume. [7]

Table 2. Principal solute composition of body fluid compartments[1,9]

Solute	ICF (mmol/L)	ECF (mmol/L)
Na^+	10	140
K^+	150	4
Mg^{2+}	25	0.9
HPO_4^-	74	0.4
SO_4^{2-}	19	0.4
HCO_3^-	9	24
$Proteinate^-$	64	1.1
Cl^-	9	114

Normal daily intake and output of water and electrolytes:

When the body is under normal condition, daily water output for average adults is 2.5-3 litres of water per day.[7] Some of the fluid loss is sensible (eg. urine, faeces) and some losses are insensible (eg. sweat, water vapour in exhaled gases) (Table 3). Table 4 shows daily electrolyte requirement in a normal healthy adult.

Table 3. Normal average adult daily water intake and output[1,8]

Output		Intake	
Urine	1500 ml	Drinking	1300 ml
Faeces	100 ml	Eating	800 ml
Skin	500 ml	Metabolism	400 ml
Lungs	400 ml		
Total	2500 ml	Total	2500 ml

Table 4. Average adult daily electrolyte requirement[8]

Electrolyte	Daily requirement
Sodium	1-1.5 mmol/kg
Potassium	1 mmol/kg
Magnesium	0.1-0.2 mmol/kg
Calcium	0.1-0.2 mmol/kg
Chloride	0.07-0.22 mmol/kg

Therefore, if the patient is nil by mouth normal daily requirements may be provided by one of the following:

- 2000 ml of glucose 5% + 500 ml of saline 0.9%
- 2500 ml of glucose 4%/saline 0.18%; plus KCL 1 g (13 mmol) added to each 500 ml of fluid.[1]

Abnormal losses:

Abnormal fluid losses include abnormal insensible losses, abnormal preoperative external losses, third space losses and blood loss. Insensible losses from the skin and lungs are increased in the presence of fever or hyperventilation. The usual insensible loss of 0.5 ml/kg/hr increases by 12% for each degree Celsius rise in body temperature.[1] Preoperative external losses are often from the gastrointestinal tract e.g. diarrhoea, vomiting, intestinal obstruction. Sequestration of plasma-like fluid found in conditions such as sepsis and trauma is referred to as 'third space loss'. Its volume is propotional to the extent of trauma and is not measured easily.

Intravenous fluids:

There are 2 types of intravenous fluids used in perioperative period: crystalloids and colloids.

(1) Crystalloids:

Crystalloid solutions are aqueous solutions of low-molecular weight ions with or without glucose. They are able to pass through the capillary membrane and are rapidly distributed throughout the entire extracellular space. Only 25-30% of colloids remain in the intravascular compartment.[3]Its intravascular half-life is 20-30 minutes. Varieties of crystalloid solution are available (Table 5). Maintenance-type solution eg. 5% glucose is required for losses primarily involving water. Replacement-type solution eg. 0.9% saline or lactated Ringer's solution is required for losses involving both water and electrolytes and generally used in most intraoperative fluid losses.[2]They should be given in a volume equivalent to three times the estimated blood loss to maintain circulating volume. Although they are very useful in clinical practice, there are some disadvantages of crystalloid solutions (Table 6).

Table 5. Composition of commonly used crystalloid solutions[3]

Solution	Electrolyte content (mmol/L)				Osmolality (mosmol/kg)
Saline 0.9% (normal saline)	Na+	154	Cl-	154	308
Glucose 5%					278
Glucose 4%/saline 0.18% (glucose-saline)	Na+	31	Cl-	31	284
Lactated Ringer's solution (Hartmann's solution)	Na+ K+ Ca2+	131 5 4	Cl- HCO3- (as lactate)	112 29	281

Table 6. Advantages and disadvantages of crystalloid solutions[7]

Advantages	Disadvantages
• Inexpensive • Non-allergic • Not associated with transmission of infection, impairment of coagulation or cross matching	• Short lived haemodynamic effects • Massive fluid resuscitation produces peripheral oedema and occasionally pulmonary oedema.

(2) Colloids:

Colloid solutions are suspensions of high-molecular weight particles such as proteins or large glucose polymers.[2]They are not able to pass through the capillary membrane and are retained primarily within the plasma volume providing an osmotic effect. They can be given in a volume equivalent to the estimated blood loss. Intravascular half-life of colloid solution ranges between 3-6 h. A wide variety of colloid solutions are available, which are derived from gelatin (Haemaccel, Gelofusine), protein (albumin) or starch (Hetastarch) (Table 7)[7]. Colloid solutions are indicated in severe intravascular fluid deficits eg. haemorrhagic shock before blood is available for transfusion, severe hypoalbuminaemia and large protein losses such as severe liver disease and burns.[2]

However, it must be remembered that there are some potential disadvantages of colloid solutions (Table 8).

Table 7. Composition of various colloid solutions

Solution	Constituents				
	Na (mmol/L)	Cl (mmol/L)	Ca (mmol/L)	K (mmol/L)	Other
Gelofusine	154	120	0.4	0.4	Gelatin 40g/L
Haemaccel	145	145	6	5	Gelatin 35g/L
Hetastarch 6%	154	154			Starch 60g/L
Dextran 40					Glucose 50g/L
Human albumin 4.5%	130-160	120		2	Albumin 45g/L

Table 8. Advantages and disadvantages of colloid solutions[7]

Advantages	Disadvantages
• Expand plasma volume rather than interstitial fluid volume results in lower fluid requirement and less peripheral and pulmonary oedema.	• Greater expense • Allergic reactions • Infection risk • Coagulopathy • Impaired cross matching

3. ASSESSMENT OF HYDRATION STATUS

History:

History may detail duration of abnormal loss of fluid, frequency of vomiting, diarrhoea, inadequate oral intake, haemorrhage, burns, bowel preparation and drain losses.[7] Thirst is a sensitive indicator of fluid deficit. It occurs in response to changes in osmolarity of 1%.[4] Urine output of 0.5 to 1.0 ml/kg/h indicates adequate renal perfusion and intravascular volume.[7]

Physical Examination:

Physical Examination should include pulse rate, blood pressure, respiratory rate, urine output, capillary return, jugular venous pressure (JVP), mucous membranes and loss of skin turgor. Loss of skin turgor occurs in response to volume deficit of about 10%. Orthostatic hypotension is as a result of 20% deficit and supine hypotension in 30% deficit.[4] Tachycardia alone is an insensitive marker of hypovolaemia. A normal pulse rate, blood pressure and central venous pressure (CVP) of 6-12 mmHg indicate adequate blood volume.[7] CVP <5 mmHg may be normal if not associated with other signs of hypovolaemia. CVP >12 mmHg indicates hypervolaemia in the absence of right ventricular dysfunction, increased intrathoracic pressure.[2] Table 9 shows the physical findings for various degrees of dehydration.

Table 9. Physical signs relating to the percentage of body weight lost [2,7]

	Mild <5%	Moderate 5-10%	Severe >10%
Pulse rate	Normal	Increased	Increased
Blood pressure	Normal	Normal /mildly decreased	Decreased
Respiratory rate	Normal	Normal	Rapid
Capillary return	<2 seconds	3-4 seconds	>5 seconds
Urine output	Mildly decreased	Decreased	Markedly decreased
Mucous membranes	Normal/dry	Dry	Parched
Sensorium	Normal	Lethargic	Obtunded
Orthostatic changes	None	Present	Marked

Investigation:

Laboratory signs of dehydration include rising Hct, progressive metabolic acidosis, urinary specific gravity >1.010, urinary osmolality >450 mosm/kg and hypernatremia. However, these measurements are not very useful intraoperatively as the results are often delayed.[2]

4. PERIOPERATIVE FLUID THERAPY IN ADULTS

In perioperative fluid management, three factors should be considered as follows.

1. Normal maintenance requirements
2. Preexisting deficits
3. Surgical fluid losses

1. Normal maintenance requirements:

Normal maintenance requirements mean fluid and electrolyte requirements needed by the average individual with a normal ICF and ECF fluid volumes over a 24-hr period.[5] In adults, normal maintenance requirements can be calculated by 1.5 ml/kg/h and it can be given as normal saline or Hartmann's and 5% glucose solution.[7]

2. Pre-existing deficits:

It is evaluation and management of the losses of fluid and electrolytes that occurred prior to operation. It includes deficit due to fasting hours and abnormal fluid losses in preoperative period such as bleeding, vomiting and diarrhoea. Table 10 shows minimum fasting periods based on the American society of Anaesthesiologists (ASA) guidelines. The replacement fluid can be estimated by multiplying the normal maintenance rate by the length of the fast added to preoperative abnormal losses.

Table 10. ASA fasting guidelines[12]

Ingested material	Minimum fasting period (h)
Clear liquids	2
Breast milk	4
Infant formula	6
Nonhuman milk	6
Light meal	6
Regular meal	8

3. Surgical fluid losses:

Blood loss is continually monitored and estimated by the following methods.

- Weigh a dry swab. Weigh blood soaked swabs as soon as they are discarded and subtract their dry weight (1ml of blood weighs approximately 1gm).
- Fully soaked sponge (4"x4") ~ 10 ml
- Laparotomy pads ('laps') ~ 100-150 ml
- Subtract the weight of empty suction bottles from the filled ones.
- Estimate blood loss into surgical drapes, together with the pooled blood beneath the patient and onto the floor.
- Note the volume of irrigation fluids; subtract this volume from the measured blood loss to estimate the final blood loss.

Other fluid losses include evaporation and internal redistribution of body fluids (third space losses).[2]

Blood loss is replaced initially with crystalloid in a ratio of 3 ml crystalloid per 1 ml blood lost or colloid in a ratio of 1:1.[7]The transfusion point can be determined by the following:

- If the blood loss is greater than 15-20% of blood volume, it should be replaced by blood transfusion.[1,2] Table 11 shows average blood volumes to estimate the amount of blood loss.[2]
- If Hb is less than 7.5 g/dl for fit patient or 9 g/dl for elderly and patients with cardiac disease, transfusion should be started.
- Allowable blood loss can be calculated preoperatively from the Hct and blood volume.[2]

Example: A 65 kg man has a preoperative Hct of 35%. Calculate the allowable blood loss to fall his Hct to 30%.

(i) Estimate blood volume
= 75ml/kg x 65 kg = 4875 ml

(ii) Red Blood Cell Volume 35%
= 4875 x 35% = 1706 ml

(iii) Red Blood Cell Volume 30%
= 4875 x 30% = 1462 ml

(iv) Red cell loss at 30%
= 1706 – 1462 = 244 ml

(v) Allowable blood loss
= 3 x 244 ml = 732 ml

When this patient's blood loss exceeds 700 ml, blood transfusion should be considered.

Table 11. Blood volume variation with age[2]

Age	Blood volume
Neonates	85ml/kg
Infants	80ml/kg
Adults	
Men	75ml/kg
Women	65ml/kg

Redistribution and evaporative surgical fluid losses are related to wound size and extent of surgical dissections and manipulations. Additional fluid requirement can be estimated according to degree of tissue trauma.

Example:

- 0-2 ml/kg for minimal surgical trauma (eg. Inguinal hernia repair)
- 2-4 ml/kg for moderate surgical trauma (eg. Cholecystectomy)
- 4-8 ml/kg for severe surgical trauma (eg. bowel resection)[2]

Postoperative losses should also be replaced including maintenance requirements, abnormal insensible losses and visible external losses such as nasogastric tube, vomiting, drains and third space losses.[7]

5. PAEDIATRIC FLUID THERAPY

Paediatric body fluid composition is different from adult patients. At the age of one year, ECF volume is 30% of body weight and by puberty, it reaches to adult values (Table 12). ECF volume in young infants is larger compared to older children and adults. Therefore, the relative proportion of losses will be greater in younger child.

Table 12. ECF volume variation with age

Age	ECF volume (% of body weight)
Neonate	45%
1 year	30%
Puberty	20%

In perioperative fluid therapy in children, there are three factors need to be considered like adult patients.

- Maintenance therapy
- Deficit therapy
- Replacement therapy

1. Maintenance therapy:

In paediatric patients, hourly maintenance fluid can be calculated by 4 / 2 / 1 rule (Holliday and Segar method) according to child's weight.[2,5] (Table 13)

Example: 25 kg child = (10x4) + (10x2) + (5x1)

= 40 + 20 + 5 = 65 ml/h

Table 13. Hourly 4/2/1 rule

Body weight	Hourly fluid requirement
<10 kg	4 ml/kg
10-20 kg	40 ml + 2 ml/kg Above 10 kg
>20 kg	60 ml + 1 ml/kg Above 20 kg

2. Deficit therapy:

Clear fluids can be allowed upto two hours preoperatively as it does not affect the pH or volume of gastric contents at induction of anaesthesia. It can also improve comfort, hydration and reduce postoperative nausea and vomiting. (Refer to table 10 for fasting guidelines)

Fasting deficit can be replaced by 50% in the first hour and 25% in the second and third hours. These deficits are usually replaced with lactated Ringer's or ½ normal saline.[2]

Example: 5 kg child with fasting period for 4 hours duration

- Deficit = 5 kg x 4 ml/kg/h x 4 h = 80 ml
- 1st hr - 60 ml (40 ml + 20 ml)
- 2nd hr - 40 ml (20 ml + 20 ml)
- 3rd hr - 40 ml (20 ml + 20 ml)

The degree of dehydration can be estimated from the child's history and physical condition. (Table 14) Delayed capillary refill, delayed skin turgor, and abnormal respiratory pattern are the most reliable clinical signs of dehydration in children.

Table 14. Clinical findings of dehydration[10]

Symptom/Sign	Mild Dehydration (5%)	Moderate Dehydration (10%)	Severe Dehydration (15%)
General condition	Alert	Lethargic	Obtunded
Capillary refill	2 s	2-4 s	>4 s
Mucous membranes	Moist	Dry	Parched, cracked
Tears	Normal	Decreased	Absent
Respiratory rate	Normal	Increased	Increased
Systolic pressure	Normal	Normal or low	Low
Pulse rate	Normal	Increased	Increased/faint
Skin turgor	Normal	Slow	Tenting
Fontanelle	Normal	Sunken	Very sunken
Eyes	Normal	Sunken	Very sunken
Urine output	Decreased	Oliguria	Oliguria/anuria

3. Replacement therapy:

Replacement therapy is designed to replace ongoing blood loss, third space and evaporative losses. Blood loss can be replaced with crystalloid (eg. 3 ml for each ml of blood loss) or colloid solution (eg. 1 ml of colloid for each ml of blood loss) until the patient's Hct reaches a predetermined lower limit which is 40% or 50% for premature or sick neonates and 20 – 26% for healthy older children.[2]

Third space loss is impossible to measure and it can be estimated by the extent of surgical procedure.

Example:

- 1-2 ml/kg/h for minimal surgical trauma (eg. Inguinal hernia repair)
- > 6 ml/kg/h for severe surgical trauma (eg. Bowel obstruction)[10]

Suggested fluid regime for paediatric patients:[6]

- 0.9% or 0.45% saline for maintenance therapy
- 0.9% saline, colloid or blood for deficit therapy and ongoing losses
- 5% or 10% dextrose for neonate, malnourished or a measured blood sugar is low.

Fluid status should be monitored postoperatively. Ongoing losses should be measured and replaced accordingly. Maintenance fluids should be given until the child can tolerate oral fluid.

6. CONCLUSION

Fluid balance is an important issue in perioperative period. Appropriate perioperative fluid therapy is mandatory for both adults and children. Fluid management should be based on individual patients, taking into account physiology of fluid distribution, pre-, per- and post-operative factors. Well-planned fluid regimes on an individual patient reduce perioperative morbidity and mortality.

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