International Journal of Medical and Health Research
ISSN: 2454-9142
www.medicalsciencejournal.com
Volume 4; Issue 1; January 2018; Page No. 128-132

Fluid and electrolyte homeostasis: Facts based comprehensive study

Dr. Geetinder Preet Kaur[1], Dr. Ramesh Ram Fry[2], Dr. Nitesh Chhikara[3], Dr. Amit Bali[4], Dr. Ramgopal Garg[5]
[1] MDS, Oral & Maxillofacial Surgery, Senior Lecturer, Swami Devi Dayal Dental College and Hospital, Barwala, Haryana, India
[2] MDS, Oral & Maxillofacial Surgery, Professor, MMCDSR, Mullana, Ambala, India
[3] MDS, Oral & Maxillofacial Surgery, Consultant, Rohtak, Haryan, India
[4] MDS, Oral & Maxillofacial Surgery, Professor, Yamuna Group of Institutes, Yamunanagar, Haryana, India
[5] MDS, Oral & Maxillofacial Surgery, Resident, MMCDSR, Mullana, Ambala, India

Abstract
Adequate and careful maintenance of fluid and electrolyte homeostasis for all the patients is an essential part of the successful preoperative, peri-operative and postoperative management and plays key role in obtaining desirable outcomes. This comprehensive study provides complete assessment of fluid and electrolyte balance with reference to the normal physiology of body fluids and mechanisms associated with the regulation of fluids and electrolytes.

Keywords: body fluids, fluid balance, electrolytes, intracellular

Introduction

Fluid and electrolyte balance is a term used to describe the balance of the input and output of fluids from the body in order to allow metabolic processes to function correctly. Around 52% of total body weight in women and 60% in men is fluid. This consists of water and molecules example, sodium, potassium and chloride. These compounds in solution dissociate into particles which carry an electrical charge called electrolytes [1].

Water is an essential carrier for nutrients and metabolites, and it comprises the major part of human body mass at any age. Water and electrolyte requirements per unit body mass are very high after birth and decrease with age until adulthood[2]. Water makes up 50% to 70% of total body weight[3]. The amount of total body water (TBW) decreases markedly from intrauterine life to adulthood [2]. Total body water is divided into intracellular and extracellular compartments. The extracellular compartment is subdivided into intravascular and interstitial spaces [3]. Sodium and potassium are the principle cations in the body. Sodium is contained primarily in the extracellular fluid and potassium in the intracellular fluid. Chloride is the principle anion in the body and is restricted primarily to the extracellular fluid [3].

Most hospital inpatients need intravenous fluid therapy as a result of altered intake, extra losses and dynamic shifts within the body. This simple and basic therapy is often overlooked but can cause significant morbidity [4].

The objective of the fluid and electrolyte balance is to restore the normal physiology and normal function of organs, with a normal blood volume, functional body water and electrolytes. Errors in fluid management are the most common cause of peri-operative morbidity and mortality.

Fluid and electrolyte balance is one of the key issues in maintaining homeostasis in the body, and it also plays important roles in protecting cellular function, tissue perfusion and acid- base balance. Fluid and electrolyte balance must also be maintained for the management of many clinical conditions. Imbalances in every electrolyte must be considered in a combined and associated fashion, and examinations must aim to clarify the clinical scenario for an effective and successful treatment [5].

Physiology

Daily Intake of Water

Under normal conditions, a 70 kg adult consumes an average of 2000- 2500ml of water per day. Approximately 1500ml of water is taken by mouth; the remaining is extracted from solid food [6].

Daily Loss of Body Water

Insensible water loss

Some of the water losses cannot be precisely regulated. This is termed insensible water loss because we are not consciously aware of it, even though it occurs continually in all living humans. Example, under normal conditions, there is a continuous loss of water for about 700 ml/day by evaporation from the respiratory tract and diffusion through the skin [6].

Sensible water loss

Which can be seen, felt and measured [6].

Table 1: Water exchange (70Kg man)

	Route	Average Daily Volume(ml)	Minimal (ml)	Maximal (ml)
Water Gain Sensible	Oral fluids	800- 1500	0	1500
	Solid foods	500- 700	0	1500
Water Gain Insensible	Water of oxidation	250	125	800
	Water of solution	0	0	500
Water Loss Sensible	Urine	800- 1500	300	1400
	Intestinal	0-250	0	2500
	Sweat	0	0	4000
Water Loss Insensible	Lungs and skin	600	600	1500

Body fluid compartments

The total body fluid is distributed mainly between two compartments- the extracellular fluid and the intracellular fluid. The extracellular fluid is further divided into the interstitial fluid and the blood plasma [6]. There is another small compartment of fluid that is referred to as transcellular fluid. This compartment includes fluid in the synovial, peritoneal, pericardial and intraocular spaces as well as the cerebrospinal fluid [6].

Intracellular fluid compartment

Out of total of 42 liters of fluid in the body, 28L of fluid are inside the 100 trillion cells and are collectively called the intracellular fluid. Thus, the intracellular fluid constitutes about 40% of the total body weight in an “average” person. The fluid of each cell contains its individual mixture of different constituents, but the concentrations of these substances are similar from one cell to another [6].

Extracellular fluid compartment

All the fluids outside the cells are collectively called the extracellular fluid. Together these fluids account for about 20% of the body weight or about 14 liters in a normal 70 kg man. The two largest compartments of the extracellular fluid are the interstitial fluid, which makes up more than three-fourth (11 liters) of the extracellular fluid and the plasma that makes up almost one- fourth of the extracellular fluid or about 3 liters [6].

Terminologies & physiologic conditions

The terms isotonic, hypertonic and hypotonic refers to whether solutions will cause a change in cell volume. The tonicity of solutions depends on the concentration of impermeant solutions. Some solutions, however, can permeate the cell membrane. Solutions with an osmolarity the same as the cell are called iso- osmotic, regardless of whether the solute can permeate the cell membrane. The terms hyperosmotic and hypo- osmotic refer to the solutions that have a higher or lower osmolarity, respectively, compared with the normal extracellular fluid, without regard for whether solute permeate the cell membrane [6].

Osmotic equilibrium between intracellular and extracellular fluids is rapidly attained

The transfer of fluid across the cell membrane occurs so rapidly that any differences in osmolarities between these two compartments are usually corrected within seconds or at the most minutes. This rapid movement of water across the cell membrane does not mean that complete equilibrium occurs between the intracellular and extracellular compartments throughout the whole body within the same short period. The reason for this is that fluid usually enters the body through the gut and must be transported by the blood to all the tissues before complete osmotic equilibrium can occur. It usually takes about 30 min to achieve osmotic equilibrium everywhere in the body after drinking water [6]. Hyper-metabolism, hyperventilation and fever increase insensible water loss. With excessive heat production, insensible loss via the skin is exceeded and sweating occurs. Insensible losses may exceed over 300mL per day per degree of temperature over 100.5^{0}F. Patients who have a tracheostomy have an additional risk for insensible loss. A non-humidified tracheostomy with hyperventilation may result in insensible water losses of more than 1.5L per day. The goal of fluid maintenance therapy is to replace fluids lost normally during the course of a day [3]. The standard recommendations for the calculation of hourly maintenance fluid replacement are 0 to 10 kg- 4ml/kg, 11 to 20 kg- 2 ml/kg and greater than 20 kg- 1ml/kg.

Table 2: Electrolyte composition of intracellular and extracellular fluid

Fluid	Plasma	Interstitial Fluid	Intracellular
Cations			
Na^+	140	146	12
K^+	4	4	150
Ca^{2+}	5	3	10^{-7}
Mg^{2+}	2	1	7
Anions			
Cl^-	103	114	3
HCO_3	24	27	10
SO_4^{2-}	1	1	0
HPO_4^{3-}	2	2	116
Organic anions	5	5	0
Protein	16	5	40

Table 3: Types of fluids

Solution	Composition (per 100 ml)	Indications
Lactated Ringer's (Hartmann's solution)	Lactic acid 0.24ml Sodium hydroxide 0.115 g Dilute hydrochloric acid in sufficient quantity Sodium chloride 0.6g Potassium chloride 0.04g Calcium chloride 0.027 Water for injection qs	▪ To replace body fluids ▪ To buffer acidosis ▪ Shock and other hypoperfusion states
Dextrose and normal saline (DNS)	Dextrose anhydrous 5% wv Sodium chloride 0.9% Water injection qs	▪ To raise total fluid volume ▪ To correct hypoglycemia ▪ Used as a vehicle for administration of drugs
Isolyte M (maintenance solution with 5% dextrose injection)	Dextrose anhydrous 5.0g Sodium chloride 91.00mg Potassium chloride 0.15 g Sodium acetate 0.28 g Sodium metabisulfite 21.0mg Dibasic potassium phosphate 0.13g Water for injection qs	▪ For iv maintenance therapy
Isolyte G (gastric replacement solution with 5% dextrose injection)	Dextrose anhydrous 5.0g Sodium chloride 0.37g Potassium chloride 0.13g Ammonium chloride 0.37g Sodium sulfite 15mg Water for injection qs	▪ Gastrointestinal losses (hyperemia, diarrhea resulting in hypovolemic shock)
Isolyte E (extracellular replacement solution with 5% dextrose injection)	Dextrose anhydrous 5.0g Sodium acetate 0.64g Sodium chloride 0.50g Potassium chloride 0.075g Calcium chloride 0.052g Sodium metabisulfite0.020g Magnesium chloride 0.031g Water for injection qs	▪ Burns ▪ Fascitis ▪ Peritonitis
Dextrose 5%	Dextrose anhydrous 5%w/v Water for injection qs	▪ To raise total volume ▪ To reverse dehydration ▪ To prevent hyperosmolar state ▪ To maintain adequate renal tubular flow(to facilitate water secretion)
Dextrose 10%	Dextrose anhydrous10%w/v Water for injection qs	▪ Prevention and correction of hypoglycemia
Dextrose 25%	Dextrose anhydrous25%w/v Water for injection qs	▪ Prevention and correction of hypoglycemia
Dextrose 50%	Dextrose anhydrous50%w/v Water for injection qs	▪ Prevention and correction of hypoglycemia
Mannitol (solution of mannitol in water or normal saline)	Mannitol (inert form of sugar mannose) 20%	▪ To raise intravascular volume ▪ To reduce interstitial and intracellular edema ▪ To promote osmotic diuresis
Haemaccel (3.5% of infusion solution)	Polymer of gelatin derieved polypeptides 3.5g Water for injection	▪ To raise intravascular volume ▪ To reduce interstitial and intracellular edema ▪ To promote osmotic dieresis ▪ To expand plasma volume (1.5L blood loss can be replaced with haemaccel)

Basic principles of intravenous fluid therapy

The key principles are to replace losses or deficits 'like for like', continue maintenance and to anticipate additional ongoing losses. The average adult requires 3-4L of water per day (2100-2800 ml for a 70kg individual). Sodium and potassium need to be replaced a 1-2 mol/kg per day [4].

Body fluid disturbances can be classified into 3 broad categories:

1. Changes in volume (hypovolemia and hypervolemia)
2. Changes in concentration (hyponatremia and hypernatremia)
3. Changes in composition (acid-base imbalances and concentration changes in calcium, magnesium and potassium)

Intravascular fluid volume status must be assessed preoperatively. Anesthetics can cause systemic vasodilation or myocardial depression. The resultant hypotension from these effects of anesthesia can be severe in hypovolemic patients.

The patient's mental status, history of recent intake and output, blood pressures and heart rate are easily obtainable and provide important information regarding potential fluid imbalances [3, 10].

Physical signs and symptoms of fluid volume imbalance

Hypovolemia

- Poor skin tugor, Dry mucous membranes, Dry axilla
- Flat neck veins, Tachycardia, Orthostatic hypotension
- Hypothermia, Weight loss, Sunken eyes [1]

Hypervolemia

- Shortness of breath at rest or with exertion, JVD, S3
- Hepatojugular reflex, Ascites, Pitting edema, Weight gain [1]

Common laboratory tests to evaluate body fluid disturbances

Hypovolemia

- Serum electrolytes, Serum urea nitrogen/Cr, Hematocrit
- Urine electrolytes and specific gravity serum albumin
- 24-hr urine for Creatinine clearance [3, 10].

Hypervolemia

- Serum electrolytes, Urine-specific gravity, 24-hr urine for Cr clearance
- Total protein, Cholesterol, Liver enzymes, Bilirubin

The serum urea nitrogen (SUN)/creatinine (Cr) ratio is the standard for assessing fluid status quickly [3].

Acid – base imbalance

Metabolic Acidosis

Diagnosis

- Decreased serum HCO_3 with approximately decreased $PaCO_3$ (simple metabolic acidosis)
- Evidence that low serum HCO_3 is primary problem (and not due to compensation for hypercapnia)
- May present with peripheral vasodilation; depressed cardiac contractility in severe acidosis; fatigue, weakness, stupor, coma

It results from an increased intake of acids or an increased loss of HCO_3. The body responds by producing buffers, increasing ventilation (Kussmaul respirations), increasing renal reabsorption and generation of bicarbonate. The kidney will also increase secretion of hydrogen and thus increase urinary excretion of ammonium ions. One of the most common causes of severe metabolic acidosis in surgical patients is lactic acidosis. With shock, lactate is produced as a byproduct of inadequate tissue perfusion. The treatment is to restore perfusion with volume resuscitation rather than to attempt to correct the abnormality with exogenous HCO_3 [8, 9].

Metabolic Alkalosis

Diagnosis

Alkalemia with increased serum (HCO_3)

- Lethargy and confusing progressing to seizures in severe cases
- Ventricular and supraventricular arrhythmias
- Altered oxyhemoglobin binding increases $PaCO_2$ and decreased PaO_2

Metabolic alkalosis consists of triad of increased HCO_3, increased pH and decreased serum chloride concentration. Because the decline in chloride does not equal the rise in HCO_3, the anion gap always increases.
The principal causes of metabolic alkalosis include:

- Addition of HCO_3 to the plasma
- Loss of hydrogen ion
- Volume depletion
- Chronic use of chloruretic diuretics
- Potassium depletion

Treatment includes replacement of the volume deficit with isotonic saline and potassium once adequate urine output is ensured [8].

Respiratory Acidosis

Respiratory acidosis is associated with the retention of CO_2 secondary to decreased alveolar ventilation. The principal causes are narcotics, CNS injury, pleural effusion, pneumonia, and mucus plug, pain from abdominal or thoracic injuries, abdominal distention and ascites. As compensation is primarily renal, it is a delayed response. Treatment is directed at the correction of the underlying cause and measures to ensure adequate ventilation [8].

Respiratory Alkalosis

Most cases are acute in nature and secondary to alveolar hyperventilation. Etiologies include pain or anxiety, neurologic disorders, drugs such as salicylates, fever or gram negative bacteremia, thyrotoxicosis or hypoxemia. Acute hypocapnia can cause an uptake of potassium and phosphate into cells and increased binding of calcium to albumin, leading to symptomatic hypokalemia, hypophosphatemia and hypocalemia with subsequent arrhythmias, paresthesias, muscle cramps and seizures. Treatment is directed at the underlying cause but may also require direct treatment of hyperventilation [8].

Anesthesia, surgery and fluid balance

Fluid shifts during the perioperative period and the physiological responses to surgical stress have significant implications for perioperative fluid prescribing. Many patients are dehydrated before theatre owing to prolonged fasting, the use of purgatives or diuretic therapy. Intra-operative losses are frequently underestimated and excess losses, both surgical and third space losses, persist into the early postoperative period. Therefore, a general tendency towards hypovolaemia is usually present leading to thirst and vasopressin secretion [7, 8, 9].
The most important response to anesthesia and surgery in the perioperative period is sodium and water retention. In general, tendency to retain water is directly related to the magnitude of surgery. A number of factors may contribute to this including: the effects of anesthetic agents on renal blood flow and GFR, effects of intraoperative hypotension or hypovolemia on renal function, increased sympathetic tone and circulating catecholamines causing renal vasoconstriction, the salt and

water retaining effects of increased plasma cortisol and aldosterone levels on response to the stress of surgery and increased ADH activity. One of the most important of these is the increase in ADH activity. During surgery, ADH increase by 50-100 folds. This concentration falls at the end of surgery but does not return to the normal for 3-5 days. This response is partly related to drugs, pain and other factors attributable to the stress of surgery. However, mostly it is a physiological response to the loss of intravascular fluid into cells or by its sequestration and immobilization in damaged tissues i.e. third space. The difference is important because it determines the choice between fluid loading and fluid restriction as the most physiological approach to fluid therapy in the peri-operative period [9].

Changes in capillary membrane porosity occur during surgery largely as a result of the cytokine-mediated responses to tissue injury and bacteremia. Despite a considerable increase in lymphatic drainage, fluid accumulates in previously dry tissues. The situation often exists where circulatory hypovolaemia is significant enough to threaten organ perfusion whilst these third space tissues are waterlogged. More fluid is required in this situation to maintain circulatory volume and adequate organ perfusion [9].

Recent Concepts

The concept of a state of zero fluid balance

There is a relatively narrow range for safe fluid therapy and too much or too little fluid can lead to postoperative morbidity. However, even now it is not unusual for surgical patients to receive 5-10 L of fluid and 600-1000mmol of sodium in the first 24 h of an operation. This inevitably leads to fluid overload, edema and adverse outcomes. On the other hand, overnight fasting and bowel preparation lead to fluid deficits and patients may arrive in the anesthetic room in fluid depleted state necessitating preoperative fluid boluses to prevent hypotension induced by induction of anesthesia. Current anesthetic recommendations that allow patients to drink clear fluids upto 2 h prior to the induction of anesthesia prevent preoperative fluid depletion and do not increase aspiration-related complications.[11] The aim of the perioperative fluid therapy to avoid both fluid overload and under hydration and maintain patients in as near a state of zero fluid balance as possible if outcomes are to be optimized.

Conclusion

Understanding the basic mechanism and the fluid and electrolyte physiology is an essential tool for successful perioperative fluid management. Appropriate fluid therapy is important to protect organ function in the perioperative period. The physiological basis and fundamentals of fluid and electrolyte management are well known but a lag still exists between knowledge and applied clinical practice. Therefore, understanding and accurately applying the knowledge of physiologic mechanisms of fluid and electrolytes will help in improving and maintenance of homeostasis.

Conflict of interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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