Dehydration — Isotonic, Hypotonic and Hypertonic Fluid Disorders

Dehydration is an imbalance in the body fluid environment. The imbalance is due to less water intake while there is more water loss. The body can lose water through normal physiologic processes in respiration, urination and sweating, or some pathologic diseases through vomiting, diarrhea and fever.

Overview

Dehydration is defined as the excessive loss of body water. The balance between fluid intake and fluid loss from the body is greatly hampered in dehydration. It ranges from mild to severe with death, occurring when the body loses more that 15% of the water content.

Hypovolemia is another related term that means decreased circulatory volume due to the loss of blood or plasma.

Pathophysiology of Dehydration

The total body water is distributed into extracellular and intracellular compartments. The extracellular compartment contains one-third of total body water and comprises of
intravascular, interstitial and intercellular spaces. The intracellular compartment contains **two-thirds** of total body water and is present inside the cells. Fluid from the extracellular compartment is depleted first, then fluids from the intracellular space is lost, resulting in cellular shrinkage and metabolic dysfunction.

Dehydration occurs due to a decreased water intake, increased fluid loss, or both. In elderly people, impaired thirst sensation, chronic illness, fever and sickness are common reasons for a **decreased water intake**. The common reasons for **increased fluid loss** include vomiting, **diarrhea**, diuresis and sweating. Working in hot weather without water replacement is another common reason of dehydration.

Dehydration can be divided, according to the serum sodium concentration, into **hypernatremic**, **hyponatremic** or **isonatremic** dehydration.

- If water loss is more as compared to the sodium loss, then serum sodium concentration increases, resulting in **hypernatremic (or hypertonic)** dehydration.
- If water loss is accompanied with more sodium loss, then serum sodium concentration decreases, resulting in **hyponatremic (or hypotonic)** dehydration.
- If water and sodium are proportionally lost, then the serum sodium concentration remains the same. It is called **isonatremic (or isotonic)** dehydration.

Apart from hypernatremia and hyponatremia, other electrolyte imbalances may also occur, such as:

**Hyperkalemia** occurs in insulin dependent diabetes mellitus, Addison’s disease, and kidney failure.

**Hypokalemia** results from increased potassium loss in severe diarrhea and vomiting.

**Hypermagnesemia** and **hyperphosphatemia** can also occur from increased concentration of magnesium and phosphates respectively.

### Evaluation of TBNa$^+$ Status

1. **Decreased TBNa$^+$** produces signs of volume depletion
   - Dry mucous membranes
   - Decreased skin turgor (i.e. skin tenting when the skin is pinched)
   - Drop in blood pressure and increase in pulse (reflex tachycardia) when sitting up from a supine position (i.e. positive tilt test)

2. **Increased TBNa$^+$** may produce body cavity effusions (ascites) and pitting edema
   - Dependent pitting edema is due to an excess of Na$^+$-containing fluid in the interstitial space (> 2-3 liters)
     - Due to the low protein content in edema fluid
     - Fluid obeys the law of gravity and moves to the most dependent portion of the body (e.g., ankles when standing)
   - Starling pressures are altered to produce pitting edema and body effusions
   - An increase in TBNa$^+$ increases plasma hydrostatic pressure
     - Due to an increase in plasma volume
An increase in TBNa+ increases the weight of the patient
- The most common cause of an increase in weight in a hospitalized patient

3. Normal TBNa+ is associated with normal skin turgor and hydration
- Fluid movement across a capillary/venule wall into the interstitial space is driven by Starling pressures (not osmosis)
- The net direction of fluid movement depends on which Starling pressure is dominant
- An increase in plasma hydrostatic pressure, or a decrease in plasma oncotic pressure (i.e., serum albumin), causes fluid to diffuse out of capillaries and venules and into the interstitial space, resulting in dependent pitting edema and body cavity effusions

Signs and Symptoms of Dehydration

Most patients with dehydration present with:
- Thirst
- Headaches
- Fatigue
- Constipation, dry mouth, dry skin, dizziness and low urine volume, unless the cause of dehydration is polyuria
- More severe symptoms will progress to confusion and even seizures or death.
- Signs of dehydration will range from dry skin, sunken eyes, dry mucous membranes, oliguria to seizures and coma.
- Signs of hypovolemia may also be present, including tachycardia, orthostatic hypotension and flat neck veins.

Dehydration is more clinically evident in the elderly patients, especially in hot weather, because of impaired thirst sensation. Old or hospitalized patients will show signs of irritability and sometimes delirium.

The symptoms of severe dehydration are very less urine output or no urine, dizziness, drop in blood pressure, rapid heart rate, fever, poor skin elasticity, lethargy, confusion, and even coma, seizure or shock.

Isotonic Dehydration

Isotonic dehydration is a condition in which both water and sodium are lost proportionally to the serum concentration maintaining the normal serum osmolality. Serum osmolality determines the movement of fluids and electrolytes across membranes. The normal serum osmolality is 285-295 mOsm/kg.
Causes of isotonic dehydration

- **Vomiting and diarrhea:** severe watery diarrhea and/or vomiting can be life threatening, especially in children. People with gastroenteritis may lose tremendous amounts of fluids and electrolytes in a short time, plus their oral replacement will also be limited due to recurrent vomiting, resulting in severe dehydration.

- **Excessive sweating:** vigorous exercise, especially in humid weather, will increase sweating and lead to fluid and electrolyte loss.

Moreover, if dehydration is not corrected, it will lead to renal injury from muscle breakdown and lactic acidosis.

Lab values in isotonic dehydration

Isotonic dehydration will show the same laboratory values as normal serum, including normal osmolality of 285-295 mOsm/kg and normal serum sodium of 135-145 mmol/L.

Urine volume will be decreased (oliguria) with low fractional sodium excretion and increased specific gravity.

Dehydration can result in elevated liver and pancreatic enzymes with decreased glomerular filtration rate. Dehydration also can result in a variety of electrolyte imbalance that will affect the clinical picture and prognosis of the patients.

Hypertonic Dehydration

Hypertonic dehydration occurs when the water excretion is more than the sodium excretion, which results in more sodium concentration in the extracellular fluid (hypernatremia). The blood osmolality is increased causing the water shift from the intracellular to the extracellular space.
Causes of hypertonic dehydration

- **Fever**: Fever will increase the respiratory rate and, subsequently, the water loss. Sweating will also increase during fever to lower the body temperature. Moreover, water intake is commonly decreased during a fever which will aggravate dehydration.

![Image: "Micrograph of spironolactone bodies. H&E stain." by Nephron - Own work. License: CC BY-SA 3.0](image)

- **Polyuria**: Increase water loss in urine causes hypertonic dehydration and may occur in **diabetes mellitus**, **diabetes insipidus** or **diuretic use**.
- **Less water intake**
- **Excessive sweating**
- **End stage renal disease**
- **Drinking urine or sea water for survival.**

Lab values in hypertonic dehydration

**Serum osmolality** will exceed 300 mOsm/kg, while **serum sodium** will be more than 150 mEq/L.

**Urine volume** will be decreased unless the cause of dehydration is polyuria or diuretics.

**Specific gravity** will be high and fractional excretion of sodium will also increase.

<table>
<thead>
<tr>
<th>Compartment Alteration</th>
<th>POsm/Na⁺</th>
<th>ECF Volumen</th>
<th>ICF Volume</th>
<th>Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hyperglycemia</td>
<td>Increased ↑Glucose ↓Na⁺ (dilutional effect)</td>
<td>Contracted</td>
<td>Contracted</td>
<td>• Diabetic ketoacidosis&lt;br&gt;• Hyperosmolar nonketotic coma (type 2 diabetes)</td>
</tr>
<tr>
<td>Hypotonic loss of Na</td>
<td>Increased ↓TBN'/ ↓TBW</td>
<td>Contracted</td>
<td>Contracted</td>
<td>• Osmotic diuresis; glucose&lt;br&gt;• Sweating</td>
</tr>
</tbody>
</table>
Hypotonic Dehydration

Hypotonic dehydration occurs when sodium loss is more than water loss which will decrease the serum osmolality. It results in the shifting of water from the extracellular space into the cells. The cells will swell and cerebral edema may occur.

Hyponatremia can be acute or chronic. If sodium loss occurs for a period more than 48 hours, it is chronic hyponatremia, which gives the body a good chance to adapt. Sodium imbalance mainly manifests with neurological symptoms ranging from headaches, nausea, lethargy and sometimes confusion, coma and death.

The term hyponatremia should be used with caution in cases of dehydration, as most cases of hyponatremia imply excess water retention, not dehydration.

Causes of hypotonic dehydration

- Addison’s disease
- Renal tubular acidosis
- Latrogenic causes; hypotonic fluids or plain water with less salt for patients with heat stroke or diarrhea.
- Diuretics: loop, thiazide, and osmotic diuretics especially with prolonged use.
- Cystic fibrosis.
Lab values in hypotonic dehydration

Serum sodium and serum osmolality will be **less than** normal range.

**Urine specific gravity** will be **decreased**

**Urine sodium excretion** will be **decreased**.

Isotonic and Hypotonic Fluid Disorders: Summary

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<thead>
<tr>
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<th>ICF Volume</th>
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<tbody>
<tr>
<td>Normal</td>
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Isotonic and Hypotonic Changes

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<th>ICF Volume</th>
<th>Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Isotonic loss</strong></td>
<td>Normal ↓TBNa⁺/↓TBW</td>
<td>Contracted</td>
<td>Normal</td>
<td>Adult diarrhea, Loss of whole blood</td>
</tr>
<tr>
<td><strong>Isotonic gain</strong></td>
<td>Normal ↑TBNa⁺/↑TBW</td>
<td>Expanded</td>
<td>Normal</td>
<td>Excessive Isotonic Saline</td>
</tr>
<tr>
<td><strong>Hypertonic loss</strong></td>
<td>Decreased ↓TBNa⁺/↓TBW</td>
<td>Contracted</td>
<td>Expanded</td>
<td>Loop diuretics, Addison’s disease, 21-Hydroxylase deficiency</td>
</tr>
<tr>
<td><strong>Hypotonic gain</strong></td>
<td>Decreased TBNa⁺/↑↑TBW</td>
<td>Expanded</td>
<td>Expanded</td>
<td>SIADH, Compulsive water drinker</td>
</tr>
<tr>
<td></td>
<td>Decreased TBNa⁺/↑↑TBW</td>
<td>STARLING pressure alteration</td>
<td>Expanded</td>
<td>Right-sided heart failure, Cirrhosis, Nephrotic syndrome</td>
</tr>
</tbody>
</table>

Complications of dehydration:

- **Hypovolemic shock**: Severe dehydration will lead to low blood volume and hypovolemic shock. It can lead to major end organ damage with acidosis and acute kidney injury that might be fatal.
- **Seizures**: Sodium imbalance can cause abnormal neuronal excitability, resulting in confusion, seizures, delirium and coma. Another cause of seizures in dehydrated patients is iatrogenic with rapid correction of underlying serum sodium abnormality. Hypotonic saline, if used in hypernatremic patients, will rapidly decrease the plasma osmolality, and water will shift to the intracellular space, resulting in brain edema and seizures.
- **Cardiac arrhythmias**: Potassium imbalance affects mainly muscles and may cause life-threatening cardiac arrhythmias, fatigue, weakness and muscle breakdown.
- **Heat stroke**: During exercise or working in a hot environment, fluid intake is recommended in order to avoid heat exhaustion, or even heat stroke.
- **Kidney failure**: Possible causes of kidney injury from dehydration include hypovolemic shock with low blood supply to the kidney, acidosis from hypovolemia, muscle breakdown, and electrolyte disturbance.
- **Thrombosis**: Increased blood viscosity from dehydration will lead to venous thrombosis. Patients may present with DVT, portal vein thrombosis and
pancreatitis. Fever will also increase thrombosis and limit water intake.

- **Coma and death**: Low blood pressure in severe dehydration will decrease the blood supply to the brain and end up in coma and death, especially in elderly patients.

### Prevention of Dehydration

Adequate hydration is recommended during all activities to prevent dehydration. Water intake is the key to replacing water loss during exercise, in hot weather, in hospitalized patients and elderly people with impaired thirst sensation.

Hospitalized patients should be monitored for water intake and total output carefully for early detection of any fluid imbalance.

Children with vomiting and diarrhea should not be replaced for fluid loss with plain water because it will develop electrolyte imbalance with hyponatremia and water intoxication.

Intravenous fluids can be used for unconscious patients while plain water, sports drinks with electrolytes and oral rehydration solutions are used for prevention and treatment of mild dehydration. **Electrolyte monitoring** is mandatory for patients under prolonged diuretic use.

### Treatment of Dehydration

Treatment of patients can vary according to the age and severity of dehydration.

*Treatment of the cause* should always be considered, along with symptomatic treatment and fluid replacement. Urine output should be monitored in the hospitalized patients as an indication for the efficient treatment and restoration of kidney function.

In severe dehydration, *restoration of the blood volume* is the main goal with a fluid bolus of 20ml/kg isotonic saline or lactated ringer. Adults can use oral fluids if they are conscious and able to drink, otherwise, intravenous fluids should be used. Correction of electrolyte abnormalities should follow.

### Infants and children with dehydration

Children are vulnerable to the effects of dehydration. Water deprivation can complicate gastroenteritis or fever and lead to severe dehydration with neurological manifestations and electrolyte imbalance.

Treatment options include fluid replacement orally if the child is conscious and able to drink. Water, fluids and an oral rehydration solution can be used. In severe cases, Intravenous fluids should be used.

Breast feeding and normal diet should be continued, as long as the treatment with fluid replacement is going to avoid weight loss or developmental delay.

### Treatment of cases with isonatremic dehydration

Fluid bolus is started for the restoration of the blood volume according to the severity of the case, followed by maintenance therapy with **0.9% normal saline.** 20 mL/kg of isotonic sodium solution or lactated Ringer solution is given to restore hydration. Oral intake should be encouraged as early as possible.
Treatment of cases with hyponatremia

Patients may present with **acute cerebral edema**. Early steps should be towards the stabilization of the patient, securing the airway, breathing and **circulation**.

**In acute severe cases** with seizures and coma, management of hyponatremia is with **hypertonic saline 3%**. Correction of hyponatremia should start at a rate of **4-6 mEq/L/hour**.

**In chronic hyponatremia**, correction of sodium concentration should be done using **normal saline 0.9%** at a rate of **10-12 mEq/L/day in the first 2 days**. Rapid correction of hyponatremia will lead to **central pontine myelinolysis**, where permanent injury to the **brain stem** will occur and result in quadriplegia and cranial nerve paralysis.

To calculate the sodium deficit:

\[
\text{Sodium deficit} = (\text{normal sodium level} - \text{serum level}) \times \text{volume of distribution} \times \text{weight}
\]

**Treatment of cases with hypernatremia**

The first step is **volume restoration** with isotonic saline or lactated ringer.

The next step is a slow correction of the hypernatremia at a rate of 10 mEq/L/24 hours to avoid cerebral edema and death as a complication. **5% dextrose in 0.9% sodium chloride** can be used with frequent monitoring of the serum sodium every 4 hours.

Hyperglycemia and hypocalcemia sometimes follow hypernatremic dehydration, so serum glucose and calcium levels should also be kept on watch.

Note: Antidiarrheal agents, routine antibiotics and antiemetics should be avoided as they may worsen the condition.

**References**

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of sodium in mammals.

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