Physiology of fluid balance

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Abstract

The body, in broad terms, is divided into intra- and extracellular fluid compartments, of which the extracellular consists of intravascular and interstitial compartments. The osmotic pressure of all of these compartments is equal, but their composition is different. This difference and the shifts in fluid between the intra- and extracellular compartments are brought about, in part, by the presence of intracellular proteins, which are negatively charged but which have no osmotic effect and cannot pass across cell membranes, and also by the inability of charged electrolytes to pass across cell membranes except via specialized transport proteins. Intake of fluid is in part voluntary but fluid is also present in food and is derived from the oxidation of food. Fluid balance is controlled by volume and osmolar mechanisms largely under the control of aldosterone and antidiuretic hormone, respectively.

Keywords electrolytes; extracellular fluid; intracellular fluid

Learning objectives

After reading this article, you should be able to:

- describe the main fluid compartments of the body, and their relative volumes
- describe the differences in composition between the fluid compartments, and explain how these differences arise
- outline factors that affect water and sodium balances within the body and describe how these balances are maintained in health
- understand the concept of osmolality and its main compartments in physiological systems.

The body contains 45–75% by weight of water; the range reflects the differences in body composition between the different demographic groups – male and female, young and old. Adipose tissue contains up to 10% water; lean tissue contains 70–75% water. In young adult males, body water is about 60% of body weight and in young adult females, who have a higher percentage of body weight as fat, about 50%. With age, the proportion of body weight made up of water decreases because lean tissue mass declines and tends to be replaced with adipose tissue. In the newborn, the figure is nearer 80–85% owing to a relative expansion of the extracellular fluid (ECF) volume.

Total body water is distributed mainly between the intracellular fluid (ICF) and ECF. About 1–2% of body water is 'transcellular water' found in cerebrospinal fluid, the humours of the eye, digestive secretions, renal tubular fluid and urine. Transcellular fluids are separated from the ECF by an endothelium and a continuous epithelial layer. The epithelium actively secretes and modifies their composition. The details of their formation and circulation are discussed with the physiology of the organs, of which they form a part.

Intracellular and extracellular fluid

A 70 kg adult male contains 42 l of water; 40% (28 l) is intracellular and 20% (14 l) extracellular. Of the ECF, 5% (3.5 l) is intravascular and 15% (10.5 l) extravascular (interstitial fluid and lymph). The ICF is divided by membranes into individual cells. ECF, in the form of plasma and interstitial fluid, bathes all the cells and constitutes the environment within which they function, as well as providing the transport system for nutrients and waste products. Its role in this context is described on pages 586–92, along with the techniques used to measure the various fluid compartments using indicator dilution.

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Fluid composition

The compositions of ICF and ECF are different (Table 1). The principal intracellular cation is potassium and the main extracellular cation is sodium. ICF has a high protein content, whereas the protein content of ECF is almost zero. Proteins have multiple charges on each molecule; at body pH the net charge is negative. After protein, the principal intracellular anions are organic phosphates (e.g. creatine phosphate, ATP).

Electrolytes: sodium and potassium are important for maintaining osmolality and cell volume, generating the resting membrane potential and generating action potentials of excitable tissue (see *Anaesthesia and Intensive Care Medicine* **9:** 251–5). Calcium is largely an extracellular ion, but has an important role in the regulation of cell metabolism, and in cardiac and skeletal muscle acts as the link between electrical activity and contraction. It also influences neuromuscular excitability and is required for blood clotting. Magnesium is mainly intracellular and is necessary for many intracellular enzyme systems, including oxidative phosphorylation and protein synthesis. Chloride and bicarbonate are the main extracellular anions. Chloride is important in the function of secretory and absorptive cells in the kidney and gastrointestinal tract. Bicarbonate is important in the control of pH and in carbon dioxide transport.

The precise composition of the ICF is not identical across all cell types, nor are the ions distributed equally throughout the cell. In the RBC for example, the chloride ion concentration is relatively high (90 mmol/l) because of its role in carbon dioxide transport (chloride shift). In muscle, calcium ions are sequestered in the sarcoplasmic reticulum where they have a fundamental role in excitation–contraction coupling.

Interstitial fluid is essentially an ultrafiltrate of plasma; the proteins remain in the circulation, which results in some

Electrolyte composition of body fluids

Electrolytes	Plasma (mmol/l)	Plasma water (mmol/kg H_2O)	Interstitial (mmol/kg H_2O)	Intracellular (mmol/kg H_2O)
Cations				
Na^+	142	153	145	10
K^+	4	4.3	4	159
Ca^{2+}	5	5.4	3	1
Mg^{2+}	2	2.2	2	40
Total	153	165	154	210
Anions				
Cl^-	103	111	117	3
HCO_3^-	25	27	28	7
Protein	17	18	–	45
Others	8	9	9	155
Total	153	165	154	210

Table 1

differences in ionic concentrations (Table 1). The negative charge on the proteins keeps some of the small diffusible cations (Na^+) in the circulation with a higher concentration of diffusible anions (Cl^-) in the interstitial fluid. Mg^{2+} and Ca^{2+} are to some extent (30–40%) bound by the plasma proteins, therefore the total concentrations of these ions are lower in interstitial fluid than in plasma. Osmotic equilibrium is maintained despite the difference between the total ionic content of the plasma, the interstitial fluid and the ICF because protein molecules have multiple negative charges and are relatively inactive osmotically.

Osmolality

The concentrations of the various ions on each side of the cell membrane, specifically Na^+ and K^+, are maintained by the Na^+/K^+-ATPase pump, but the osmolalities of the two compartments are equal. If they were not, there would be a net movement of water between them, and the cells would shrink or swell (and burst). Na^+ concentration determines the amount of water in the extracellular space and K^+ concentration determines that in the intracellular space. Plasma, interstitial and intracellular osmolality are identical (average 287 mosmole/kg of water) and in the ECF Na^+ accounts for about 90% of it.

If the osmolality of ECF is altered, the size of the intra- and extracellular compartments changes in a predictable fashion.

- With the addition of water the osmotic pressure of the extracellular compartment falls. Water moves by osmosis out of the extracellular and into the intracellular space and the system comes to equilibrium with the cells swollen and the osmotic pressure of both intra- and extracellular compartments equal but diminished.
- Isotonic saline increases the size of the extracellular space but there is no change in osmotic pressure and no movement of water in or out of the cells.
- Adding hypertonic saline increases the osmotic pressure of the extracelluar compartment and water moves out of the cells into the extracellular space. The system comes to equilibrium with an enlarged extracellular space, shrunken cells and increased osmolality.

Daily water balance in an average 70 kg man

Input (ml)	
Water in beverages	1000
Water in food	1200
Water of oxidation	300
Total	2500
Output (ml)	
Skin and lungs	900
Gastrointestinal tract (faeces)	100
Kidneys (urine)	1500
Total	2500

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Table 2

Although body fluids contain uncharged molecules (e.g. glucose, urea), which contribute to these osmotic forces, their effect is small and the main influences that determine the distribution of water between the compartments are the electrolytes.

Plasma and interstitial fluid

The relative volumes of plasma and interstitial fluid are determined by colloid osmotic (oncotic) pressures exerted across the capillary walls. The osmotic pressures on the two sides are equal, but oncotic pressures are exerted by the plasma proteins that remain within the vascular space (see *Anaesthesia and Intensive Care Medicine* **8:** 73–8).

Fluid balance

If an individual has a stable body size and composition, the volume and composition of the body fluids must also be stable. This stability is maintained despite intakes of water and electrolytes, which can vary widely from day to day. The controlling mechanism is normally the kidney. Water intake is mainly determined by habit and social influences; some water is contained in food and some arises from metabolic sources as a result of oxidation of fat and carbohydrate. Water is lost as urine, sweat, and via the lungs and gastrointestinal tract. Average figures for daily water balance in a semi-sedentary individual in a temperate climate are given in Table 2. Obviously, with heavy work in a hot, dry atmosphere, the intake and skin losses would be greater, and the urine losses possibly lower, unless water intake were increased markedly. Likewise, with diarrhoea and vomiting, the figures for the gastrointestinal tract would be greater. Children have a higher throughput of water because of their higher surface:volume ratio and higher metabolic rate for their weight.

Control of fluid intake

Fluid intake is driven by thirst. Thirst is primarily associated with dryness of the mouth and throat, mediated by a decrease in secretions by the salivary and buccal glands. It may be associated with dehydration (intracellular or extracellular). It is controlled by the hypothalamus, which relays information to the cerebral cortex, where thirst is appreciated at the conscious level.