# Organization and composition of body fluids

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**Abstract**

Disorders of fluid balance and electrolyte homeostasis are commonly observed in critically ill patients and in those who require emergency anaesthesia. Consequently, anaesthetists and intensive care physicians must understand the physiological principles that govern fluid balance. This article discusses the compartmentalization of total body water and describes methods by which the volume of the fluid compartments may be measured. The novel concept of the endothelial glycocalyx is discussed in addition to the conventional and contemporary models of capillary filtration dynamics. The core elements of fluid balance and cardiovascular homeostasis are also explored.

**Keywords** Body fluid compartments; extracellular fluid; intracellular fluid; total body water

**Royal College of Anaesthetists CPD Matrix:** 1A01

## Learning objectives

After reading this article, you should be able to:

- describe the compartmentalization of total body water in healthy individuals
- list certain disease states that influence the volume of specific body fluid compartments
- describe capillary filtration dynamics
- outline the mechanisms by which blood pressure and intravascular blood volume are regulated

## The organization and composition of body fluid compartments

Water is the largest individual component of body mass. The proportion of body mass attributed to total body water (TBW) varies with age (Figure 1), gender, body habitus and the presence of disease. For example, an adult female normally has a lower proportion of TBW (50% of body mass) than males due to a higher proportion of adipose tissue, which is relatively anhydrous when compared to other body tissues. For the same reason, obese persons have less TBW as a proportion of their total body mass. The daily fluid and electrolytes required for maintenance intravenous fluid are listed in Table 1.

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## Fluid compartments

Total body water is distributed within two main body compartments: the intracellular fluid (ICF) and extracellular fluid (ECF) compartments. The cell membrane forms the boundary between the ICF and ECF compartments. The ECF compartment is subdivided into interstitial fluid (ISF), plasma and transcellular fluids. The volume of each fluid compartment in a healthy 70 kg man is illustrated in Figure 2.

### Interstitial fluid

Interstitial fluid constitutes the largest reservoir of ECF and is that which bathes the external environment of cells. It is formed by the filtration of blood plasma through the walls of local capillaries. It provides communication between the intravascular compartment and individual cells, delivering substrates and enabling cells to regulate their own intracellular composition. The ISF has a similar electrolyte composition to that of plasma with a relatively low protein concentration. Disease states which increase the volume of this fluid compartment manifest clinically as interstitial oedema. Such diseases typically include any that cause hypoalbuminaemia (e.g. nephrotic syndrome), elevated venous pressures (e.g. in cardiac failure), increased capillary permeability (e.g. critical illness) and in disordered lymphatic drainage (e.g. following lymph node clearance).

### Plasma

Fluid within the intravascular compartment exists as blood plasma, which is the acellular component of blood. Although the circulating blood volume is approximately 5 litres, only 3.5 litres is plasma. The additional contribution to the circulating blood volume comes from the volume of circulating blood cells, such as erythrocytes, which are suspended within the plasma.

### Transcellular fluids

Transcellular fluids comprise the smallest component of the ECF compartment. These fluids exist within body cavities that have an epithelial lining. These are cerebrospinal fluid, lymph, bile, intraluminal gastrointestinal fluid, intraocular fluid and the serous fluid found within the pleural and peritoneal cavities. The volume can be significantly increased in disease (e.g. pleural effusion, ascites and gastrointestinal ileus). The ionic composition of these fluids vary according to their physiological purpose (Table 2).





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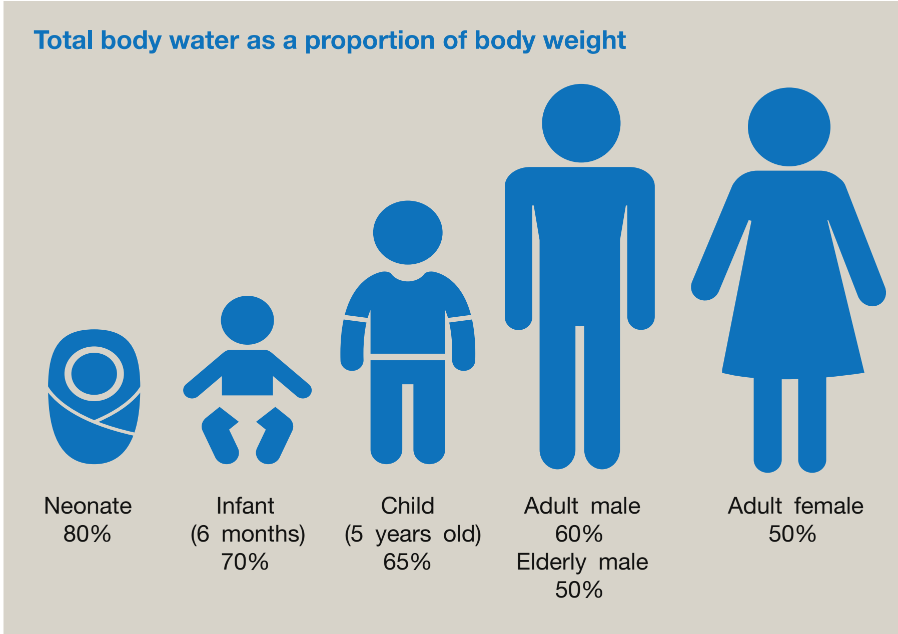


**Figure 1**

### Daily water and electrolyte requirements for intravenous maintenance therapy in adults

| Required element | Daily requirement |
|---|---|
| Water | 25–30 $ml^{-1}$ kg $day^{-1}$ of water (ideal body weight) |
| Sodium | 1 mmol $kg^{-1}$ $day^{-1}$ |
| Potassium | 1 mmol $kg^{-1}$ $day^{-1}$ |
| Chloride | 1 mmol $kg^{-1}$ $day^{-1}$ |
| Glucose | 50–100 g $day^{-1}$ (to prevent starvation ketosis) |

Source: NICE Clinical guideline 174, 2013[7]

**Table 1**

## Calculating the volume of body fluid compartments

If a known mass of an exogenous substance is administered to a body compartment, the measured concentration of this substance can be used to determine the volume of the compartment. This dilution technique is in accordance with the equation:

$$Volume\,(L) = \frac{mass\,(Kg)}{concentration\,(Kg\,L^{-1})} \qquad (1)$$

For an indicator substance to give an accurate estimate of the volume of a body fluid compartment, it should ideally be entirely confined to that compartment, be evenly distributed though out it, and have predictable elimination kinetics. Furthermore, it should be non-toxic and free from any osmotic effects that might spuriously affect the volume of the measured compartment.

Various methods exist to calculate TBW, ECF, whole blood and plasma. Total body water can be measured using water, which contains hydrogen isotopes in the form of deuterated water (deuterium oxide, $^2H_2O$) or tritiated water (tritium oxide, $^3H_2O$). The ECF may be measured by using radioisotopes of sodium, bromide and chloride; however, these ions enter cells and may overestimate the ECF volume. Alternatively, the ECF may be measured using inulin or mannitol. These, however, do not uniformly permeate the ECF and can underestimate its volume. Plasma volume can be measured by using radiolabelled albumin ($^{131}I$ isotope) or Evans blue dye. If the haematocrit is known, this will allow the total plasma volume to be estimated (blood volume = plasma volume/[1 − haematocrit as a decimal fraction]). The total erythrocyte volume can be measured using red cells that are isotopically labelled with $^{51}Cr$ isotopes.

The measured volumes of these compartments can subsequently be used to derive the volumes of other compartments. The volume of ICF can be estimated by subtracting the volume of the ECF from TBW (ICF = TBW − ECF). Additionally, the ISF compartment can be estimated by subtracting plasma volume from the ECF compartment (ISF = ECF − plasma volume).

## The composition of ICF and ECF

Intracellular fluid is separated from ECF by the cell membrane which regulates the ionic composition of the ICF. This is achieved by the transmembrane transport systems of diffusion, osmosis, active transport and facilitated diffusion. Cell membranes are 'semipermeable', in that they are freely permeable to water molecules but not to solutes. In particular, cations such as potassium and sodium are relatively impermeable to the cell membrane and must move across the membrane by dedicated transporter mechanisms. The precise composition of the ICF varies according to the specialization of individual cells. However, in general, the ICF is rich in potassium and magnesium ions, and protein, but has low concentrations of sodium, chloride and bicarbonate ions.




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