The organization and composition of body fluids

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Abstract

The water contained in the body is divided amongst compartments of differing sizes and compositions. The dynamic balance across these compartments is an essential component of normal physiology. Here, the calculation of these volumes by measuring the dilution of markers able to permeate specific compartments is considered. Furthermore, the potential disadvantages to the approach are discussed. The differences in ionic concentration between intracellular and extracellular fluid are quantified and the effects of greater relative protein concentration within cells are also considered. To illustrate daily fluid balance in a healthy individual, a typical intake and output over 24 hours is quantified before consideration of iatrogenic contributions to this equilibrium. The way in which clinically administered fluids of varying compositions affect the fluid compartments is subsequently discussed. The endogenous processes contributing to volume homeostasis are then deliberated including the detection of fluid imbalance through intracellular and extracellular systems as well as the hypothalamic and renal effector mechanisms. Finally, the regulation of sodium is discussed with examination of the mechanisms controlling natriuresis and the reciprocity with potassium balance.

Keywords Extracellular fluid; fluid balance; fluid compartments; intracellular fluid; ion composition; sodium homeostasis; volume homeostasis; volume of distribution

Royal College of Anaesthetists CPD Matrix: 1A01

Learning objectives

After reading this article you should be able to:

- understand how total body water is divided into compartments and describe how they can be measured experimentally
- compare the ionic composition of the intracellular and extracellular compartments
- quantify the typical daily input and output of body fluids of a 70-kg man
- understand how different types of administered fluids distribute across these compartments
- describe the detector and effector mechanisms contributing to endogenous fluid volume homeostasis
- understand the regulation of sodium in the body and the relationship with volume and potassium regulation

Fluid compartments

Fluid volumes

The distribution of body mass for a typical 70-kg man can be seen in Figure 1. Although approximate, these values can be useful when considering fluid balance. The majority of the total body water (TBW) exists within cells in the intracellular fluid (ICF). While only a third is external to cell membranes in the so-called extracellular fluid (ECF). About 75% of the ECF is outside the vascular system, primarily in the form of interstitial fluid. It also includes a small volume that can be considered transcellular, for example cerebrospinal fluid and intra-ocular fluids. These are defined separately owing to their secretory origins and enclosure within epithelium-lined cavities. However, as their water content is not freely available for fluid exchange these will not be considered in detail. The remaining quarter of ECF represents the plasma–water volume of 3.5 litres, which with cellular content forms approximately 5 litres of blood.

This approximate guide to fluid compartments does not hold true for the whole population, as fairly obvious differences in body composition are observed. As the proportion of body mass comprising adipose tissue increases, a comparatively anhydrous tissue, the contribution of water to body weight will decrease. Typically females have a greater percentage body fat and so a lower percentage body weight will be water derived. Similarly, an increase in age is associated with a greater proportion of body fat, replacing previously water rich tissues.

The measurement of these values can be achieved using marker dilution techniques. By introducing a water-soluble dye into the body that is restricted in its distribution throughout the compartments the volume of distribution can be calculated from which the compartment volume can be inferred. In order to estimate TBW, deuterated or tritiated water can be used, as these will distribute precisely as normal water does. Sodium bromide or inulin can be used to measure the ECF as they are unable to cross the cell membranes. The ICF volume can then be calculated from the difference between TBW and ECF. Finally, radiolabelled albumin or red blood cells can be given intravenously to quantify plasma volume.

Once a marker has been allowed to equilibrate, the volume of distribution (V) can be calculated from the total amount injected (M), the amount excreted during the time taken to equilibrate (E) and the measured concentration. Using Equation 1, this gives the volume of the compartment being considered.

$$V = \frac{M - E}{C} \quad (1)$$

Equation 1. Calculating volume of distribution for an administered marker.

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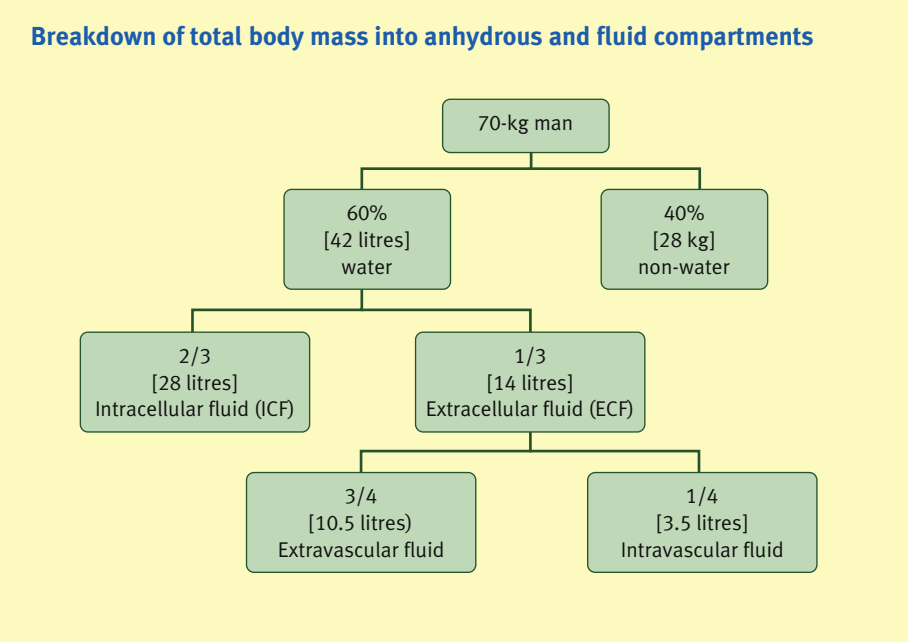

Figure 1

Elimination of the marker will include metabolism, either hepatic or cellular, and renal excretion. Correcting for this metabolized fraction cannot be achieved accurately. The measurement of renal excretion is also cumbersome, requiring the emptying of the bladder before administration and after equilibration. This can be avoided by utilizing a method that mathematically compensates for elimination. This is achieved by taking serial measurements of plasma concentration once initial redistribution has occurred in order to infer the rate of elimination. As elimination is typically exponential, the logarithm of marker concentration, Log*C*, can be plotted to give a linear relationship with time (Figure 2). From this, linear regression can be used to extrapolate the dye concentration before measurements began (and before initial distribution was complete).

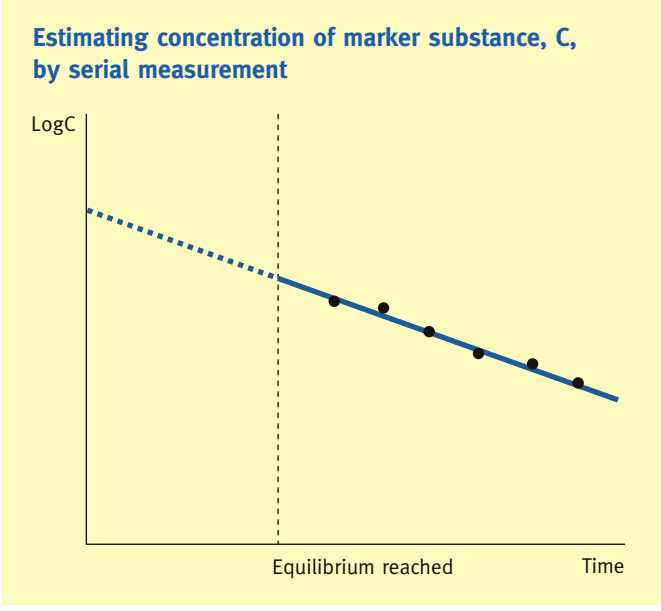

Figure 2

The extrapolated concentration at time zero, C_0, will represent the theoretical concentration if even distribution of the marker occurred instantaneously. As the value for E must be zero, Equation 1 can be simplified as:

$$V = \frac{M}{C_0} \qquad (2)$$

Equation 2. Estimating volume of distribution using serial measurements of concentration.

The accuracy of this method has been questioned. A common criticism arises from the variation in estimated ECF volume between different marker compounds. For example, the derived volume of distribution for inulin is less than that of sodium bromide. It is suggested that perhaps inulin is so large a molecule that it cannot reach all interstices of the compartment or that NaBr is able to permeate the ICF in small quantities. Nonetheless, each molecule has a 'house standard' distribution volume, deviations from which can then be interpreted.

Fluid composition

The fluids in the extracellular and intracellular compartments show marked differences in their ion content. The relative concentrations of the major positive (cations) and negative (anions) ions can be seen in Figure 3. Overall, in each compartment there is an equal positive and negative charge. In addition, the total osmolarity must be equal across plasma and the intracellular space otherwise, as the cell membrane is freely permeable to water, osmosis would occur until equilibration is achieved.

The concentrations given in Figure 3 represent plasma water and the intracellular fluid of myocytes as illustrative examples.