TECHNIQUE OF FLUID BALANCE

PRINCIPLES AND MANAGEMENT OF WATER AND ELECTROLYTE THERAPY

BY

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PREFACE

During recent years several books on fluid balance have been published. Despite the fact that most of these give an excellent account of the subject I have felt compelled to prepare this further monograph. My reasons are twofold. Firstly, I believe there is a need for a shorter account than most of those already published to provide the busy doctor, and particularly one holding his first hospital appointment, with a concise and essentially practical outline of the maintenance of body fluid equilibrium and the correction of an established imbalance. Secondly, I feel there is a growing tendency to make water and electrolyte therapy too dependent upon the results of blood electrolyte estimations. Carefully interpreted and assessed against the patient's history and clinical state, such estimations can be of the greatest value, but it must be appreciated that a vast number of patients have to be treated where no biochemical analyses can be obtained. One of the aims of this monograph therefore is to guide the doctor who has no laboratory facilities as well as those practising in hospitals equipped with modern pathological departments. It is, moreover, important that the latter should become familiar with procedures for prescribing parenteral fluids without laboratory control, otherwise they may find themselves ill-equipped if later they have to treat patients without this aid.

The development of the scheme of management outlined in these pages would not have been possible without the help of many clinical colleagues at Southmead Hospital, and particularly Mr. A. G. McPherson, who have given me opportunities to assist in the treatment of patients under their care. Drs. N. F. W. Brueton and D. and F. Tovey gave valuable assistance in the detailed supervision of these patients and I wish to acknowledge my appreciation of the contributions they have made to this scheme. I am grateful also to Dr. D. A. K. Black who read the typescript and gave me the benefit of his wide knowledge of this subject. Miss P. Coombs patiently undertook all the typing and, lastly, it is a pleasure to record my thanks to my wife for her considerable help with the preparation of the manuscript.

In the preparation of this book, I should like to acknowledge that I found *Fluid Balance in Surgical Practice* by L. P. Le Quesne, M.A., B.M., B.Ch.(Oxon), F.R.C.S.(Eng.) and published by Lloyd-Luke (Medical Books) Ltd., London, of great assistance.

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CHAPTER I

THE VOLUME, DISTRIBUTION AND CHEMICAL COMPOSITION OF THE BODY FLUIDS

THE planning of water and electrolyte therapy is based on a knowledge of the volume and distribution of the body fluids. These fluids are aqueous solutions and water constitutes about 60 per cent. of the total body weight. Since 1 ml. of water weighs 1 G., the total water in a 70 kilogram man (11 stones) is approximately 42 litres. When calculating body water from the weight in an individual case, however, it must be appreciated that fat is poor in fluid, and in obese subjects a figure of 40 - 50 per cent. of body weight provides a more accurate approximation.

The normal distribution of body water is shown in Table I, from which it will be seen that two-thirds of the water lies within the cells (intracellular fluid) and one-third is extracellular. The extracellular water consists of interstitial fluid, which bathes the cells and is their vehicle of transport of nutrient and waste materials, and intravascular fluid, the plasma, contained within the blood vessels. The ratio of interstitial fluid to plasma is normally 3 : 1. A knowledge of this ratio and of the volume of fluid normally present in the two major compartments is of value in estimating the extent of the fluid deficit or excess in a patient suffering from fluid imbalance (p. 50).

TABLE I

Distribution of Body Water
(70 Kg. man (154 lb.))

Total body water (60 per cent. of body weight):	42 litres
Intracellular fluid (two-thirds of body water):	28 litres
Extracellular fluid (one-third of body water):	14 litres
Interstitial fluid:	10·5 litres
Plasma:	3·5 litres

Chemical Composition

The chemical composition of the extracellular fluid is quite different from that within the cells (Fig. 1). In plasma and interstitial fluid, the principal basic ion (cation) is sodium with chloride and bicarbonate as the chief acidic ions (anions), whereas in the intracellular fluid potassium and organic phosphate are the main cation and anion components.

The term 'ion' is used because it is important to appreciate that such substances as NaCl or $NaHCO_3$ (the electrolytes) do not exist in combined molecular form in the body fluids but dissociate into positively charged sodium ions (Na^+) and negatively charged chloride and bicarbonate ions (Cl',HCO_3'). As a result, the concentration of any ion may be varied independently of the others and each may be excreted preferentially. Other substances, such as urea and glucose, are also normally present in the body fluids but since they do not dissociate into charged particles they are not electrolytes.

Although most cell membranes are freely permeable to water it is evident, from these striking differences in chemical composition, that there is normally no free interchange between the electrolyte components of the two major fluid compartments. This was thought to imply that the cell membrane is impermeable to sodium and potassium ions. There is now evidence, however, from studies using radioactive isotopes, that the membrane is freely permeable to sodium and only relatively less so to potassium, but that in health sodium is actively extruded from the cells whilst potassium is held intracellularly through combination with large complex molecules, such as myosin in muscle cells, which cannot cross the membrane.

Apart from the large difference in protein concentration, there are only insignificant differences in chemical composition between interstitial fluid and plasma. Water and electrolytes pass freely across the capillary endothelium, and the fluid in these compartments is therefore considered not as two separate fluids but as the same continuous extracellular fluid.

Internal Exchange of Water

This lack of free interchange of ions and the ready passage of water between the cells and the fluid bathing them creates an osmotic balance between the intracellular and extracellular fluids. As a corollary, any change in the total

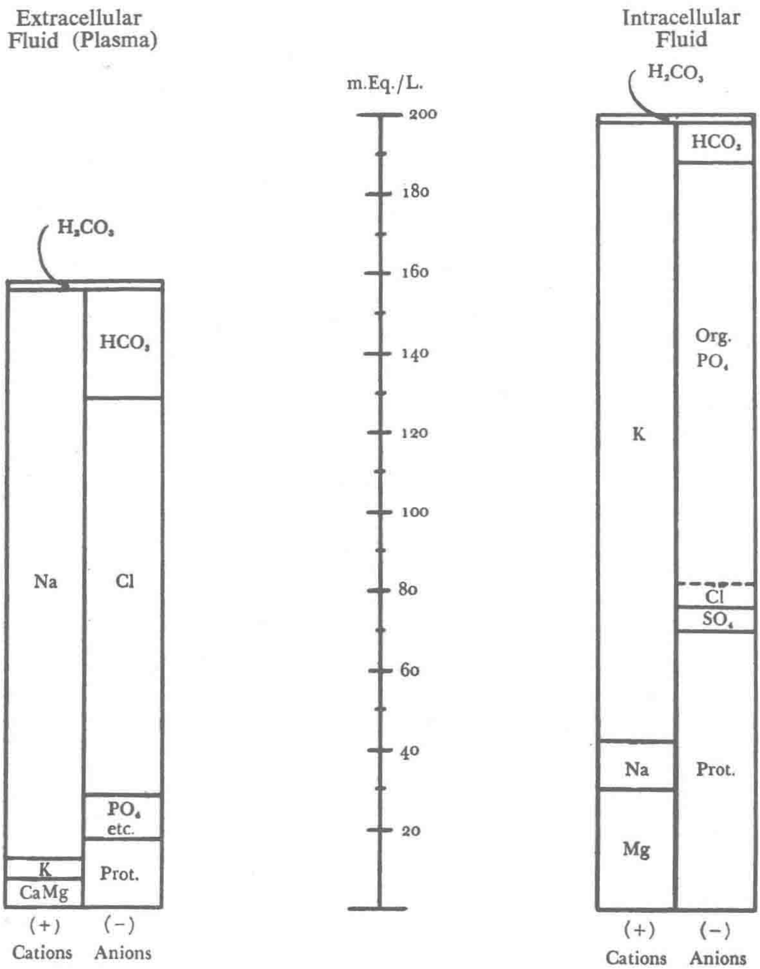


Fig. 1. *Chemical composition and electrolyte pattern of the body fluids. The concentration of each component expressed in milliequivalents per litre is indicated by the height of the columns.*

concentration of the solutes in either fluid must result in a redistribution of water between the two compartments to restore the balance. Thus an increase in the concentration of sodium ions in the extracellular fluid will result in water being sucked out of the cells, whilst a decrease in the concentration of sodium ions causes water to be drawn into the cells, to restore the osmotic equilibrium.

Since the basic and acidic ions are electrically charged there can be no excess of free cations (+) or anions (−) in the body fluids, and, as shown in Fig. 1, the sum total of basic ions balances that of acidic ions. Because of this and since the ions may be excreted preferentially, the total quantity of acidic ions in the body fluids at any moment is dependent upon the content of basic ions. It thus follows that the volume and distribution of the body fluids is controlled largely by the sodium ions of the extracellular fluid and the potassium ions of the cells. In respect of osmotic balance therefore the acidic ions may be ignored, but they are of importance in pH control. The body fluids contain also carbonic acid (H_2CO_3), which results from the combination of CO_2 dissolved in plasma with water. This very weakly dissociated acid together with the bicarbonate ions is of great importance for the control of body pH, for the pH of the body fluids is dependent on the ratio of carbonic acid to bicarbonate. At the normal pH of 7·4, this ratio is 1 : 20 and if the ratio of the one to the other is increased or decreased the pH becomes disturbed. Should an excess of chloride ions in the extracellular fluid displace bicarbonate therefore the pH will become changed towards acidity, whereas a decrease in chloride provides opportunity for the formation of more bicarbonate from the interaction of Na ions with H_2CO_3 and a consequent change in pH in the direction of alkalinity.

Units of Measurement

As a result of usage, the measurement of the chemical components of the body fluids is frequently given in terms of milligrams per cent. This is an expression of weight and a moment's reflection will show that as such it can convey no clear picture either of the relative concentrations of the ions or of their combining capacity. For example, the statement that the concentration of sodium in plasma is 310 mg. per cent. and that of chloride 355 mg. per cent. may suggest chloride ions to be present in excess of sodium ions. However, a given number of chloride ions weighs more than the same number of sodium ions, so that the true interrelationship can only be compared when the factor of difference in weight is eliminated and the relative number of the chemical combining units is compared. This is done when concentrations of ions are expressed as milliequivalents per litre.

It will be remembered that the gram-equivalent weight of a substance is that amount which combines with or displaces 1 gram of hydrogen, and is calculated from the atomic weight and the valency. 35·5 grams of chloride ions and 23 grams of sodium ions react with or displace 1 gram of hydrogen ions, hence 23 grams of sodium ions will combine with 35·5 grams of chloride ions. A milliequivalent is one-thousandth part of a gram-equivalent and concentrations of ions expressed as milliequivalents are calculated from milligrams by multiplying the latter by the valency and dividing by the atomic weight. We see therefore that:—

(*a*) 310 mg. per cent. of sodium ions = 3,100 mg. per litre = (3,100 × 1 ÷ 23) or 135 m.Eq. per litre.

(*b*) 355 mg. per cent. of chloride ions = 3,550 mg. per litre = (3,550 × 1 ÷ 35·5) or 100 m.Eq. per litre.

As regards chemical equivalence therefore in this example, sodium ions are present in excess of chloride ions, leaving 35 m.Eq. of sodium ions per litre to react with other acidic ions such as bicarbonate (see Fig. 1).

In terms of common parlance, a stranger to the game might well be puzzled if told that at a forthcoming football match 770 kilograms of team A will play against 660 kilograms of team B. He would promptly be enlightened, however, when he saw that there were eleven men in both team A and team B. An understanding of the significance of the units of measurement is as vital to a full appreciation of the problems of fluid balance as it is to those of football!

A table for the conversion of milligrams per cent. to milliequivalents per litre is included in Appendix A.

CHAPTER II

PHYSIOLOGY OF FLUID BALANCE

Water Balance

Water is lost constantly from the body by four routes: by the kidneys (urine), the alimentary tract (faeces), the skin (insensible perspiration and sweat) and by the lungs (water vapour). The water lost is replaced by water ingested as fluid, by that contained in solid food and by that derived from the oxidation of foodstuffs. Normally the intake exceeds the losses through the skin, lungs and faeces, and the excess is excreted in the urine.

The 24-hour 'water balance sheet' for an average man in a temperate climate may be represented as follows:—

Credit		*Debit*	
Ingested as fluid	1,000 - 1,500 ml.	Urine	1,000 - 1,500 ml.
Water of solid food	700 ml.	Faeces	150 ml.
Oxidation of food	300 ml.	Skin	500 ml.
		Lungs	350 ml.
	2,000 - 2,500 ml.		2,000 - 2,500 ml.

It is apparent that the water lost by extra-renal channels is approximately balanced by the water obtained from the ingestion and oxidation of solid foods. In health, therefore, the urine volume depends largely on the water intake. It is also clear that when no food is taken fluid intake should be increased by 1 litre a day to cover that normally obtained from solid food.

Electrolyte Balance

Electrolyte balance is normally maintained in a similar way to water balance: that is, the dietary intake usually exceeds requirements and the surplus is excreted in the urine. Daily losses of electrolytes in health are almost confined to the urine. Although large quantities of each of the principal ions contained in the body fluids are excreted into the gut in the alimentary secretions, practically all is reabsorbed and losses in a formed stool are negligible. The fluid lost from vaporisation from the lungs and from the skin as insensible perspiration is almost devoid of electrolytes, but visible sweat is a hypotonic solution and contains sodium and chloride in amounts varying from 10 - 75 m.Eq. per litre, with negligible quantities of potassium.

Renal Adjustment

Healthy kidneys possess a wide range of excretory power for each of the basic and acidic ions of the body fluids, and by their control of the extent to which water and electrolytes shall be excreted the kidneys are the most important regulators of the body fluid volume and its pH. Healthy kidneys possess, for example, a range of excretion of water varying from 20 - 1,200 ml. per hour, whilst the excretion of sodium ions may be reduced at times of sodium depletion to as low as 2 m.Eq. per litre of urine, virtually a 'sodium-free' urine, or increased, when sodium ions are supplied in excess, to 500 m.Eq. per litre, equivalent in sodium content to 3·3 per cent. saline.

Even during periods of deprivation, however, and with normally functioning kidneys, the excretion of water and essential ions cannot be reduced below a certain minimum. This 'obligatory loss' means that water and electrolytes must be supplied daily for the body fluids to remain in equilibrium. Conditions in which there is tubular damage and a failure of renal concentrating power increase the daily obligatory losses, and in other types of renal disease there may be a reduction in the upper limits of excretion of both water and electrolytes.

CHAPTER III

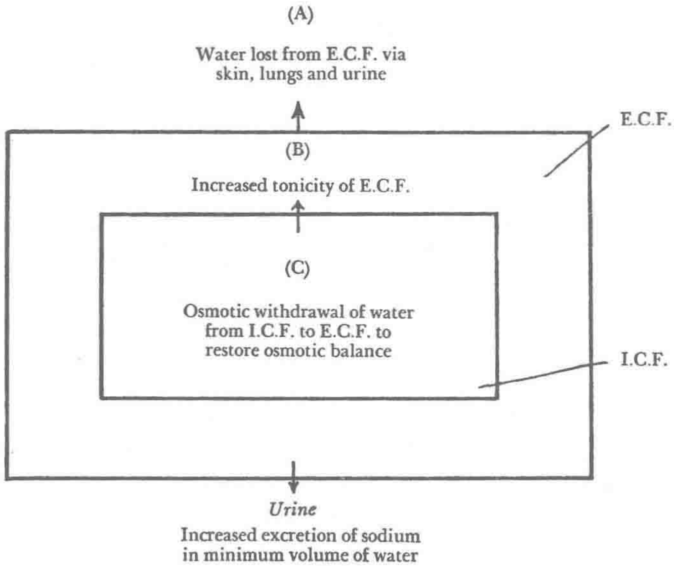
CONSEQUENCES OF DEPLETIONS OF PRINCIPAL BODY FLUID COMPONENTS

In clinical practice disturbances resulting from depletions of body fluid components are more frequently encountered than excesses. The latter result mainly from incorrect treatment and are left for consideration until Chapter 7. Although depletions of a single principal component such as water, sodium or potassium are rare there are certain advantages in considering the effects of a depletion of each component separately. Moreover, this approach is valuable in planning the prevention or treatment of fluid imbalance and, although mixed disturbances are the rule, not infrequently a disturbance of one particular component predominates.

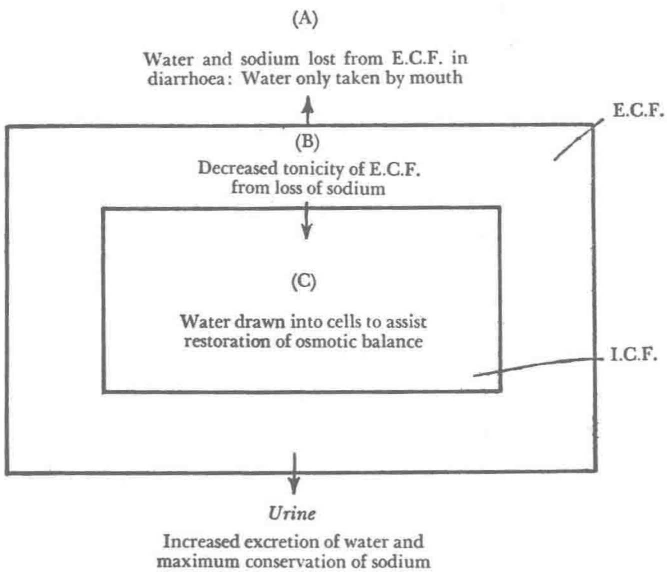
Water Depletion

Deprivation of water has the following results. Water continues to be lost via the skin, lungs and kidneys. The loss through the skin and lungs cannot be reduced below a daily minimum of 700 ml., but by increased reabsorption of water in the kidney tubules there will be a reduction in normal urinary volume. The final volume of urine secreted depends both on the total quantity of solutes requiring excretion, since there is a minimal volume of water in which these solutes can be dissolved, and the concentrating capacity of the kidneys.

The water lost is drawn first from the extracellular fluid which becomes hypertonic, when to restore osmotic equilibrium, water will be withdrawn from the intracellular compartment. The water loss is therefore spread rather uniformly throughout the body fluids.



(a) Water Deprivation: The loss of body fluid is borne by both extracellular and intracellular compartments (E.C.F. and I.C.F.)



(b) Sodium Depletion: The loss of body fluid is borne by the extracellular compartment only.

Fig. 2. *Contrasting effects of water depletion and sodium depletion.*