FLUID BALANCE IN OBSTETRICS

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LLOYD-LUKE

Fluid Balance in Obstetrics

A CRITICAL REVIEW

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Too much of water hast thou, poor Ophelia.
Hamlet

Classification is necessary. But unless you can progress from classification to mathematics, your reasoning will not take you very far.
A. N. Whitehead in "Science and the Modern World", 1943

The generalizations . . . must necessarily be based on a small number of particular instances, which are assumed to be typical but which cannot be the whole of the complicated truth.
G. M. Trevelyan in "English Social History", 1944

PREFACE

FLUID balance in obstetrics has now become a specialist field. Much of the current literature is taken up with it and often the articles on the subject are difficult and erudite for the practising obstetrician. Of recent years there has been a dichotomy in medicine such that research is quite often divorced from practice, because the workers in each sphere are unable or unwilling to see each other's problems. So widespread is this phenomenon that calls are frequently made for special people to bridge the gap between the laboratory and the wards so that each may understand the other. The pressure of work in both places is such that perhaps only specialists can hope to have a foot in each. But since no such appointments have yet been made, someone must try to perform the office, however inadequately. This I have tried to do, but since the field is now so vast, nobody is more aware than I am that the subject can only be indifferently covered by one person.

This book attempts to give the practising clinician a synopsis of the fluid balance problems of obstetrics. Where practical guidance can be given, this has been done, drawing largely on the work of others, often in different disciplines of medicine and surgery. This has been necessary because often no relevant work has been performed in obstetrics.

Knowledge is so meagre as yet that it is not possible to give a collected coherent account of fluid and electrolytes, but disconnected facts are of little value. Therefore much hypothesis and some large assumptions have been made. This is reasonable if the assumptions and hypotheses are recognized for what they are and are not construed as being established fact. I hope the text and the previous background knowledge of the reader will make it clear where the surer foundation of science has been left for airier realms. I have tried to give the speculations some solidity by the use of elementary mathematics. This has the advantage of giving some discipline, and common sense is not entirely outreached. Moreover, where assumptions have to be made in order to proceed mathematically, they show where an experimental verification may be of help in proving or disproving the hypothesis. It is hoped that this approach of a practising clinician may be of some slight value to the experimentalist. Since much work of elucidation must come from the clinician the analyses in this book may show him where the gaps in knowledge are, and hence where he may reasonably direct an attack.

The purist in physiology and particularly endocrinology may well be disappointed by obvious omissions made to provide a connected account. But the book is not for him; rather is it for those who need a working basis for their practice. I hope it may serve them in this or at least stimulate them to a realization of the problems in this field and perhaps correct my shortcomings.

I have had to draw extensively on other people's work, but I would especially like to express my indebtedness to books by Le Quesne on *Fluid Balance in Surgical Practice* (Lloyd-Luke), Black on *Essentials of Fluid Balance* (Blackwell), Strauss on *Body Water in Man* (Little Brown) and Samson Wright on *Applied Physiology* (Oxford University Press). My thanks are due also to Messrs. Wm. Heinemann (Medical Books), J. R. Geigy, S.A., the Honorary Editors, *Proceedings of the Royal Society of Medicine*, and the Editor, *Jl. Obstetrics and Gynaecology*, for their kind permission to reproduce copyright material and illustrations.

Mr. Douglas Luke, my publisher, supplied the original stimulus for this work and has helped in many ways to make it possible. My colleagues Mr. P. R. Norris and Mr. P. J. Huntingford have been kind enough to read the manuscript and make many helpful suggestions, although they are in no way responsible for any of the views here set forth. My family is to be thanked for its forbearance with a sometimes irritable and often secluded author.

PHILIP RHODES.

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Chapter I

PHYSICAL CHEMISTRY

Body fluids are in dynamic equilibrium. Yet in this activity can be discerned an element of constancy, first clearly enunciated by Claude Bernard as "la fixité du milieu intérieur est la condition de la vie libre". The fixity of which he spoke is largely illusory, for there is a ceaseless coming and going of atoms and molecules in all parts of the body; but the overall concentrations of chemical substances tend to remain unchanged at the heart of this lively movement. This is the old problem of philosophers of Being and Becoming, and of poets such as Wordsworth who saw the contrast of stability at the heart of change. Such relative permanence in the body fluids and their contents in the face of mobility is brought about by two main mechanisms which may be inadequately classed as physiological and physico-chemical. Such classification reveals ignorance, for in the final analysis one might expect physiology to be interpreted in terms of chemistry, and chemistry in terms of physics. The days when this may be done still seem far distant, so that this simple classification must at present suffice.

Osmosis is a factor in the movement of fluids and electrolytes across membranes. It is difficult to describe but is easily demonstrated by a simple experiment. If copper ferrocyanide is precipitated within the substance of a porous pot, a semi-permeable membrane is formed. This means that water can cross it but solutes such as glucose cannot. If now a glucose solution is put in the pot and the whole is immersed in water, water is "sucked into" the solution through the membrane, thus diluting the glucose. If a glass tube is suitably fixed to the top of the pot, the fluid will rise within it. After a time the fluid will stop rising. When it does so the height of the column is exactly balancing the force which is drawing water into the pot. This force is the *osmotic pressure* of the glucose solution, and the height of the column of fluid is a measure of it. This, of course, is a cumbersome method of measurement and would scarcely be of value in medical practice. But by variations on the method of estimation of osmotic pressure, it can be shown that this varies with the number of dissolved particles in any solution. The greater the number of such particles the greater is the osmotic pressure. This is the central fact, essential to understanding fluid and electrolyte changes, for osmosis controls the movements of ions and molecules across cell membranes.

What is needed therefore is a measure of the number of particles in any solution. From this the osmotic pressure can be calculated, because a gram-molecule of any substance dissolved in 1 litre of water will exert an osmotic pressure of 22·4 atmospheres (1 atmosphere = 760 mm. Hg). An example comparing glucose and urea shows that 180 Gm. of glucose and 60 Gm. of urea dissolved in 1 litre of water exert the same osmotic pressure. (Molecular weights of glucose, $C_6H_{12}O_6$, and urea, $CO(NH_2)_2$, are 180 and 60 respectively. The molecular weights can be calculated from the atomic weights C = 12, H = 1, O = 16, N = 14.) Such solutions of glucose and urea are said to be *isosmotic*. It should be noted that the weights of the substances in solution are very different, but their osmotic effects are equal because the number of particles in each solution is the same.

Osmolar solutions are those which exert an osmotic pressure of 22·4 atmospheres, and an *osmole* of glucose is 180 Gm. and of urea 60 Gm. in 1 litre of water. In physiology an osmole is inconveniently large as a unit of measurement, so one-thousandth of this value is used and is called a *milli-osmole*.

Molar solutions are those which contain a gram-molecule of a substance in 1 litre of water. Thus 180 Gm. glucose and 60 Gm. urea in 1 litre of water make molar solutions. In this example it is obvious that a molar solution is the same as an osmolar one. But this is not always so. Glucose and urea do not dissociate in solution at all. On the other hand, salts dissociate almost completely, so that sodium chloride splits up into its constituent Na^+ and Cl'. This has the effect of doubling the number of particles in solution. Thus if a molar solution of sodium chloride is made by dissolving a gram-molecule of NaCl in 1 litre of water (58·5 Gm. NaCl, since atomic weights are Na = 23 and Cl = 35·5 Gm.), it will exert an osmotic pressure of 2 × 22·4 atmospheres because of complete dissociation. Therefore in this case a molar solution is twice osmolar.

Of course no molecules dissociate completely, but for the purposes of this discussion they can be assumed to do so with such substances as sodium chloride, especially in dilute solutions. In physical chemistry strong and weak electrolytes are described. The former dissociate up to 50 per cent. in concentrated solution and nearly completely in dilute solution. The weak electrolytes dissociate in variable amount, but the percentage dissociation depends in large measure on the concentration. In physiology it is sufficiently accurate to assume that molecules which dissociate at all will do so completely, for they are in dilute solution. Greater precision is unnecessary.

Equivalent weights and milli-equivalents

The following equations represent simple chemical interactions:

1. $NaOH + HCl = NaCl + H_2O$
2. $KOH + HCl = KCl + H_2O$

In each case Na and K have displaced hydrogen from the hydrochloric acid, and so may be said to be equivalent in their power of replacing hydrogen. But the weights of sodium and potassium involved in the reactions have been quite different. Using gram-molecular solutions, the equations can be written:

1. 40 Gm. $NaOH$ + 36·5 Gm. HCl = 58·5 Gm. $NaCl$ + 18 Gm. H_2O
2. 56 Gm. KOH + 36·5 Gm. HCl = 74·5 Gm. KCl + 18 Gm. H_2O

These gram-molecular weights are calculated from the atomic weights of the substances, which are Na = 23, O = 16, H = 1, Cl = 35·5, K = 39. It is apparent that 40 Gm. NaOH are the equivalent of 56 Gm. KOH in the power to combine with hydrochloric acid, and that 23 Gm. Na and 39 Gm. K will each displace 1 Gm. of hydrogen from the acid, and that these weights of Na and K will combine with 35·5 Gm. Cl. Therefore 1 Gm. of hydrogen is the equivalent weight of 23 Gm. Na, 39 Gm. K and 35·5 Gm. Cl. Put in more general terms, the equivalent weight of any substance is that amount which will displace or combine with 1 Gm. of hydrogen. This definition covers cations which displace hydrogen and anions which combine with it.

The substances Na, K, H, Cl are all monovalent, which means that they react or combine with hydrogen on a one-to-one basis, and their equivalent weights are the same as their atomic weights expressed in grammes. But divalent ions displace hydrogen on a two-to-one basis. Their equivalent weights are therefore half the atomic weight expressed in grammes. Consider the substance $CaCl_2$ (atomic weight of calcium is 40). Here 40 Gm. Ca^{++} have combined with $2 \times 35{\cdot}5$ Gm. Cl′. But the equivalent weight of Cl is 35·5 Gm., i.e. it combines with 1 Gm. hydrogen. Therefore the equivalent weight of calcium must be 20 Gm. Similar considerations apply to all other ions. The general lesson is that the valency of an element must be taken into account when calculating its equivalent weight. From this discussion it should be obvious that chemical reactions are dependent on the numbers of particles taking part and not on the weights of substances involved. The object of using equivalents is to be rid of absolute weights in solution, and to try to get a measure of the numbers of particles reacting. Tovey (1957) uses a homely illustration in this context. In a football match 770 Kg. of one team may play 660 Kg. of another team, and yet there are only eleven players on each side. The number eleven has more significance than the exact weights.

For physiology, equivalent weights are inconveniently large so that the measure used is the milli-equivalent, which is one-thousandth of the equivalent. It is abbreviated as mEq and is usually expressed as milli-equivalents per litre of solution. Thus x mEq/l. are equivalent chemically to x mEq of K or of Cl or any other ion. This obviates the necessity for the use of molecular or atomic weights to understand the structure of mixed solutions. In fact, the use of weights only gives a distorted view of such solutions, as will be shown later.

Unfortunately some laboratories still report the results in milligrams per cent. (i.e. per 100 ml.) for electrolyte estimations. To convert such results into milli-equivalents, the following formula is used:

$$\text{mEq/l.} = \frac{\text{mg. per cent.} \times 10 \times \text{valency}}{\text{atomic weight}}$$

The factor 10 is needed to convert milligrams per 100 ml. to milligrams per 1,000 ml. (1 litre). The role of the atomic weight and valency in the formula should be clear from the foregoing examples.

Le Quesne (1957) has worked out the formula for various electrolytes and simplified the conversion still further. He gives the following table:

TABLE I

$$\frac{\text{Na mg. per cent.}}{2{\cdot}3} = \text{Na mEq/l.}$$

$$\frac{\text{K mg. per cent.}}{3{\cdot}9} = \text{K mEq/l.}$$

$$\frac{\text{Ca mg. per cent.}}{2} = \text{Ca mEq/l.}$$

$$\frac{\text{Cl mg. per cent.}}{3{\cdot}5} = \text{Cl mEq/l.}$$

$$\frac{\text{CO}_2\text{ combining power Volumes per cent.}}{2{\cdot}2} = \text{Bicarbonate mEq/l.}$$

This is compiled by knowing the atomic weights and valencies previously given. CO_2 is divalent and has an equivalent weight of 22 Gm. (atomic weight 44, C = 12, O = 16).

Electro-neutrality of solutions

In an electrically charged solution positively charged ions such as Na^+, K^+, Ca^{++}, Mg^{++}, NH_4^+ will tend to move to the negative electrode or cathode. They are therefore called cations. Conversely, negatively charged ions such as Cl', HCO_3', SO_4'', HPO_4'' move to the anode. They are anions. In any solution, the numbers of cations must exactly equal the numbers of anions. This is true of all body fluids, though this arrangement may be temporarily upset in conducting tissues such as nerve or muscle when an impulse is passing. Within milliseconds, however, the electrical balance is restored by migrations of ions through cell membranes.

The electro-neutrality of plasma is shown in Table II, where all values are in mEq/l.

TABLE II (from Wright, 1952)

PLASMA (mEq/l.)

Na^+	143	Cl'	103
K^+	5	HCO_3'	27
Ca^{++}	5	HPO_4''	2
Mg^{++}	2	SO_4''	1
		Organic acid	6
		Protein	16
	155		155

This demonstrates electro-neutrality and the proportional role of each ion in the total plasma osmotic pressure. Below is given a similar sum using the plasma levels in mg./100 ml. (Figures from Geigy Scientific Tables.)

TABLE III

PLASMA (mg./100 ml.)

Na^+	333·00	Cl'	365·00
K^+	16·34	HCO_3'	59·40
Ca^{++}	10·00	HPO_4''	3·20
Mg^{++}	1·93	SO_4''	3·38
		Organic acids	1·00
		Protein	6,520

This shows no obvious comparability of anions and cations, and in particular gives overwhelming preponderance in weight to the plasma proteins. A glance at Table II reveals how relatively little they contribute to the osmotic structure of plasma.

Summary.—Fluid and electrolyte balance depends on the movements of chemical substances across cell membranes. Many factors are involved in such transfer, and still remain to be investigated. Chief among the purely physical factors is osmosis. A measure of this is osmotic pressure, which depends on the number of particles in solution. The terminology of milli-equivalents expresses a relationship between such numbers and the osmotic pressure they exert, and therefore should be used in preference to the system which uses weights only.

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Chapter II

THE PHYSIOLOGY OF THE NON-PREGNANT WOMAN

THERE is now a vast literature on fluid balance which it is virtually impossible to summarize. But concepts in this field have changed of recent years, so that an attempt will be made here to give a connected account of some of the facts. A background knowledge of this nature is essential to an understanding of the physiological and pathological variations which occur in obstetric practice.

WATER BALANCE

Total body water

Most standard works on this subject use as a basis for discussion a hypothetical man weighing 70 Kg. (154 lb.). An average woman weighs less than this, and for ease with calculations the standard assumed in this book will be 60 Kg. (132 lb.). This weight accords with clinical impression, although Thomson and Billewicz (1957) in Britain analysing 4,124 cases, suggest that 55 Kg. is more usual. Stander and Pastore (1940) in America found the average weight of primiparae to be 57·3 Kg. and of multiparae 60·5 Kg. in 2,502 women.

Estimates of the total water content of the body vary between about 50 per cent. and 70 per cent. of the weight. Older papers tend to give the higher percentage and more recent ones the lower. The method of estimation of total body water affects the result obtained, and modern investigations are probably nearer the truth. The principle of the method is to introduce some easily identifiable substance in known amount into the bloodstream. Ideally it should diffuse rapidly and evenly through all the compartments of body water. The degree of dilution of the material in blood samples is then a measure of the volume of water in which it is distributed. Antipyrine and urea have been used in the past, but since it is not certain that they diffuse easily into the cells, their place has been taken recently by deuterium oxide. This is "heavy water", deuterium being an isotope of