WILKINSON

BODY FLUIDS IN SURGERY

SECOND EDITION

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By

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PREFACE TO SECOND EDITION

In this new edition every chapter has been extensively revised, much new material has been incorporated and a number of new diagrams have been added. The descriptions of "acid-base" balance, acidosis and alkalosis have been very largely rewritten and combined in a new chapter on the maintenance of chemical neutrality in the body. For what seems to be the first time in a book of this kind the Bronsted-Lowry convention has been used in the discussion of acid-base equilibrium in the hope that the use of this simpler terminology will make the subject less confusing; the eventual adoption of this convention is as certain now as that of milliequivalents was fifteen years ago and will no doubt be as strongly resisted.

Since more major surgery is done in those hot countries where the bulk of the world population is found the effects of hot and humid climates on the distribution of water and minerals in the body become increasingly important to the surgeon. At present very little is known of such effects in various races but as much as possible has been included in appropriate sections of this edition.

The section on the effects of injury also has been almost completely rewritten and enlarged and now includes discussions of the effects of starvation and of the hormonic basis of the bodily reaction to injury.

Recent rapid increases in the range and scope of surgical operations to relieve gross abnormalities of the alimentary tract in newborn babies have shown that much of the ultimate success of such operations depends on the post-operative care which is provided. Our knowledge of the physiology of the newborn child is meagre and post-operative treatment has so far been largely empirical and scaled down from the orthodox treatment provided for adults. As more is learned of neonatal functions after operation during the first week of life it is becoming evident that estimation of neonatal requirements in this way is unsatisfactory and that more direct measurements are needed. In a new chapter an account is given of present knowledge of the important variations in composition and function in the infant and their bearing on post-operative management.

My debt to others has increased and from a number of colleagues I have had the benefit of comments and advice during discussions which often took root unnoticed and is difficult to acknowledge; in particular Professor Moncrieff, Dr. Barbara Clayton and Dr. A. H. Snaith have read sections and made valuable suggestions. I wish to acknowledge also the kindness of the Editor of the *Lancet* in allowing me to reproduce Figs. 5, 6, 8, 9, and 10.

Once again I am indebted to Mr. Macmillan and his staff for their continued help and for their expeditious and efficient handling of the production of this book.

LONDON, 1960. A. W. W.

PREFACE TO FIRST EDITION

THERE are few short cuts or routine answers for the surgeon who has to solve the problems set by the patient who has suffered large losses of body fluids. His therapeutic decisions must be based on a knowledge of normal body composition, an accurate and detailed history of the illness and fluid loss of the individual patient and an understanding of the effects these disturbances will have on structure and function. Although previous experience will modify his interpretation of the clinical features and the treatment he adopts, the deeper his understanding of the physiology of the body fluids the closer will such treatment approach the ideal. There seems to be a need not only for advice in the management of the common disturbances of equilibrium in the composition and distribution of the body fluids, but also for a set of simple rules on which to base a routine of treatment in all sorts, sizes and conditions of patients. Such a set of rules does not exist; to make allowances for individual variations within the so-called limits of normal of sex, age, stature and nutritional state, is difficult if not impossible in a universal scheme of diagnosis and treatment. Moreover, the speed and chemical delicacy of the complicated inter-related compensatory reactions which follow the loss of body fluids of any kind are perhaps too little appreciated by most clinicians in their search for therapeutic simplicity.

In this book an attempt has been made to provide in a convenient form, first, sufficient information for a basic understanding of the behaviour of the body fluids in health and disease, and secondly an account of the management of the disturbances of the body fluids which occur in surgical patients. It has been written primarily for those responsible for the care of surgical patients in the belief that the detailed management of disturbances of fluid balance in his patients rightly remains the responsibility of the surgeon.

Until about 1939 our knowledge of the physiology of the body fluids was almost confined to measurements by chemical methods of concentration of substances dissolved in plasma and extracellular fluid, and of the volume of plasma and of extracellular fluid. During the last 15 years developments of the dilution technique especially with the aid of radioactive and stable isotopes have led to the evolution of new methods for the estimation of the volume of red cells, plasma, total body water, intracellular water, total exchangeable sodium, potassium and chloride and many other constituents of the body fluids and tissues. From the narrow view given by studies of concentrations of constituents we have progressed to a wider understanding of the total watery environment of the cells and of the total quantities of substances in solution and combination inside as well as outside the cells.

However, it remains important to recognise that even these newer methods of measurement do not provide a complete picture of what happens in the body and that the values obtained are subject to errors and variations, especially in disease and after injury ; the greatest value of these measurements is to be derived from the comparison of the results of repeated observations in the same subject. Many of the methods require complicated apparatus and personal skill and are still suitable only for research purposes or occasional use. Their wider adoption will depend to some extent on further simplification and improvement. The basic knowledge which has been obtained, however, has already been incorporated in our understanding of the behaviour of the body in several circumstances. The value of the application of this new knowledge to the treatment of surgical patients is another reason for attempting to express in simple terms some of the advances in this field, and as far as seems possible or justifiable to relate them to the common clinical disturbances which are liable to complicate modern surgical procedures.

Until a few years ago it was generally believed that the transfer of substances across capillary membranes was due to such relatively simple processes as filtration and diffusion, while transfer through the cell wall depended on the selective permeability of the cell wall to different substances. It now appears that transport across the cell wall may depend rather on active secretory processes requiring the expenditure of considerable energy and demanding complex metabolic processes for its accomplishment. The convenient arbitrary division of body fluids into intracellular and extracellular portions is now clearly of limited value and although helpful to an understanding of some problems of fluid and ionic distribution, does not give any idea of the dynamic existence of minerals and water in the body.

In this book emphasis has been placed on the clinical as opposed to the laboratory approach to the patient. Even the most complete laboratory data at present obtainable will give only a limited understanding of the state of the patient at a particular moment. Repeated visits to the bedside at regular intervals do not cost the patient any blood or discomfort and are commonly more rewarding than the perusal of reports of biochemical estimation of the composition of his body fluids. The hardest thinking must be done before any blood is withdrawn for chemical examination, and the examination of this blood should be planned to show if possible whether the clinical diagnosis is right or wrong. This is not to say that biochemical estimations are not of value in clinical surgical practice. Only by the continued application of the scientific method of measurement to the study of surgical problems can any improvement in our present state of ignorance be expected. As a spur to assiduous study at the bedside and in the laboratory a proper sense of humility is required against the background of lack of knowledge and imperfect understanding of the behaviour of the body in normal and diseased conditions.

To keep this book reasonably short much material and many references have been excluded which would have had places in a comprehensive review of this subject. Nevertheless sufficient references are given to provide an ample introduction to the original work. Most writers are more or less deeply impregnated with and indebted to the work of those who have preceded them; in this field the debt to Gamble, Coller, Moyer, Darrow, Cuthbertson, Marriott and McCance, to mention only a few of the pioneers, is heavy and will endure. To my chiefs, the late Sir John Fraser, Sir James Learmonth and Professor W. C. Wilson my debt is a more personal one. To them I owe the stimulation of my interest in the study of shock and other disturbances of the body fluids in surgical patients, and the encouragement and opportunities for investigation on which that interest was nourished and grew. The late K. W. Lane first aroused a biochemical interest which has been maintained and its practical application made possible by Dr. C. P. Stewart, to whom and to his colleagues I am indebted for much assistance during the last 18 years. To the members of the staffs of hospitals in Edinburgh and Aberdeen,

and especially to Mr. T. McW. Millar and Mr. W. A. D. Adamson, I am greatly indebted for allowing me to study and to treat patients under their care and for giving me the advantages of their watchful interest and experienced advice in the interpretation of the confusing problems I encountered. From the many resulting discussions at the bedside and elsewhere are derived in no small part the opinions expressed in this book.

I am indebted to Messrs. Butterworth & Co. Ltd. for allowing me to incorporate material from a chapter in *Surgical Progress* 1953 for the sections on shock, anuria, loss of intestinal secretions and plasma substitutes and for allowing me to reproduce part of Table II, Table V and, in a modified form, Table IV. Tables XII-XV are modified from similar diagrams by Gilman and Brazeau by kind permission of Dr. A. Gilman.

Messrs. E. & S. Livingstone Ltd. have produced this book with their usual high skill and craftsmanship, and I am very grateful to them for all their help.

October, 1955 A. W. W.

CONTENTS

CHAPTER I

THE CONTENT AND DISTRIBUTION OF WATER, SODIUM AND POTASSIUM IN THE BODY

It is not usually difficult to collect and measure the total volume and even the concentrations of some of the constituents of fluid which is lost by vomiting, discharge from a fistula or in the stools. To make the fullest use of these measurements there must be some knowledge of the composition of an individual body at the outset of an illness as well as at particular stages during treatment; with such information the effects of the fluid losses in producing the clinical disturbance may be judged, as well as the margin of tolerance which remains and the rate, type and quantity of replacements. Unfortunately no two human bodies are exactly alike and the range of variation about the mean for age, sex, weight or height is large. There is no close relationship between weight, height, fatness, muscle mass or bone weight, and therefore estimates of the body content of water, sodium, potassium or any other constituent which are not based on direct measurements in the individual but are calculated from so-called standard tables must be subject to large errors. In spite of this, such estimates are often of great value in judging the effects of disease and in designing suitable treatment.

RELATIONSHIP BETWEEN BODY FAT AND WATER

The quantity of water in the human body has usually been assumed to be a fixed proportion, about 70 per cent., of the total body weight; the observed body weight has also been used for the calculation of plasma and extracellular fluid volume in attempts to control fluid replacement therapy with greater accuracy. Recently it has become evident that when such estimates ignore the presence of storage fat in the body, they may be very inaccurate and misleading. Hardy and Drabkin (1950) found that blood volume might vary from 70 ml. per kg. body weight in a very obese subject to 105 ml. per kg. in a very thin one; yet Gibson and Evans (1937) had shown that in subjects of about average nutrition blood volume was closely related to height.

More recently Allen *et al.* (1956) have analysed a large number of their own and published determinations of blood volume, and have concluded that the fat content of the body is the most important variable factor and that blood volume is in general related most closely to a combination of body weight and the cube of the height rather than to height or surface area, to a cubic rather than a square function.

The acute changes in volume and distribution of water and electrolyte which are associated with surgical operations and inflammation of all kinds do not involve body fat, which in this connection may be considered as inert tissue. On the other hand, the catabolism of storage fat as a source of energy during many kinds of disease and after injury is one factor causing the marked loss in weight; such weight loss is another source of error in the calculation of fluid volumes from whole body weight.

Fat floats on water, and fat people are more buoyant than lean ones. When the fat content of a body increases, the density of that body in water diminishes and its specific gravity becomes less. By weighing a body in air and when submerged in water its specific gravity can be directly measured, and from this figure the fat content of the body can be calculated. Behnke (1942) found that fat content had an important bearing on the functional efficiency of the body and that men whose fat content was excessive did not well withstand high-altitude flying or deep diving. It is well known that, in general, unduly fat people are not good subjects for surgical procedures, and this has been commonly ascribed to their poor mechanical efficiency: obese patients are more difficult to move in bed, cough with more difficulty and have to exert themselves more because of their larger bulk; some are so fat that they cannot sit up without help and a few become breathless and cyanosed if laid flat in bed.

From an analysis of body composition in a large number of men, Behnke postulated a basic body structure of relatively constant composition which he called the "lean tissue mass". This consists of 70 per cent. water, 20 per cent. solids and an irreducible minimum of 10 per cent. of structural fat. This type of composition is not peculiar to the human species. It was found (Pace and Rathbun, 1945; Rathbun and Pace, 1945) that in six species of small animals, including the guinea-pig and monkey, although the fat content varied widely the lean tissue mass was fairly constant, and when excess fat was excluded the lean tissue mass contained about 73 per cent. water.

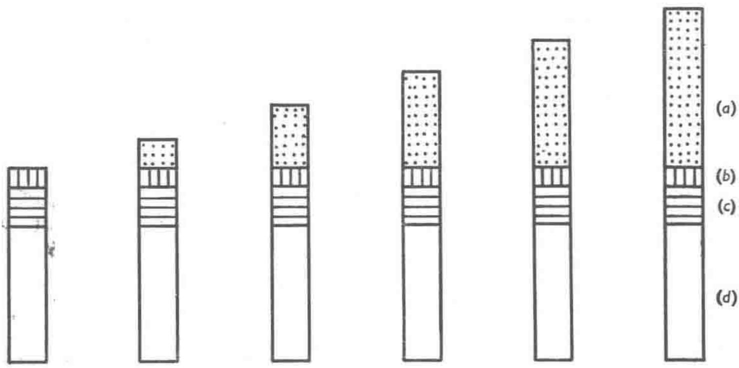
When storage fat is superimposed on this basic structure, the body weight increases, and although the weight and composition of the lean tissue mass do not alter, the percentage of water in the whole body decreases. The fat content of the body may vary from 10 per cent. to nearly 50 per cent. of the total body weight, and in excessively obese subjects the body water may be less than 40 per cent. of the total body weight.

TABLE I

The Effect of Increasing the Fat Content of the Body

	Total Body Weight (kg.)	*Fat*			*Solids (kg.)*	*Water*	
		Basic (kg.)	*Storage or Excess*			*% Body Weight*	*litres*
			kg.	*% Body Weight*			
Basic Structure	60	6	—	—	12	70·0	42
Average Man	70	6	10	14·2	12	60·0	42
Fat Man	80	6	20	25·0	12	54·0	42
	90	6	30	33·0	12	44·5	42
Very fat Man	100	6	40	40·0	12	42·0	42
	110	6	50	45·5	12	38·0	42

The effect of increasing the body content of fat is shown in Fig. 1 and Table I. For the sake of clarity, the basic quantities of water, solids and structural fat have been shown unchanged throughout, although small changes do occur. The basic structure is that of an unusually thin person without any storage fat. The normal individual is represented by the second block diagram (Fig. 1), and he contains water equivalent to 60 per cent. of his body weight and storage fat equal to 14·2 per cent. of body weight; this is the composition of an average healthy male subject. In the remaining four block diagrams, as the proportion of fat increases the proportion of body water falls, and this relationship is also shown in Fig. 2, in which the declining percentage of body water and the increasing percentage of fat are plotted against body weight. The fat content of healthy adults normally increases with age (Brožek and Keys, 1952) from 10 per cent. at the age of 20



	BASIC STRUCTURE	NORMAL ADULT MALE	INCREASING DEGREES OF FATNESS			
TOTAL BODY WEIGHT						
Stones	9st 6lb	11st	12st 8lb	13st 8lb	15st 10lb	17st 4lb
Lb.	132	154	176	190	220	242
Kg	60	70	80	90	100	110
STORAGE FAT						
Kg	0	10	20	30	40	50
% Body Weight	0	14	25	33	40	45
TOTAL BODY WATER						
Litres	42	42	42	42	42	42
% Body Weight	70	60	54	45	42	38

Key.—(*a*) Excess or "Storage" fat; (*b*) Essential or structural fat; (*c*) Lean tissue solids; (*d*) Water.

FIG. 1.—The effect of increasing the fat content of the body.

years to 25 per cent. at the age of 55 years, and females are usually fatter than males.

Because of the practical difficulties associated with direct measurement in surgical patients of total body water and its subdivisions such as extracellular fluid and plasma volumes, it is often useful to be able to calculate the total body water of a patient from body weight. The inverse ratio between fat content and body water renders such calculations from total body weight misleading unless allowance is made for excess of storage fat. McCance and Widdowson (1951) suggested that calculations of this kind should be based not on the actual measured weight of the patient but on the "ideal weight" of the individual, and this is probably the best method to employ in clinical practice. "Ideal weight" is a function of sex, height and age, and can be obtained from standard tables such as those of the Metropolitan Life Insurance Company.

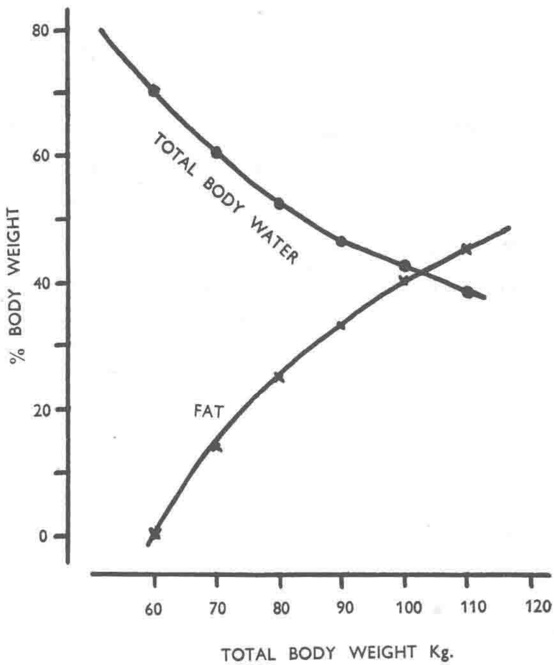


FIG. 2.—Relationship between rising fat content and declining water content.

Allen *et al.* (1956) have collected data from which they have derived formulas with which both the blood volume and the fat content of any individual can be calculated. They believe that their method of calculation is accurate in spite of variations in race, age, sex, obesity, malnutrition or the periodic effect of sex hormones. They have found that in infants and children before puberty there is no variation between sexes, and although in non-pregnant women the blood volume is 600 ml. less than in