The composition and function of body fluids

SHIRLEY R. BURKE

THIRD EDITION

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To

Miss Clara E. Gestel

Preface

A basic understanding of the role of body fluids in health and of how deviations from the normal, either in quantity or composition, affect the well-being of the individual is important to students in the health professions. The purpose of this text is to assist beginning students in acquiring this knowledge. The approach used builds upon the student's knowledge of basic physiological principles directly related to clinical problems involving body fluids.

Many changes in content as well as organization have been made in this edition. A new chapter on transcellular fluids has been added and significant changes reflecting new information and suggestions from instructors have been made in the discussions of blood, urine, and fluid therapy. The many illustrations added to this edition will facilitate both the learning of theoretical concepts and an understanding of their place in clinical practice.

I am grateful for the comments and criticisms of many teachers who took their valuable time to write concerning earlier editions of this text, and I am especially indebted to Kathleen B. Ammon, Assistant Professor of Nursing, University of Pittsburgh, for her suggestions and careful review of the manuscript for this edition.

Shirley R. Burke

To the student

A good text should be a second instructor for you. It should discuss ideas and point out situations in which these ideas may be helpful in solving real problems rather than merely record information. You can obtain information from reference books, but what is done with the information may make the difference between success or failure in your attempts to help those you serve. A knowledge of specific facts is important, but for you who are students in the health professions it is even more important that you be able to apply the facts in practical situations. For this reason many examples of common deviations from the normal are presented in this text and are frequently illustrated in diagrams.

The real purpose of the teaching-learning process is to prepare one to cope with the future. *Now* is as close as any of us can get to the future. Therefore you should realize that at this point it is better for you to understand one generalization and thereby be able to predict three out of five facts correctly than it is to remember all five facts but not understand them. Unless you understand the concepts, you will be unable to know which to use in some future unpredictable situations. As a student in a health profession, you can be sure that you are going to encounter many completely unforeseen situations. This is one of the reasons you will find your chosen profession so exciting.

A clear idea of the purposes of this book will assist you in the learning process. How often we have the feeling that if we had only known what was expected of us we would have been better able to meet those expectations! You are urged at the outset to give careful consideration to the following goals and to review these from time to time, to assess your own progress. You will be expected to do the following:

1. Gain a concept of the relationship of the quantity of body fluids to the state of health of the individual

2. Discuss the consequences of typical defects in the regulatory mechanisms of body fluids
3. Be able to predict many of the symptoms resulting from imbalances of quantities of fluids in the different body fluid compartments
4. Describe the role of normal electrolyte balance in maintaining homeostasis
5. Gain a knowledge of the processes by which certain disease states may lead to electrolyte imbalance
6. Discuss the mechanisms by which the body maintains normal blood pH
7. Describe how disease processes may lead to acid-base imbalances, and discuss the body's normal compensatory mechanisms
8. Know some of the functions of substances other than electrolytes that are contained in the body fluids
9. Therapeutically support some of the normal body defense mechanisms

This text is an outgrowth of my experience in teaching basic sciences to nursing students and to a variety of other students in the health professions. I am grateful to these students for their thoughtful questions, which formed the nucleus from which this text grew. The invention of language made it possible for us to ask questions. Answers can be given with a grunt or gesture, but questions must be asked. All human progress, including yours, arises not so much from answers as from questions. I would be honored to have you consider me one of your teachers and to hear your comments and questions.

Shirley R. Burke

Contents

1

Quantity of body fluids and compartmental distribution

About 60% of the average adult male body weight is water. In a man weighing 70 kg, this will amount to about 42 liters of fluid. The total average body water in an adult female represents a smaller portion of her weight, about 50%.

Most (62.5%) of the body water is in the intracellular compartment, where it provides the medium in which the cell's metabolic reactions occur. Alterations in the quantity of this intracellular fluid (ICF) therefore will seriously affect the health of the individual. The extracellular fluid (ECF) accounts for about 37.5% of the body fluids. Extracellular water provides the supply route to and from the cells for gases, food, waste products, and the products of cellular metabolism. It provides the tissue lubricant essential for the normal functioning of moving parts and is the solvent for a great many substances, including nutrients and waste products. This extracellular fluid is important in the maintenance of the delicate acid-base balance of the body and is essential in the regulation of body temperature.

The extracellular fluid is subdivided into several compartments as follows:

The *vascular compartment* contains the blood plasma and accounts for about 7% of the body fluids.

Interstitial fluid is the fluid outside the blood vessels. It surrounds the tissue cells and is the final medium of exchange between the bloodstream and the cells. Lymph is interstitial fluid that has entered lymphatic vessels. The lymph and tissue fluid together account for about 18% of the body fluid.

Connective tissue fluid is found in the ligaments, tendons, skin, and bone. It is actually a part of the interstitial fluid but is often considered as a separate physiological compartment. This fluid represents approximately 10% of the body fluid.

Transcellular fluids are composed of epithelial secretions. The fluids of this compartment include gastrointestinal secretions, intraocular fluids, sweat, cerebrospinal fluid, urine, and serous and synovial fluids. Collectively the transcellular fluids account for about 2.5% of the total body fluid.

Although we talk about fluid "compartments," it is important to understand that these fluids are in constant motion, moving from one compartment to another. Despite this fact, the total quantity in each compartment remains remarkably stable in the healthy individual. The approximate quantities in the major compartments are 40% (of body weight) in the intracellular, 15% in the interstitial, and 5% in the plasma compartment.

Let us consider some of the factors that maintain this quantity of fluid. Fluid intake includes not only the water we drink but also the oxidative water resulting from the metabolism of food as well as the water content of the foods themselves. The water content of our food is considerable; it varies depending on the type of food. For example, meat contains about 50% to 75% water, whereas green vegetables may contain as much as 95% water. In a mixed diet of 2500 calories, the water content of the solid food will be approximately 800 ml, and there will be an additional 300 ml from the oxidation of the foodstuffs. The oxidation of a gram of protein produces 0.41 ml of water, a gram of fat produces 1.07 ml of water, and a gram of carbohydrate produces 0.55 ml of water. The total daily fluid intake from imbibed water, preformed water, and oxidative water should be about 30 ml/kg of body weight. Thus a healthy 70 kg adult will require about 2000 ml of water daily. This water will be distributed proportionately to each of the fluid compartments.

Fluid output is derived entirely from extracellular water and eliminated in the feces, expired air, perspiration, and urine. The water content of stool is relatively small, about 100 to 150 ml per day. Approximately 400 ml of water per day is lost in expired air, and another 400 ml is lost in the form of perspiration. The fluid lost by way of perspiration can be influenced greatly by ambient temperatures and humidity; the insensible perspiration water losses (of which we are unaware as opposed to sensible perspiration, which is clearly evident) are a function of energy metabolism, and so in a healthy adult the removal of this water is a fairly constant factor. About 20% of body heat resulting from normal metabolic processes is removed by this insensible water loss.

The adjustable component of fluid output is urine, which, however, is limited by the maximum concentrating ability of the kidney. The specific gravity of urine is an index of urine concentration, and the normal range is 1.010 to 1.030. The ability of the kidney to concentrate urine falls rapidly at values above 1.025, and minimal urine output for an adult is 500 ml per day, with a specific gravity not exceeding 1.032. The specific gravity of urine is influenced by the fluid intake. Normally, the specific gravity of urine will be low when large quantities of fluid are consumed, and the urine will be more concentrated in the presence of a decreased fluid intake.

BODY SIZE, AGE, AND METABOLISM

Excretions are derived from the extracellular fluid, which is an approximately fixed fraction of body mass; thus it is important to note that, since weight increases more rapidly over the growth period than does the surface area (Table 1-1), there is a proportionate increase in the volume of the extracellular fluid with respect to the rate of water expenditure. Although the infant has relatively more body water than the adult (about 80% of infant body weight is water), he also has a relatively greater surface area, which prescribes a basal heat production per kilogram of body weight about twice as rapid as that of the adult so that insensible losses per kilogram are also about twice as great (Fig. 1-1). It is well to

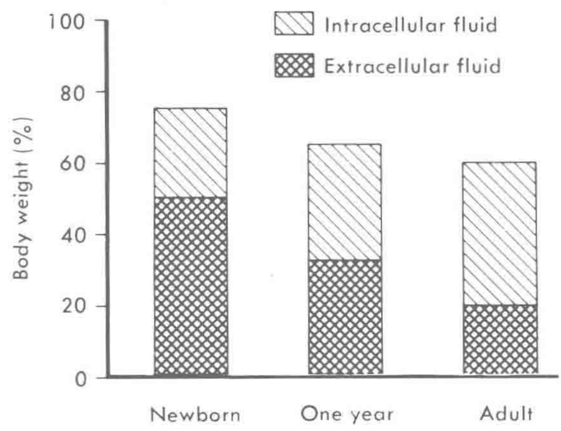

Fig. 1-1. In a newborn more than one half of the body fluid is extracellular. As the child grows, proportions gradually approximate adult fluid distribution. (From Phipps, W. J., Long, B. C., and Woods, N. F.: Medical-surgical nursing, St. Louis, 1979, The C. V. Mosby Co.)

note that, as size increases, the composition of the body changes. In the adult the relatively greater amount of bone and other connective tissues that consume little oxygen and therefore do not contribute much to body heat production may be as important a factor as surface area in the differences in energy metabolism and the resulting insensible water losses.

The infant's larger energy metabolism also requires increased water expenditure by the kidney. Whereas minimal urine output for an adult weighing 70 kg is about 500 ml, minimal urine output for an infant weighing 7 kg is about 100 ml rather than 50 ml. The significance of this is that the infant's fluid balance is much more vulnerable under circumstances that lead to dehydration, such as unusual loss of fluids due to diarrhea, vomiting, or deprivation of fluid intake.

It should be noted from Table 1-1 how much more rapidly body weight increases during the growth period than does surface area. By the age of 6 months the weight has more than doubled, whereas the surface area has increased a relatively small amount. By the age of 10 years the weight has increased almost tenfold, whereas the surface area has increased only about fivefold. Since insensible water losses are determined by surface area, the infant is more vulnerable to abnormal water losses than the adult.

At any age heat production and metabolic rate are principal determinants of water turnover, and therefore circumstances that will increase either of these are likely to lead to dehydration unless fluid intake can be similarly increased. The signs and symptoms of dehydration and some of the resulting problems will be discussed in Chapter 3.

The insensible water losses of children and adults can be calculated by using the DuBois chart (Fig. 1-2) and the calorie table (Table 1-2). First, use the DuBois chart to determine surface area by drawing a line from the correct height in the first column to the weight in the third column. This line will intersect the surface area (given in square meters) in the second column. Next, refer to the calorie table to find the number of calories per hour per square meter. About 20% of the total heat pro-

Table 1-1. Relationship of growth parameters

	Newborn	6 mo	1 yr	10 yr	Adult
Weight (kg)	3.4	7.4	10.0	31.0	70.0
Height (cm)	50.0	66.0	75.0	139.0	170.0
Surface area (m^2)	0.21	0.36	0.45	1.12	1.75

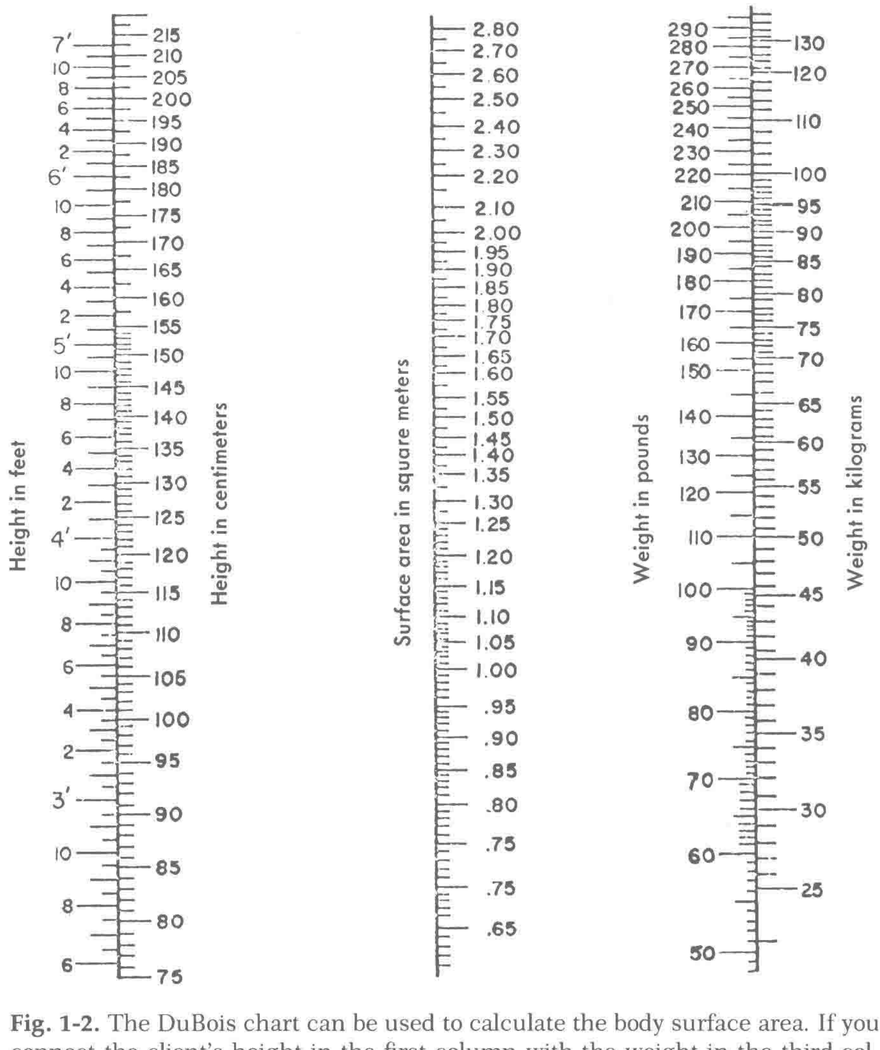

Fig. 1-2. The DuBois chart can be used to calculate the body surface area. If you connect the client's height in the first column with the weight in the third column, the line will intersect the correct surface area in the middle column. (Prepared by W. M. Boothby and R. B. Sandiford.)

Table 1-2. Boothby and Sandiford's normal standards (calories/square meter/hour)

Age	Males	Females
15	45.3	39.6
16	44.7	38.5
17	43.7	37.4
18	42.9	37.3
19	42.1	37.2
20-24	41.0	36.9
25-29	40.3	36.6
30-34	39.8	36.2
35-39	39.2	35.8
40-44	38.3	35.3
45-49	37.8	35.0
50-54	37.2	34.5
55-59	36.6	34.1
60-64	36.0	33.8

duction in 24 hours will be dissipated in the form of insensible perspiration. Each gram of insensible perspiration absorbs 0.58 calorie of heat.

In addition to infants, who are particularly vulnerable to excessive fluid losses, obese individuals and the elderly are also in jeopardy when faced with relatively small water losses. The total body water as a fraction of body weight in the obese individual is much less than in the lean muscular adult. Adipose tissue contains little water; therefore the water balance is less stable. The obese individual may have as little as 25% to 30% of his body weight vested in water. Clearly, this does not give a wide margin of safety.

Some unethical physicians have been reported to prescribe a variety of unsafe medications to cause weight loss. Diuretics are an example of such medications that will decrease a person's weight, but the weight lost because of the diuretic is water, not fat. These patients can ill afford to lose such water. Other medications prescribed along with the diuretics may be drugs to increase body metabolism, but since such drugs sometimes cause tachycardia (rapid pulse), these physicians include a digitalis preparation (to slow the heart rate). It would appear that giving digitalis is a precautionary measure that may prevent patients from seeking out legitimate medical advice because of heart palpitations. It should also be noted that digitalis toxicity is more likely to occur in the presence of hypokalemia (low blood potassium), and most diuretics cause increased excretion of potassium by the kidneys. Other problems caused by an abnormal amount of potassium in the blood are discussed in Chapter 5.

Total body water of people over 65 years of age may be only 40% to 50% of body weight. The elderly also have other special problems with respect to fluid balance. Water losses normally are accompanied by electrolyte losses. When water deficit is the result of inadequate fluid intake, the preservation of normal ionic concentration necessitates the removal of a corresponding quantity of electrolytes. Conversely, when electrolytes are withdrawn, a corresponding removal of water is necessary. In the elderly, neither the kidney nor the endocrine glands may be capable of making such delicate adjustments. The elderly are subject to the same possible causes of desiccation (water loss) as anyone else, but in addition, they are frequently afflicted with atherosclerosis, which may impair their sense of thirst (as well as other senses), and so their fluid intake may be less than their physiological requirements.

Consider the fact that the body has an intermittent water intake and a continuous output of variable degree. This requires a certain amount of flexibility regarding the total body fluid volume. For this reason, as in other biological systems, it is obvious that rigidity is physiologically impossible. Since vascular compartment mechanics demand a fairly stationary volume, and the functions of the transcellular fluids normally require a small but relatively unchanging quantity, these compartments cannot provide the required flexibility. Intracellular water is the basis of cellular metabolism, and it, too, must remain approximately constant. The role of the interstitial fluid in the maintenance of fluid homeostasis is obvious.

In a very general way fluid balance means that the total body water remains relatively constant, with the fluid intake equal to the output. The relative distribution of the total body water into the intracellular, intercellular, transcellular, and plasma compartments is also an important part of what is meant by fluid balance. This will be discussed in later chapters.

SUMMARY QUESTIONS

1. Which body fluid compartment contains the greatest quantity of water?
2. Why are infants particularly vulnerable to desiccation?
3. Why might atherosclerosis compound the dangers of dehydration in the elderly?
4. Why may large fluid losses be particularly dangerous in an overweight individual?