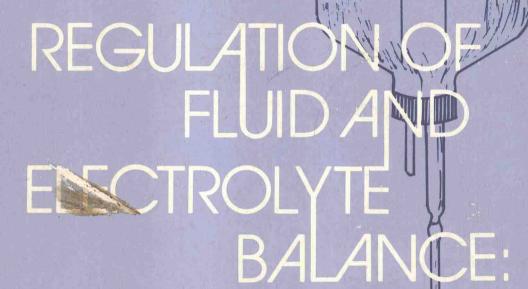
REED AND SHEPPARD



A Programed Instruction in Clinical Physiology

# REGULATION OF FLUID AND ELECTROLYTE BALANCE:

A Programed Instruction in Clinical Physiology

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#### SECOND EDITION

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#### **PREFACE**

The purpose of this Programed Instruction is to provide a self-teaching instrument for the study of fluid, electrolyte, and acid-base balance. The book is written for any member of the health team who shares responsibility for maintaining or restoring physiologic balance in the patient.

Understanding the body's mechanisms for preserving its internal environment is essential to effective management when alterations occur. It is not enough, for example, to be able to identify and administer a particular fluid intravenously. Effective therapy requires that the team know the indications for administering that fluid, its effects and side effects, and the rationale for continuing or discontinuing its administration. Omission or overextension of intravenous therapy can be, in many instances, lethal.

Basic physiological mechanisms regulate total body water and electrolyte concentrations, as well as their distribution and compartmentalization. Still other mechanisms stabilize acid-base balance. Many concepts basic to these regulatory mechanisms will have been introduced in the student's previous study of physiology from the systemic approach. This program re-examines these concepts in the context of actual clinical situations and integrates the principles underlying regulation into case studies and descriptions of disease processes.

The order of presentation of topics in the five Units of the book represents a deductive movement from the theoretical to the applied. Unit One investigates the basic concepts of fluid, electrolyte, and acid-base balance. Units Two, Three, and Four treat, in turn, fluid balance, electrolyte balance, and acid-base equilibrium. The fifth Unit presents case histories involving multiple problems which occur in the various aspects of homeostasis.

On completion of this program, a conscientious student can expect to have a working knowledge of the following specific topics:

- (1) The terminology related to fluid, electrolyte, and acid-base balance.
- (2) The normal distribution of fluids, ions, and molecular substances in the various compartments and the mechanisms which produce this compartmentalization.
  - (3) The role of the various organ systems in maintenance of internal environment.
- (4) Total body water, compartmental fluid shifts, edema, dehydration, and alterations and therapy pertinent to specific disease conditions.
  - (5) Principles related to electrolyte balance and the pathophysiology of imbalance.
- (6) Analysis of data and laboratory values related to intake and output, chemistry profile, and blood gases.
- (7) The role of blood buffers, the respiratory system, and the kidneys in stabilizing pH.
- (8) Identification of disease processes in which alterations in homeostasis are likely to occur.
- (9) Rationale of approaches to patient care in clinical situations which alter fluids, electrolytes, and acid-base balance.

The programed method employed in this book moves by logical stages in a natural

#### vi PREFACE

progression from the familiar to the unknown. The method enables the student to participate actively in the learning process through reading, reasoning, and writing. Repetition reinforces memory. The method is geared to maximal understanding and retention in minimal time.

The principal reference source for the theoretical content of Units One through Four was Arthur C. Guyton's *Textbook of Medical Physiology*, Fifth Edition. Illustrations used throughout the book were reproduced or adapted from figures in the same textbook with the kind permission of Dr. Guyton and the Publisher. The primary reference for Unit Five was John H. Bland's *Clinical Metabolism of Body Water and Electrolytes*. Topics for clinical applications were derived from Joan Luckmann and Karen Creason Sorensen's *Medical-Surgical Nursing: A Psychophysiologic Approach*.

The authors wish to acknowledge the expertise of Janice Schneider, B.S.N., and Bonnie Williams, B.S.N., of the Methodist Hospital School of Nursing, Memphis, Tennessee. Their critical review of the first edition and their suggestions for revision are greatly appreciated.

#### INTRODUCTION

Before studying the basic principles which underlie the regulation of fluid and electrolyte concentrations, it will be helpful to consider why their relatively stable state is important and to speculate on how this stability came about.

Supposedly, eons ago, when the temperature of the earth cooled sufficiently to form the oceans, these waters contained very little salt. Salinity gradually increased, however, as mineral deposits washed into the waters from the primordial continents until, with the passage of time, life appeared. Early forms of living things found the seas to be an ideal environment because their vastness prevented drastic changes in acidity, temperature, and ionic constitutents.

The high potassium content of those ancient waters was compatible with protoplasmic life within the cell and probably diffused easily across the membranes of unicellular organisms. As the sodium content of the oceans increased, this element, too, was probably incorporated as a necessary ingredient of the cellular environment. As one-celled organisms developed into multicellular forms, they enclosed within each cell fluids high in potassium and they surrounded these cells with fluids high in sodium.

If ancient seas were favorable to life, as apparently they were, animal forms may have preserved within themselves their original medium as they migrated from water to land along that long evolutionary path from unicellular structure to the complexity which is man.

Indeed, the nature of blood serum and interstitial fluids suggests that to this day every cell of the body still bathes in an internal medium identical with that of its oceanic origin.

Thus the environment of the ancient seas endures. Individual cells can live, multiply, and maintain their characteristic functions only so long as the interstitial fluids which surround them provide their optimal environmental requirements. The normal functioning of the cell demands that the composition of these fluids be relatively constant. Regulatory mechanisms maintain this constancy. An investigation of these regulatory mechanisms, and their disruption by disease, makes up the content of this book.

#### **HOW TO USE THIS BOOK**

The book is arranged in two tracks to meet the varying needs of different student groups. The main track includes all the information basic to patient care for students in accelerated programs in which time is a major consideration. The second track includes, in addition to the material in the main track, further information for the student who desires more detailed coverage in greater depth. Clear directions for proceeding are given at those places throughout the book where the additional material of Track Two is inserted.

This book divides the subject matter into five Units, each of which is subdivided into a number of Items. Each Item presents a factual explanation of a single topic, followed by several questions. The questions are of two types: fill-in and multiple-choice. The correct answer to every question appears immediately below the question. Alternative correct answers to the fill-in questions appear in parentheses.

Do not look at the answers given in the book until you have written in what you think are the correct answers. Use the piece of cardboard provided to cover the answer below each question while you write in the appropriate words in the blanks of a fill-in question, or encircle your choice of the alternative answers to a multiple-choice question. Then slide the cardboard cover down the page to reveal the correct answer, and check the accuracy of your own answer.

Avoid guessing. If you are not sure of your answer, reread the explanatory part of the Item. The need for such rereading is to be expected occasionally and perhaps even frequently. Rereading the Item will reinforce learning, eliminate vagueness, and enhance your confidence.

Turn now to page one and begin the course.

## **CONTENTS**

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# OF FLUIDS AND ELECTROLYTES

#### DISTRIBUTION OF BODY FLUIDS

#### ITEM 1

Total body fluids in the average adult occupy a volume of approximately 40 liters and are referred to collectively as *total body water*. Various membranes, including cell membranes, capillary membranes, serous membranes, and mucous membranes, separate total body water into compartments.

Intracellular fluid (ICF) is that part of total body water contained within cells. Extracellular fluid (ECF) includes all the remainder of total body water not contained within cells. The two most important extracellular fluids are serum and interstitial fluid. Serum is the liquid component of blood, including all the dissolved and suspended particles except cells. Interstitial fluid is that fluid which immediately surrounds tissue cells. In some disease conditions, extracellular fluid accumulates in potential spaces in the body. Potential spaces, as their name implies, do not normally exist. They can be created, however, between membranes and within loose connective tissue when fluid accumulates as a result of fluid shifts and pressure differences. For example, the abdominal cavity can be considered a potential space—one that would become an actual space if fluid accumulated excessively in conditions which impede drainage.

The composition and activity of intracellular fluids are remarkably constant, regardless of tissue type. For this reason, intracellular fluids can be considered as a unit. Similarly, extracellular fluids are so alike that they, too, can be considered collectively, regardless of their source.

QUESTION 1
ANSWER
QUESTION 2
ANSWER
QUESTION 3
ANSWER
QUESTION 4

#### 4 BASIC PHYSIOLOGY OF FLUIDS AND ELECTROLYTES

QUESTION 5	Fluid that surrounds tissue cells is calledfluid.					
ANSWER	interstitial					
QUESTION 6	In some pathological conditions, extracellular fluid can accumulate inspaces within the body.					
ANSWER	potential					
QUESTION 7	Intracellular fluid in various types of cells throughout the body can be considered as a unit because it is similar in and					
ANSWER	composition activity					
QUESTION 8	Extracellular fluid can also be considered as a unit because it too isin					
ANSWER	similar composition					

#### 1TEM DYNAMIC EQUILIBRIUM 2 OF BODY FLUIDS

Body fluids are normally in a state of *dynamic equilibrium*; that is, they maintain their constancy of composition in spite of an intake and output of fluid and dissolved particles which may vary drastically.

Extracellular fluids are continually mixed by the propelling action of the circulatory system and the interchange of fluid between capillaries and interstitial spaces. Fluid shifts in and out of the intracellular compartment through the semipermeable cell membranes. This perpetual state of mobility of individual molecules and ions causes a constant interchange of body fluids from one compartment to another. In spite of this continual mobility, various physiological mechanisms keep the composition of each fluid compartment within a relatively narrow normal range.

Dynamic equilibrium may be summed up as follows: although the composition of the fluid in each compartment is relatively stable, the situation as a whole is one of incessant replacement and exchange.

#### **ELECTROLYTE DISTRIBUTION**

The situation of stable composition of fluids amidst continual mobility and interchange is called				
dynamic equilibrium				
The pumping action of the heart mixes fluids and promotes the interchange of fluid between and spaces.	QUESTION 10			
extracellular capillaries interstitial				
Fluid is exchanged within cells because of the of cell membranes.	QUESTION 11			
semipermeability				
Composition of body fluids remains relatively even though the composition in any one compartment is in a state of constant				
stable change (exchange, replacement, mobility)				

### ELECTROLYTE DISTRIBUTION ITEM

Electrolytes are those chemical substances which dissociate in solution to form electrically charged particles, or *ions*. The same ions are present in both extracellular fluids and intracellular fluids, although the concentrations of these ions in the two compartments are strikingly different.

Intracellular fluid contains large quantities of potassium, phosphate, and magnesium and small amounts of sodium, calcium, chloride, and bicarbonate. In extracellular fluid the distribution of electrolytes is exactly reversed. Extracellular fluid has large quantities of sodium, calcium, chloride, and bicarbonate and much smaller concentrations of potassium, magnesium, and phosphate.

Figure 1 lists the concentrations of various ions and molecules in extracellular fluids and in intracellular fluids. Look closely at the distribution of the first two ions, Na<sup>+</sup> and K<sup>+</sup>. Notice the striking difference in the concentration of sodium and potassium in the extracellular and intracellular compartments. Note also the difference in concentration of Cl<sup>-</sup> and HCO<sub>3</sub> in the two compartments.

The concentration of ions is given in terms of *milliequivalents per liter* (mEq./L.). A milliequivalent is the standard unit of measurement for the chemical reactivity of charged

#### 6 BASIC PHYSIOLOGY OF FLUIDS AND ELECTROLYTES

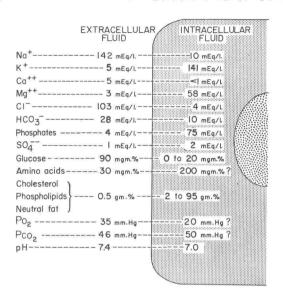


Figure 1. Chemical compositions of extracellular and intracellular fluids. (From Guyton: Textbook of Medical Physiology. 5th Ed. Philadelphia: W. B. Saunders Company, 1976.)

particles in body fluids. Molecules are given in *milligrams per 100 ml*. fluid (mg.%) or in *grams per 100 ml*. fluid (gm.%). Concentration of blood gases is in *millimeters of mercury* (mm. Hg). The significance of these units will be discussed in later Items.

QUESTION 13	Substances which form electrically charged particles in solution are termed; the charged particles themselves are called							
ANSWER	electrolytes ions							
QUESTION 14	Extracellular and intracellular fluids differ in kinds of/concentration of (circle one) ions.							
ANSWER	concentration of							
QUESTION 15	Measurement of chemical reactivity of ions in body fluids is given in  A. milligrams per 100 ml. fluid  B. milliequivalents per liter  C. millimeters of mercury							

ANSWER

The correct answer is B, milliequivalents per liter (mEq./L.)

		ELECTRICAL NEUTRALIT	Y WITHIN FLUID COMPA	RTMENTS	7
Intracellular fluids contain relatively more					QUESTION
A. potassium, phosphate, magnesium					16
B. sodium	n, chloride, bic	arbonate			
The correct answer is A.					ANSWER
Extracellular fluids are high in the following electrolytes:, and,					QUESTION 17
	sodium .	., chloride bicarbona	te (in any order)		ANSWER
Refer to Figure 1, Item 3, and fill in the normal values in milliequivalents per liter (mEq./L.) for sodium and potassium in the following chart.				QUESTION 18	
	10	onic Composition of Bod	y Fluids		
	Ion	mEq./L. in Extracellular Fluids	mEq./L. in Intracellular Fluids		
So	odium				
Po	otassium				
			AL NEUTRA WITHIN F COMPARTMI	LUID	ITE 4
compartments, compartment charges, is bala	the total cher the total nur anced by an	ferent distributions of t mical reactivity within a c mber of milliequivalents equal number of millied nce of positive and ne	ompartment is neutral. We of <i>cations</i> , or ions wiquivalents of <i>anions</i> , or	Vithin each th positive ions with	
Cations are	particles in so	lution which have	charges.		QUESTION

positive

**ANSWER** 

19

#### BASIC PHYSIOLOGY OF FLUIDS AND ELECTROLYTES Particles which are negatively charged in solution are termed \_ QUESTION anions ANSWER QUESTION both compartments, cations balance anions in terms of chemical In reactivity ANSWER Electrical neutrality within each compartment means that the total electrical charges QUESTION 22 balance the total electrical charges of \_\_\_\_

# ITEM COMPOSITION OF FLUIDS 5 IN mEq./L.

Figure 2 illustrates the balance between cations and anions in serum (plasma), interstitial fluid, and cell fluid. Notice that when given in milliequivalents per liter, positive ions are balanced by negative ions. Total cations, in milliequivalents, equal total anions, again in milliequivalents.

cations . . . anions

Although the total chemical reactivity, or combining power, of cations and anions is equal within a given compartment, the total number of ions is not necessarily equal. The total number of cations compared to the total number of anions in the same compartment does not constitute electrical neutrality. Some ions, positive or negative, have two or three times the combining power of others. Neutrality is the result of the total balance of chemical reactivity.

QUESTION

23

ANSWER

Both intracellular and extracellular compartments are approximately equal in

- A. total number of positive and negative ions
- B. total chemical reactivity due to cations and anions

ANSWER

- A. This answer is incorrect. Each compartment does not contain an equal number of positive and negative ions. Rather, there is a balance of positive charges against negative charges in the same compartment, as far as chemical reactivity is concerned. Reread the question, then read Answer 23–B.
- B. This answer is correct. In each compartment, the total reactivity of cations is balanced by an equivalent reactivity of anions in the same compartment. Thus, as far as chemical equivalence is concerned, there is electrical balance in each compartment.