FLUID AND ELECTROLYTES IN PRACTICE

STATLAND

Fluid and Electrolytes In Practice

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Preface

The material in this book was first presented as a series of lectures to undergraduate and postgraduate students at the University of Kansas School of Medicine, in 1950. It was at the request of many of these students that the notes have here been assembled, amplified and presented as a practical guide to fluid and electrolyte therapy.

In presenting the necessary chemistry and physiology, perhaps I have erred on the side of oversimplification, in order to keep the text intelligible to those practicing physicians who have long been removed from the basic sciences. While nothing has been sacrificed in accuracy or completeness by this, I have felt that it was justified in the interests of practicability. The physiologic principles upon which proper therapy is based have not been concentrated into any single chapter; rather, they are discussed at different points throughout the text where the discussion seemed to adapt itself to a logical explanation of the clinical picture and the management. For this reason frequent cross references are made in order to avoid repetition.

Part One presents the basic principles of fluid movements and the major abnormalities of volume, concentration and acid-base balance. In this section the management of the surgical patient has been stressed particularly. In Part Two the application to management of special diseases is discussed more fully. A thorough understanding of Part One is necessary in order to apply effectively the principles of management discussed in Part Two.

The volume of literature on this subject has become so great that it is impossible to mention all the excellent papers that have been published. Therefore, the bibliography includes only a representative selection of articles which either demonstrate certain important principles or have some clinical bearing on these principles. I have drawn heavily on the work of J. L. Gamble, J. P. Peters, D. C. Darrow and A. M. Butler, who have been the pioneers in this field. The more recent literature has been stressed particularly, in the bibliography.

I am especially indebted to Dr. Alexander Leaf at the Massachusetts General Hospital for his discussions and help in the early stages of preparation of this book. I am grateful to Dr. Jack Zellermayer, Dr. Sidney Rubin and Dr. Morris Statland for reading the manuscript and for their many suggestions. Miss Lois Brunner and Miss Rita Carr, medical technicians, were of great help in developing the fluid balance service and in the study of fluid problems in many patients. I wish also to thank Mrs. Angelika Howard and Mrs. Evelyn LeVine for their help in checking the bibliography, and Mrs. Mary Lou Stickel for typing the manuscript. The drawings were made by Miss Arlene Nichols.

H.S.

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Part One

GENERAL PRINCIPLES

CHAPTER ONE

Fluid Structure

ELECTROLYTES

By electrolytes we refer to those substances which, when placed in water, dissociate into charged particles called ions. Positively charged ions are spoken of as **cations**, and in the blood they are Na^+, K^+, Ca^{++} and Mg^{++}. The negatively charged ions, called **anions**, are Cl^-, PO^{--}, HCO_3^-, organic acids and proteins. Other substances, such as urea and glucose, are also present in blood serum, but since they have no electric charges and do not dissociate into charged particles they are not electrolytes.

CHEMICAL EQUIVALENTS

In studying the alterations in blood chemistries and their concentration we are not concerned with how much the ions weigh (mg. %), but rather with how many ions there are (mEq./L.). The milliequivalent system of terminology is an important tool in the understanding of this subject and it is virtually impossible to follow electrolyte shifts when they are expressed as milligrams per cent. If the reader will forgive a simple but point-making analogy, one might compare this to the hostess making up her list of guests to a dance. She does not invite 1,000 pounds of girls for 1,000 pounds of boys. Rather, she is interested in how many of each, and, regardless of difference in weights, the number of individual males and females (anions and cations) must be equal.

As an example, since the atomic weight of sodium is 23, 23 Gm. of sodium is one equivalent of sodium, chemically speaking. Expressing this in milligrams, rather than grams, and in milliequivalents, instead of equivalents, therefore:

23 mg. of sodium is 1 milliequivalent
46 mg. of sodium is 2 mEq.
69 mg. of sodium is 3 mEq.. and so on.

The atomic weight of chlorine, on the other hand, is 35. Therefore, 35 Gm. of chlorine is one chemical equivalent, and 35 Gm. of chlorine combines equally with only 23 Gm. of sodium. Expressed in milligrams then:

35 mg. of chlorine is 1 mEq.
70 mg. of chlorine is 2 mEq.
105 mg. of chlorine is 3 mEq., and so on.

It is apparent then that dividing the number of milligrams of a monovalent substance by its atomic weight gives the number of combining particles or milliequivalents. Milligrams are ordinarily reported in terms of 100 cc. of solution and milliequivalents are reported in terms of 1,000 cc. of solution so we have to multiply by 10 in converting from milligrams to milliequivalent terminology.

So far we have discussed ions which have a valence of 1, that is, ions, which have a single electric charge. Since each atom of a bivalent substance has 2 charges, it can combine with 2 monovalent ions. The atomic weight of such a substance therefore represents 2 chemical equivalents. The atomic weight of calcium is 40. Therefore, 40 mg. of calcium is 2 mEq., since this amount would combine with 2 mEq. of Cl^-, which is monovalent. The rule then becomes: To convert mg. % to mEq./L.:

$$\frac{\text{mg. \%}}{\text{atomic wt.}} \times 10 \times \text{valence} = \text{mEq./L.}$$

TABLE 1. CONVERSION OF THE MORE COMMONLY USED ELECTROLYTES FROM MG.% TO MEQ./L.

Na^{+}	mg.% x 10 ÷ 23	= mEq./L.
K^{+}	mg.% x 10 ÷ 39	= mEq./L.
Cl^{-}	mg.% x 10 ÷ 35	= mEq./L.
Ca^{++}	mg.% x 10 ÷ 40 x 2	= mEq./L.
Mg^{++}	mg.% x 10 ÷ 24 x 2	= mEq./L.
CO_2	Vol.% ÷ 2.22	= mEq./L.

Table 1 shows the conversion of the commonest electrolytes from mg.% to mEq./L. Note that carbon dioxide combining power is converted to milliequivalents by dividing volume per cent by 2.22.

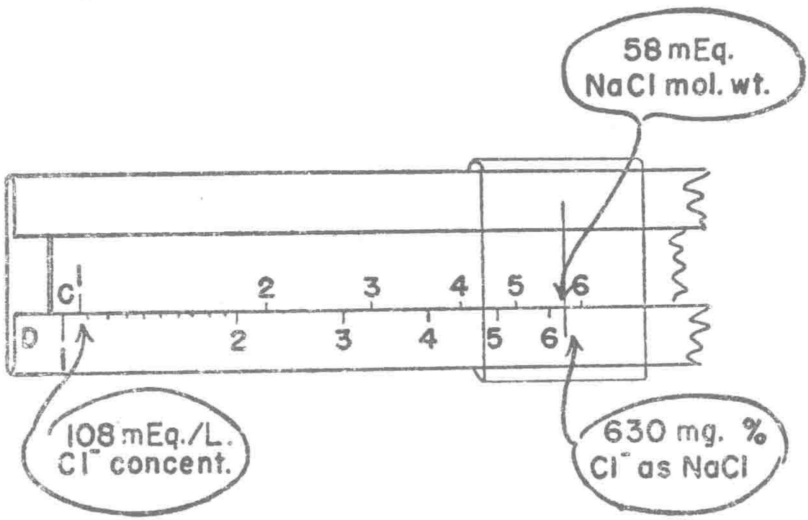

FIG. 1. Slide rule conversion of milligram per cent to milliequivalents per liter. Serum chloride, expressed as sodium chloride (NaCl) in mg. %, may be converted to mEq./L. by one setting on the slide rule. The determination in mg. % is set under 58 (molecular weight of NaCl), and the Index 1 indicates the reading of chloride (Cl) in mEq./L.

Until hospitals begin to use the milliequivalent system in reporting serum electrolytes, it will be necessary for the physician to make quick conversions. For this purpose a celluloid pocket slide rule is most helpful. As shown in Figure 1, the slide rule will convert milligrams per cent of chloride, reported as sodium chloride, to milliequivalents per liter by a single setting. One should make certain however that the chlorides are measured in serum and not in whole blood since the two values are appreciably different. For electrolyte balance purposes, blood chemistries are of relatively little value compared to serum chemistries, since the determinations may be altered by the degree of anemia or by hemoconcentration. This is true because of the marked difference of chemical values in the serum as compared to blood cells.

OSMOTIC EFFECTS

If two different solutions are separated by a membrane impermeable to the dissolved substances, there will occur a shift of fluid through the membrane from the least concentrated to the more concentrated solution, until the solutions are of equal concentration. This is termed osmosis and the dissolved substances are said to exert an osmotic force in causing the fluid shift. The magnitude of this force is dependent upon the number of particles dissolved and not upon their weights or valences. Thus 10 atoms of sodium have the same osmotic force as 10 atoms of calcium or 10 molecules of protein, in spite of the differences in valence and weight. Sodium, therefore, exerts a more potent osmotic force than the same weight of protein since there are so many more molecules of sodium than protein in a given weight of both substances. The term milliosmole refers to this osmotic effect of a substance. One mEq. of sodium (23 mg.) exerts 1 mOsm. of pressure. However, 2 mEq. of calcium (40 mg.) also exerts only 1 mOsm. of pressure. Bivalent atoms have a chemical equivalence of 2 but the osmotic force of only 1 particle. Therefore:

$$\frac{\text{mg. \%}}{\text{atomic wt.}} \times 10 = \text{mOsm./L.}$$

By way of review, normal saline has 150 mEq. of sodium. How many milliequivalents of chloride in this solution? The answer is 150 mEq. of chloride, since there is 1 atom of chloride for each atom of sodium. How many milliosmoles of sodium chloride in this solution? The answer would be 300, since there are 150 mOsm. each of sodium and chloride. The osmotic force of this solution would be the effect of both ions combined. Again, if a solution of calcium chloride, $CaCl_2$, has 150 mEq. of chloride, how many milliequivalents of calcium has it? The answer is 150 mEq. of calcium. How many milliosmoles of calcium? There are 75 mOsm. How many milliosmoles of $CaCl_2$? The answer is 225 mOsm. of $CaCl_2$ which represents the total of 150 of chloride and 75 of calcium.

FLUID COMPARTMENTS OF THE BODY

In planning therapy for the depleted patient a knowledge of the volumes normally present in the various fluid compartments is of great value and well worth remembering. Since the chemical make-up of fluid is fairly constant, one can often estimate the quantity of electrolyte loss from each compartment if the total fluid loss is known. Loss of 1 L. of cell fluid, for example, will carry with it its dissolved electrolytes and some of the protein.

The body fluids are divided into two major compartments (Fig. 2) and the volumes, expressed as a fraction of the total body weight, are as follows:

Total body fluid.............60 per cent of body weight
Cellular fluid
  compartment (CF)........40 per cent of body weight
Extracellular fluid
  compartment (EF)........20 per cent of body weight

The total fluid of the body varies within fairly wide limits depending upon the amount of fatty tissue, which has less water, and of muscular tissue ("lean body mass") which has a greater percentage of water. More accurately speaking the average figure would be about 56 per cent of body weight. In