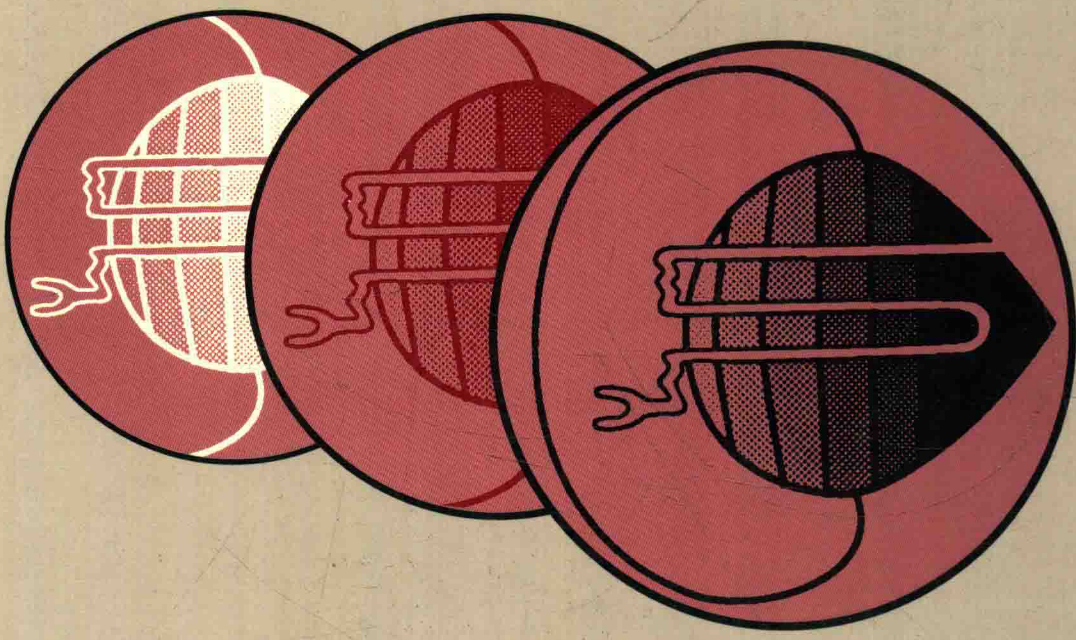
FLUIDS AND ELECTROLYTES

A Conceptual Approach

Second Edition



E. KINSEY M. SMITH, M.D.

Fluids and Electrolytes

A Conceptual Approach

Second Edition

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Fluids and Electrolytes

A Conceptual Approach

Second Edition

To P.J.S.

Preface to the Second Edition

The second edition of this book follows the same format as its predecessor and its companion volume - "Renal Disease - A Conceptual Approach". Concepts have been emphasized and the problems faced by students with limited science background and the stress of a "packed curriculum" have been kept in mind. The illustrations are an essential complement to the text and in the first edition suffered from variability of style and quality. This has been corrected by the skill and imagination of David Lemmond using computer based technology.

The text has been revised, significant new knowledge has been incorporated and an index has been added. In spite of this, the book has not been increased in length, and it is hoped that this will avoid a sense of "information overload" at a time when more scholarly modern texts are often perceived to be intimidating because of their complexity and size. This book is complementary to such texts and should serve as an introduction to their use and not as a replacement for them.

I wish to thank the Audio Visual Department at McMaster who have provided superb resources, the students who continue to make academic life a happy challenge and my colleagues in the Faculty of Health Sciences who have supported my attempts to be an educator over the past two decades.

Kinsey Smith (1991)

Preface to the First Edition

This illustrated text was developed primarily for undergraduate medical students at McMaster University. Some of these students do not have any background in the physical or biological sciences, and many of the basic concepts they need for the understanding of body fluid regulation are foreign to them. Moreover, the constraints of a three year undergraduate course emphasize the value of clear introductory resources which link basic concepts to relevant clinical problems.

This book attempts to introduce the idea of a regulated internal environment and its responses in health and disease. The illustrations provide a visual summary, the text a simple and direct description of the illustrated concepts. It does not pretend to be comprehensive and the student should not use it to replace more detailed and scholarly resources. The method of presentation is not conventional, but the underlying concepts are well established and lean heavily upon the influence of other authors; the references provided at the end of the book represent only a small selection of useful resources and do no more than point the way to wider reading. The lucid writings of the late L.G. Welt and R.F. Pitts have been especially valuable to me and I make no apology for the major influence they have had in the development of the concepts that are illustrated here. Many ideas for visual presentation have come from the enthusiasm of Dr. Elizabeth Brain and members of the Audio Visual Department, and thanks are due to those colleagues amongst students and faculty who have provided stimulation and advice over the past decade.

This text is based in part upon material that has been used in a slide/tape format for a number of years. It is now offered to a wider readership in the hope that it may prove useful in other medical, nursing and paramedical programmes and perhaps as a reminder for more advanced students.

Kinsey Smith (1980)

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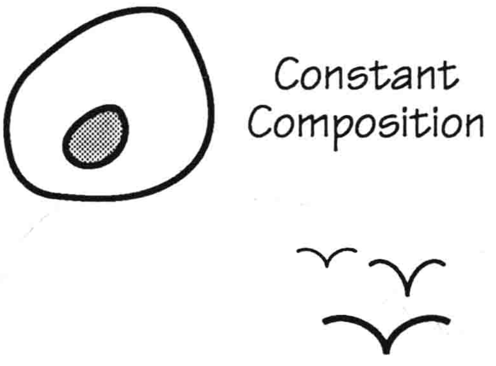
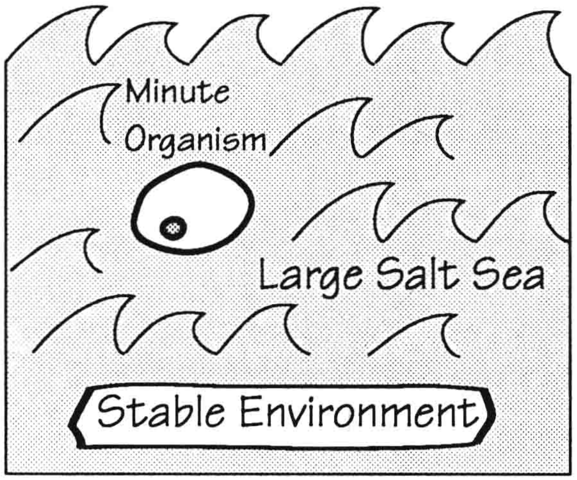
The Cellular Environment



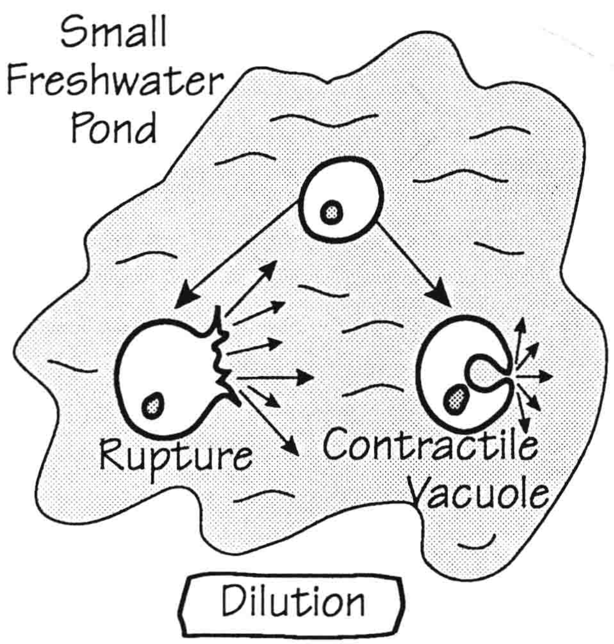
The Cell

The unit of biological function is the single cell which requires a defined composition to function normally. It must be capable of acquiring vital nutrients as they become depleted and of rejecting those end products which are not required and are potentially toxic.



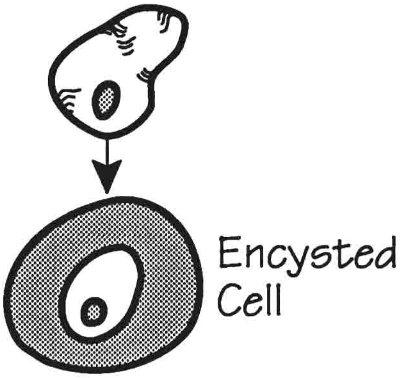
...and its Surroundings

Simple, single-celled organisms evolving in an almost infinitely large salt sea may be considered as having an unvarying external environment. In this setting, regulation of their volume and composition is relatively simple. Surrounding osmotic pressures do not change appreciably and the concentration of solutes around them is constant. Waste products can simply diffuse out of the cell and become infinitely diluted in the surrounding sea.

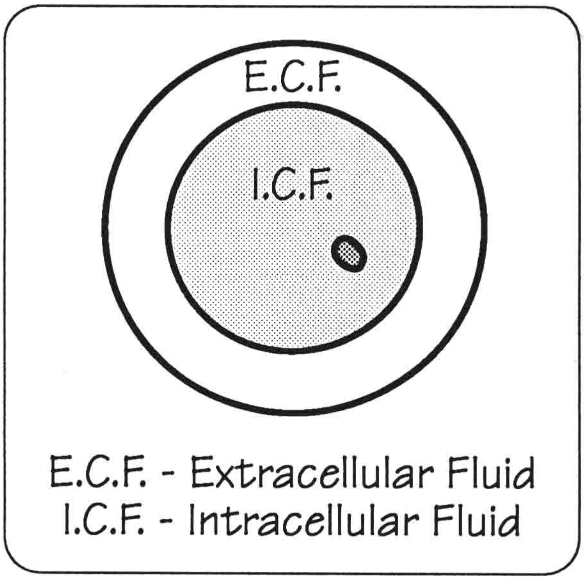


A single-celled organism (such as an ameba) living in a small fresh water pond faces a more hostile environment. A vigorous rain storm may dilute the already solute-poor water in the pond and produce increasing osmotic pressure gradients which cause water to enter the cell which will swell up to the point of bursting.

Adaptations which prevent this happening include the evolution of such devices as "contractile vacuoles" which can eject unwelcome volume.



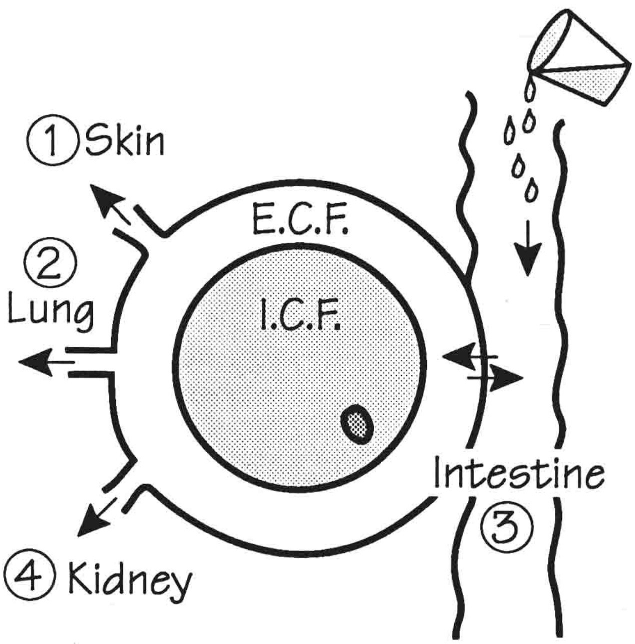
If the pond dries up, the reverse process occurs and the cell becomes shrivelled and dehydrated. The protection such an organism can provide for itself is to become encysted, surrounding itself with a "waterproof coat" which will allow it to withstand desiccation and become reactivated when conditions improve. The price paid for this survival is to undergo periods of immobility and inactivity.



"The Milieu Interieur"

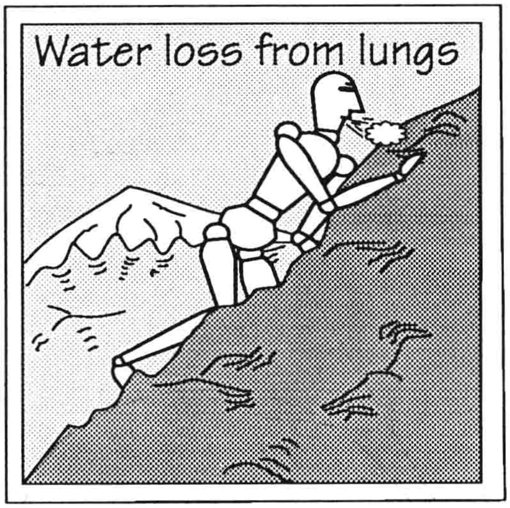
Warm blooded multicellular animals, like man, have adapted to life on dry land by taking with them a "personal environment", the composition and volume of which are precisely regulated even in the face of widely varying external conditions. This environment is like a "shell" of fluid which allows the cells to ignore changes in the outside world. This insulating shell is the "milieu interieur" (internal environment), first recognized by Claude Bernard and provided by the extracellular fluids.

In complex animals the body fluids can thus be separated into two compartments, the intracellular fluid (I.C.F.) and the extracellular fluid (E.C.F.).



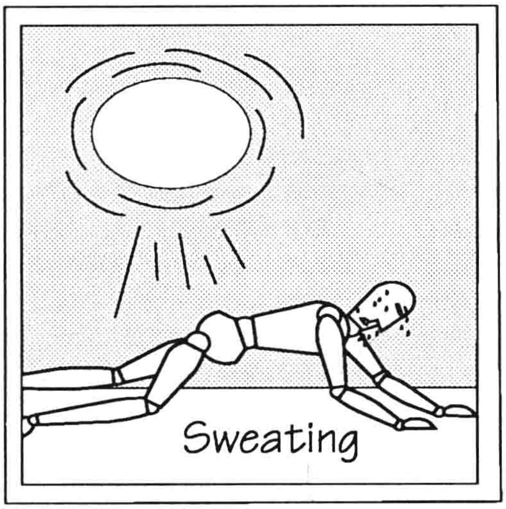
The only natural entry point to the body fluid compartments is by the mouth and intestinal tract. There are four exit routes from the extracellular fluid space and these are:

1) The skin, where loss occurs by perspiration and is related to temperature and humidity.
2) The lung, where loss is related to the need to moisten the air we breathe.
3) The intestine, where diarrhea or vomiting may cause abnormal losses.
4) The kidney, which is the only exit route that can be closely regulated.



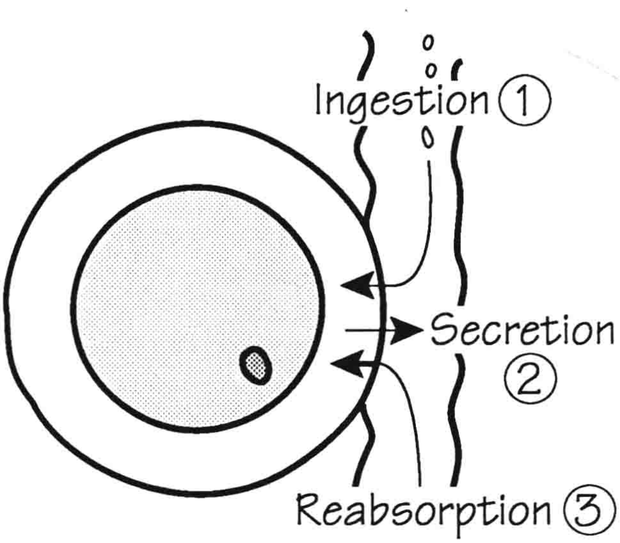
Fluid Loss from the E.C.F.

Losses via the skin and the lung are dependent upon external factors which cannot be controlled. Thus men climbing high mountains in cold, dry air will have enormous water losses from the lungs as hypoxia demands increased ventilation. In early attempts to climb Mount Everest the inability to carry enough fuel to melt enough snow to prevent dehydration was a major cause of failure.



Men suddenly transported to a hot climate may sweat unmanageably and become dangerously volume deplete. Adaptation to such a climate takes a week or two and studies of troops air-lifted into the South Pacific during World War II led to better understanding of body fluid regulation.

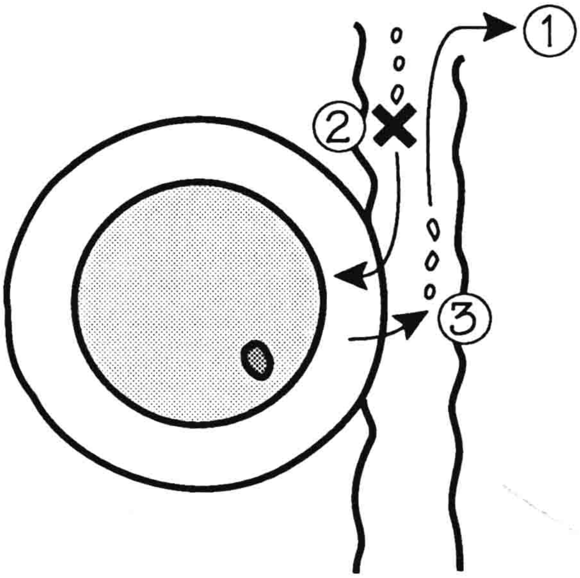
Intestinal losses are not "physiological" (as are losses from skin or lung), and are related to pathological states where vomiting or diarrhea occur.



The normal intestine absorbs fluids that are ingested (1); secretes large amounts of digestive fluids (2); and then reabsorbs virtually all that it secretes (3).

The fluids in the intestine are separate from the E.C.F., but because of the large surface area of the intestinal mucosa and its close contact with the E.C.F. compartment, potential fluid losses from the E.C.F. into an abnormal intestine can be large.

If mucosal function is disturbed, the intestinal wall can cease to be a barrier to the E.C.F. with the result that diarrheal losses or losses into a dilated bowel, as in paralytic ileus, represent direct losses from the E.C.F.



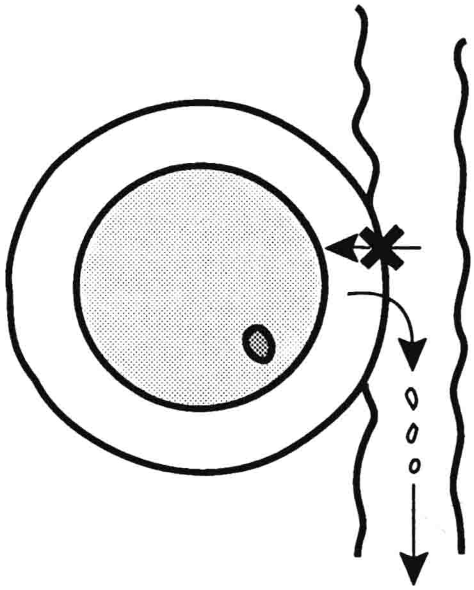
Vomiting:

Vomiting causes fluid loss in three ways:

1) By ejecting fluids already taken by mouth.

2) By limiting further intake of normal fluid volumes.

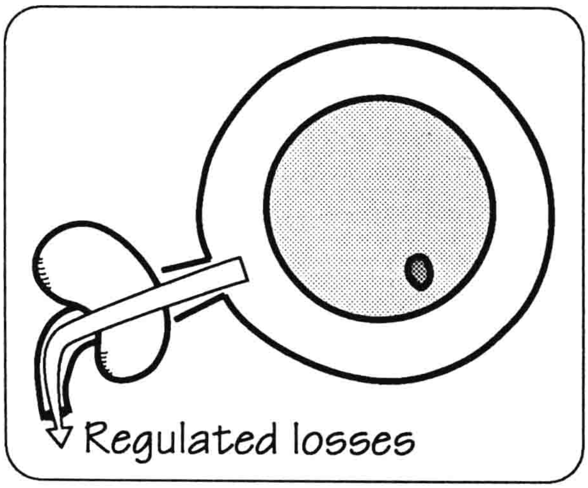
3) By the ejection of fluids secreted into the upper intestine, primarily the gastric juices.



Diarrhea:

Diarrhea involves the failure to reabsorb the fluids secreted into the intestine and often a change in the permeability of the mucosa. This allows the intestine to become the site of what, in effect, are direct losses of E.C.F. The resultant intestinal losses (either up or down) tend to be isotonic with respect to the E.C.F.

It is only from the terminal part of the large intestine that diarrheal losses are hypotonic and therefore reflect losses of free water rather than E.C.F.

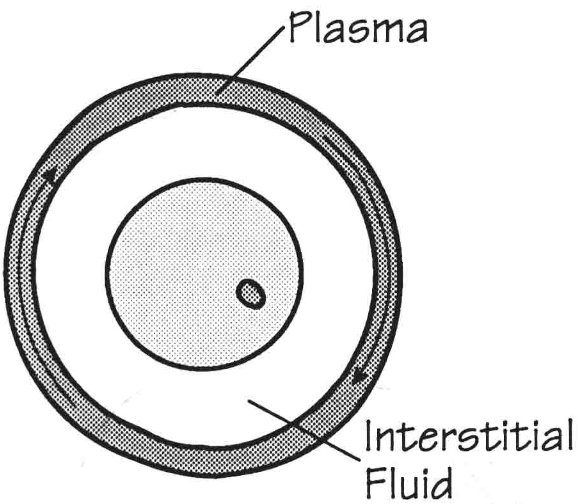


The Kidney:

Losses from the lungs, skin and intestine are not open to tight physiologic control and are determined by changing environmental events.

Only the losses from the kidney can be regulated precisely and this organ therefore plays a crucial role in the regulation of the E.C.F. volume in health and disease.

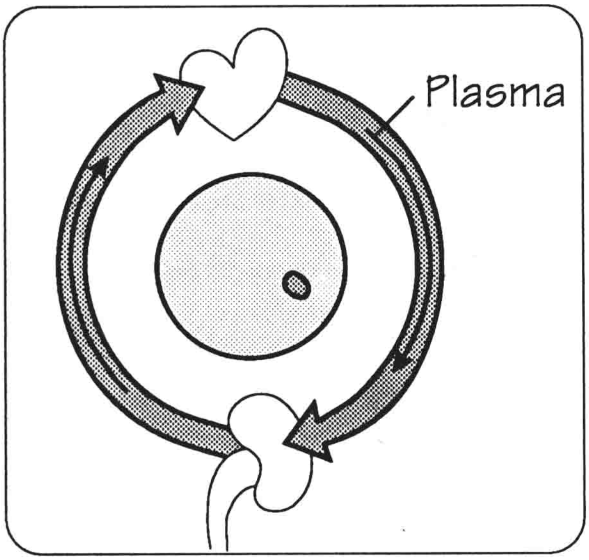
Subdivision of E.C.F.



The E.C.F. is more complicated than we have indicated so far since it can be subdivided into two compartments.

One, the larger part, contains the interstitial fluid which surrounds the cells closely and intimately.

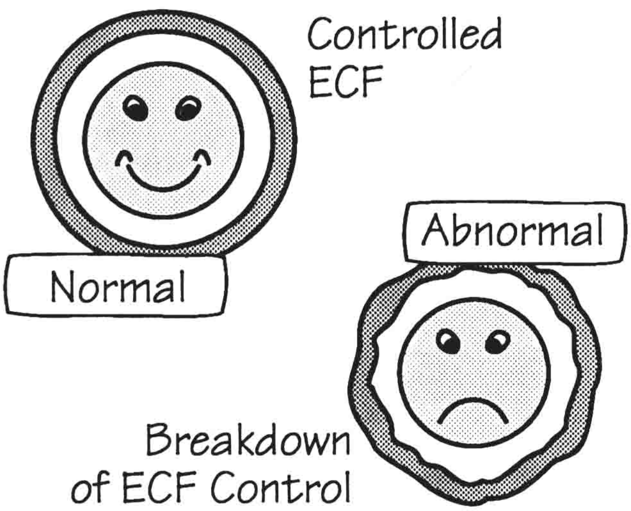
The second contains the plasma which, of course, circulates throughout the body and can therefore act as a "bulk transporter" of water and solutes in the E.C.F. It can also serve as a route for the even and rapid distribution of very small quantities of substances such as hormones and drugs. It is separated from the interstitial fluid by the walls of the capillaries.



Circulation within the plasma compartment is uni-directional with the heart serving as the pump which ensures its continued movement.

In some diagrams we will show the plasma compartment as in this diagram which indicates the importance of the heart as a pump for the plasma and the kidney as a sensor and regulator of its volume.

The link between heart and kidney is precise and intimate. Mechanical factors (e.g. flow and pressure) neurogenic factors (via autonomic nerves) and humoral factors (e.g. aldosterone and atrial natriuretic peptide) provide this linkage.

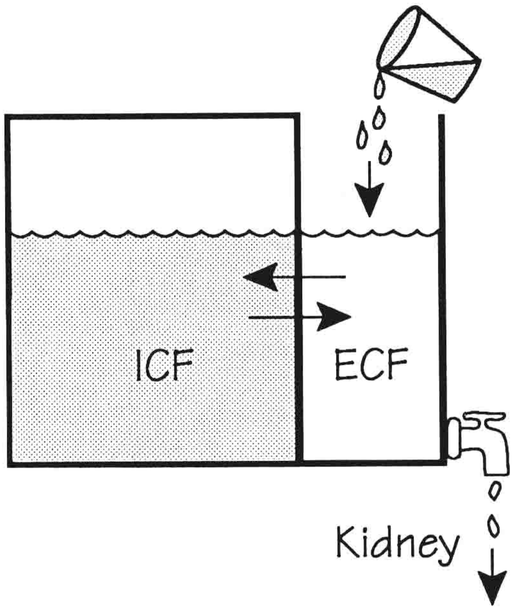


In normal health, changes in the volume and composition of the E.C.F. are within narrow limits and changes in the E.C.F. compartments complement each other.

In this setting, the I.C.F. is effectively protected from surrounding environmental change.

In abnormal clinical situations, changes in volume and composition of the E.C.F. become wider, and the balance between the E.C.F. compartments may become disturbed.

In this setting, the volume and composition of the E.C.F. varies outside narrow limits of tolerance and the cells can no longer rely upon a constant surrounding environment.

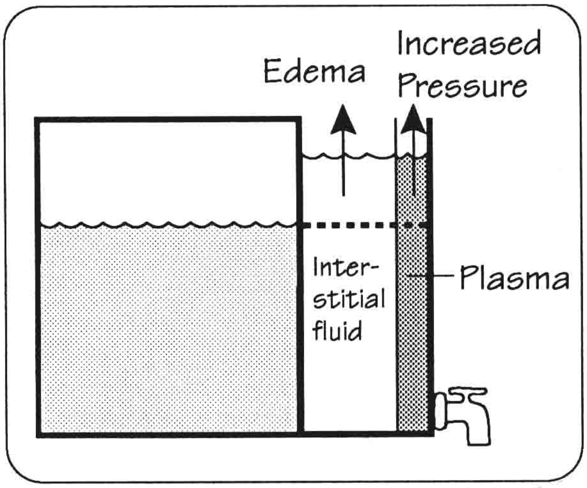


The Tank Model

Whilst in reality the E.C.F. surrounds the I.C.F. like a shell, it is often more convenient to depict the compartments as shown here.

The I.C.F. is drawn as a closed space which indicates that there are limits to its ability to expand, and that the only way into and out of the I.C.F. is via the E.C.F.

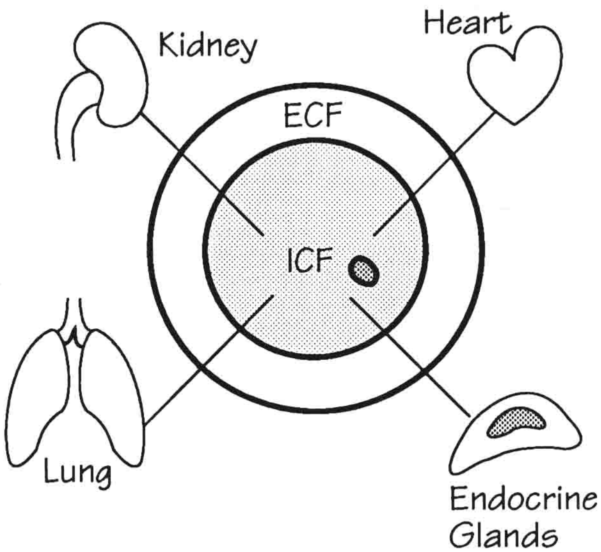
The tap represents the kidney and the horizontal wavy line the normal level of the fluid volume in each compartment.



The E.C.F. includes the plasma and interstitial fluid compartments.

Expansion or contraction of these spaces can be recognized by such changes as the presence or absence of edema (for the interstitial space) or changes in venous or arterial pressure (the plasma space).

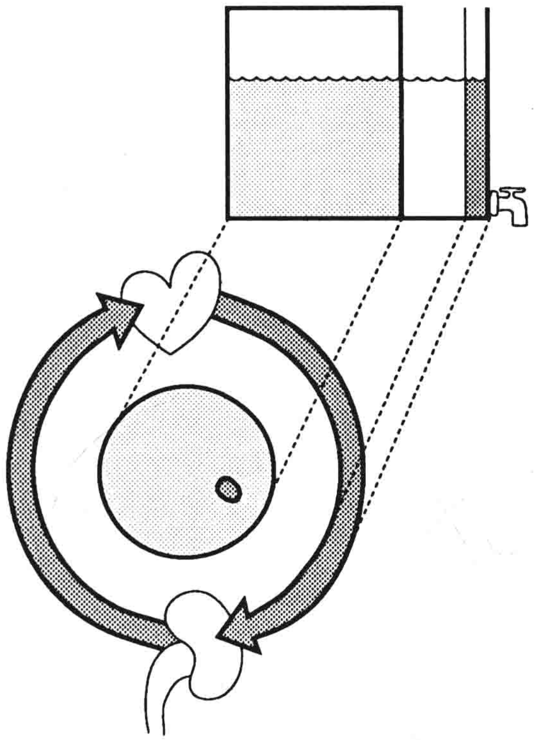
These will be reviewed in more detail in Chapter 3.



Cells as Regulators

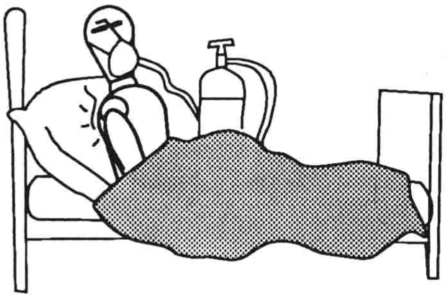
Whilst the body cells in general are protected from environmental changes by the constancy of the E.C.F., some of the cells in the body are specially adapted to have a major role in regulating volume and composition of the E.C.F.

These include cells of organs such as the kidney, the lung, the heart and the endocrine glands.



The Purpose of this Book

This book is about the body fluid compartments and the principles governing the regulation of both their volume and composition. It is concerned with concepts, and not with the details of distribution of every solute in every body compartment.



These concepts are fundamental to the understanding of the practical management of disorders of the body fluids. They can be related to such widely differing situations as heart failure and massive diarrhea due to cholera.

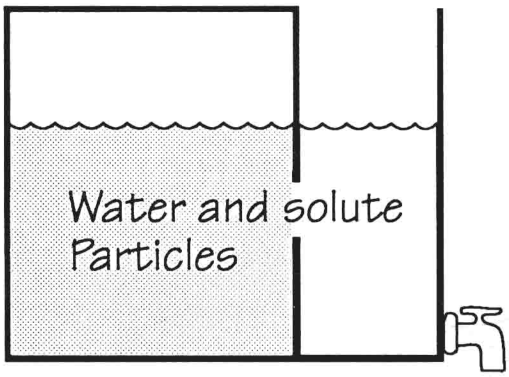
They can be applied to the understanding of diuretics, diabetes and drug distribution.

They are, quite simply, basic building blocks for good medicine.

Coming to Terms with Terms

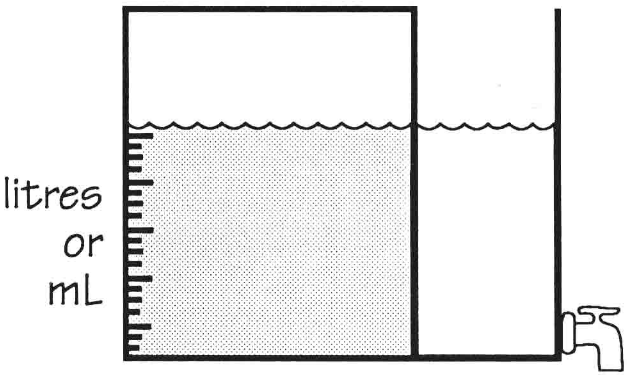
Before going any further into the distribution and regulation of fluids and electrolytes, it is important to understand their measurement and the units by which they are expressed. The problem here is that changes have occurred as the S.I. system of units has been introduced. "S.I." stands for Systeme International des Unitės which attempts to relate all units of measurement to seven "base units". Where such units, together with the units derived from them, are applicable to clinical science they have been introduced as a rational advance. The rate at which these units have been introduced and accepted in clinical practice was more rapid in Europe than North America and the completeness with which they will be accepted is not yet clear. For these reasons, the terms used in clinical medicine are not "pure" and for the time being this is likely to remain the case. This chapter will attempt to clarify the concepts of current usage, with the understanding that the S.I. system is likely to become more widely used as time passes.

There remains a major dichotomy in North America where S.I. units are now universal in Canada but not in the United States. Those involved in clinical care must accept the need to be aware of both systems for some time to come.



Body Fluids

All body fluids are aqueous solutions and therefore consist of water (the solvent) and dissolved particles (the solutes).



Water - The Solvent

When we talk about a "volume" we mean a volume of water and its dissolved solutes. Water can be regarded as the major solvent for biological systems. The volume occupying any "space" or "compartment" is measured in litres (L) or millimetres (mL).