THE PLACE OF ELECTROLYTE STUDIES IN SURGICAL PATIENTS*

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During the past generation surgery has made rapid strides as a result of concentrated attention to the problems of abnormal physiology in patients with surgical diseases. Better understanding of the control of shock, more adequate attention to water and electrolyte balance, and improved anesthesia have been more important than the concurrent advances in surgical technique in giving the surgeon relatively safe access to the contents of the thorax and the brain, the last two anatomical frontiers to be attacked in the evolution of modern surgery. As a result of this shift in emphasis, the surgeon is now called upon as never before to master the practical applications in surgical therapy of fundamental biochemical and physiological methods, particularly if he is unwilling, as are most well-trained surgeons, to turn over to his medical colleagues the nonoperative aspects of surgical care. The surgeon who is willing to relinquish his responsibility for pre- and postoperative care of his patients is in danger of becoming nothing more than a technician and merits no place in the company of scientific medicine. It must be realized that few surgeons are likely to possess the fundamental training in biochemistry and physiology to bring forward new contributions in this field of research. However, it is entirely appropriate and, in fact, essential that surgeons assume the responsibility for applying to their clinical problems the knowledge which has been gained in the preclinical laboratories and the parallel research efforts of their medical colleagues. The topic of the present symposium provides a particularly apt illustration of this thesis. Surgeons must share to a large extent the indebtedness which all fields of medicine owe to Folin, Gamble, Peters, Van Slyke, Darrow, and all of their disciples. The work of these individuals laid the foundation for our present understanding of the prob-

* Read at the Stated Meeting of The New York Academy of Medicine, December 2, 1948.
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The Surgical Metabolism Unit is financed in large part by a grant-in-aid from the Research Grants Division of the U. S. Public Health Service.

lems of fluid and electrolyte balance and no discussion of this subject could be complete without frequent references to their work. However, many of the data which they have recorded, and many of the interpretations based upon these data, are concerned particularly with diseases more frequently encountered by the internist or pediatrician than by the surgeon, and in order to develop the rules of management of conditions of a peculiarly surgical nature, it has been necessary that some surgeons should themselves participate in studies in this general field. Significant contributions in this field have been made by a number of surgeons, including Coller and Maddock, Moore, Moyer, Evans, and Abbott, all of whom are still carrying on active work.

Certain general differences could be pointed out between the problems encountered in surgery and those encountered in the fields of internal medicine and pediatrics. In the first place, the surgeon is more frequently confronted with rapid external losses of body fluids and the resulting intercompartmental shifts between circulating blood, extracellular space, and intracellular fluid compartments. Although most surgical patients enter the hospital with fairly normal kidney function, adequate at least for the prevention of shifts in the hydrogen ion concentration of the blood such as might occur in ordinary degrees of dehydration, the surgical patient is subject to transient disturbances in renal function due to trauma and anesthesia. Very possibly the largest number of problems for the surgeon derive from his dependence upon parenteral fluid therapy at some time during the course of management of every patient undergoing a major operative procedure. A not insignificant proportion of his difficulty in this area may in fact be a *result* of the fluid replacement therapy which he employs, particularly if a selection of fluid has not been based on adequate knowledge of the nature of the existing imbalance. The surgeon must constantly be concerned with the effects of trauma and of operative procedures and anesthesia upon renal function and must recognize that the consequences of over-administration of salt and water during periods of renal dysfunction are just as dangerous as the state of dehydration itself. Edema of the soft tissues and especially of the bowel and the lung is notoriously productive of difficulties for the surgeon, and in the final analysis may account for a significant proportion of postoperative deaths. In recently reviewing a series of case histories of patients dying after radical surgical procedures on the pancreas and duodenum, we have been impressed with the large number who displayed evidences of improper management in respect to salt and water metabolism. Furthermore, during the past two years, with better attention being given to the avoidance of excessive salt and water replacement, we have been gratified to observe a sharp reduction in the operative mortality from these procedures. We may say without hesitation that the surgeon who is ambitious to maintain his mortality at an irreducible minimum must be just as much concerned with the necessity for physiological fluid replacement therapy as with the technical details of the surgical procedure itself.

The clinical problems of electrolyte balance in surgery fall into three main categories; first, the pre-operative correction of dehydration and electrolyte losses due to the patient's disease. In this category are pyloric stenosis, intestinal obstruction, peritonitis, pancreatitis, and severe burns. Second, the prevention and treatment of imbalance due to the operative procedure and its immediate sequelae. As examples of this, one might cite the ileostomy, the biliary or pancreatic fistula, and the employment of tube drainage of any portion of the intestinal tract. Finally, there is the group of problems mentioned above which derive from improper fluid replacement therapy. The significance of problems in this last category has only recently begun to be appreciated and will receive special emphasis in this discussion.

During the past eighteen months we have maintained on our surgical service a segregated five-bed metabolism ward which is adequately staffed with nurses and technicians so as to permit complete nitrogen and electrolyte balance studies directed toward the solution of some of the major problems in pre- and postoperative care. The original data presented in this paper are a product of the combined efforts of the team of workers assigned to this unit. One of us (H.T.R.) has been particularly concerned with the application to surgical problems of recent knowledge as to the significance of sodium and potassium shifts following periods of dehydration. This work has been made possible by the availability of an accurate flame photometer[1, 2] for direct measurement of sodium and potassium in body fluids, and the work here reported would not have been possible without access to this instrument. The time will undoubtedly come when this instrument will be an indispensable item of equipment in every clinical laboratory. Many of the previous errors in the assessment of the patient's electrolyte status have been due to almost exclusive reliance upon measurements of chloride and bicarbonate concentrations. Even application of the formulas for indirect calculations of the total base are subject to substantial errors and at the same time fail to give any rêpresentation as to the absolute amounts of sodium and potassium in extracellular fluid. Obtained primarily as a research instrument, the flame photometer has now become so essential to the day-to-day management of our regular patients that it has been necessary to install a second instrument for routine laboratory use.

In presenting this subject no apologies are offered for employing the terminology which has been widely popularized by Gamble and other investigators cited above.[3] In this terminology the concentrations of the various electrolytes are expressed in terms of milliequivalents per liter rather than in terms of milligrams per 100 cc. of fluid. A very brief discussion of the chemical background for this terminology may not be amiss before proceeding with this discussion. Turning back our none-too-facile memories to the college course in inorganic chemistry we may recall that a molar solution is one comprising the molecular weight of a compound in a liter of water. A milliequivalent of an ion is 1/1000 of its atomic weight, so that a milliequivalent of the positively charged sodium ion is 23 milligrams. This combines in a liter with a similarly calculated figure for the negative chloride ion, which is 35.5 mgms. to make a total of 58.5 mgms. of NaCl, or a millimolar solution. In discussing concentrations of the various electrolytes, their relationship, or equivalence to one another, is of paramount importance because in the plasma of a normal individual, the sum of the positively charged ions bears a constant and approximately equal relationship to the sum of the negatively charged ions. Variations in this relationship can occur only in conditions of uncompensated acidosis or alkalosis. When chloride ions are lost by vomiting hydrochloric acid, the deficiency of chloride in the extracellular fluid is met by an increase in HCO_3 ions to exactly the same number. Transposition of concentrations as milligrams per cent to milliequivalents per liter may be made by the employment of formulae derived for each electrolyte from its atomic weight and valence and in making the transition from one system to another, it may frequently be necessary to apply such calculations. It is realized that the use of this terminology has not yet become wide-spread among surgeons, but application of newer knowledge in this field makes it imperative that surgeons start thinking in these terms. Relations of ions in equilibrium with one another is fundamental to intelligent management of electrolyte studies, and it is impossible to move about in this field of knowledge without the use of modern tools of terminology. The time has come when editors of surgical publications and books should require the expression of electrolyte values in the terms of milliequivalents and millimoles per liter. The change would be no more complicated than that which has been successfully accomplished in transferring from the apothecary's system to the metric system in gravimetric and volumetric expressions.

There is no problem in surgery in which electrolyte studies are more essential than that of the dehydrated patient. However, when a patient comes in with dehydration due to prolonged vomiting, diarrhea, a severe burn, or water deprivation from any cause, the first step is necessarily to establish the diagnosis, but correction of the dehydration should not be delayed while diagnostic studies are being carried out. It is especially important to deal with dehydration promptly if it seems probable that an operative procedure will be required to correct the patient's disease, because dehydrated individuals are notoriously poor-risk subjects and are extremely vulnerable to anesthesia, blood loss, and shock. The dehydrated patient has a reduced blood volume, and a reduced interstitial fluid reserve together with an increased viscosity of the blood, so that the volume flow of blood through the tissues and vital organs is already compromised, and if one adds to this the consequences of anesthesia, transient hypotension, and further reduction in blood volume, the outcome is costly. However, the type of fluid replacement needed and the amount of fluid required will vary significantly according to the degree of dehydration and the source of the water loss. Figure 1, taken from an article of Dr. William Abbott,[4] shows diagramatically the volumes of fluid normally available for external loss at different levels of the gastro-intestinal tract. However, the composition of gastro-intestinal secretions varies at the different levels of the tract, and it makes a big difference whether the dehydration is due to pyloric obstruction, when acid gastric secretions are predominant in the fluid-loss, or whether the lesion is a low intestinal obstruction, where the predominant portion of lost fluid is the alkaline secretion of the small bowel. Also the relative amounts of sodium, potassium, chloride, and bicarbonate lost will vary according to the

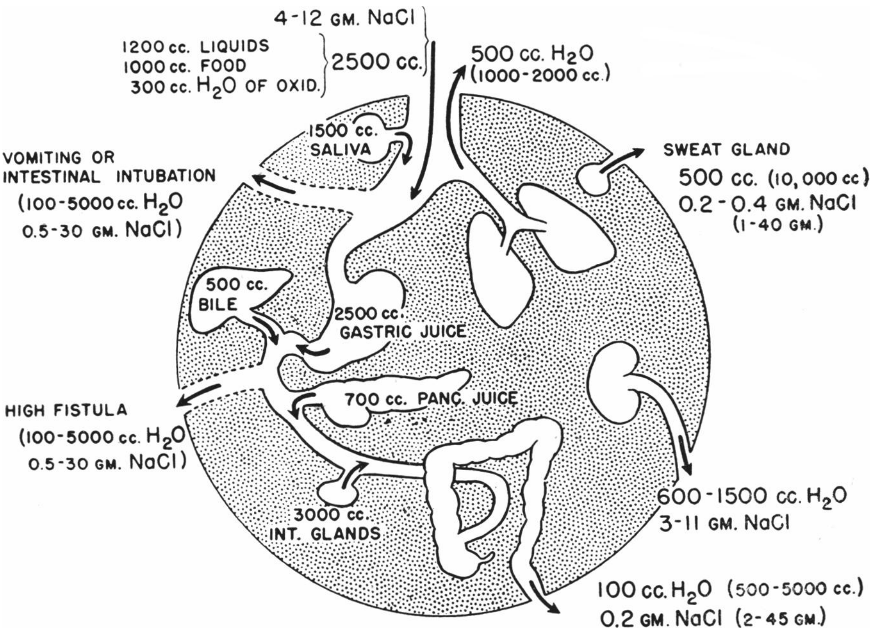

Fig. 1—Quantitative aspects of fluid and salt exchange in health and disease. (Abnormal losses indicated in parenthesis) From Abbott, W. E., Am. J. M. Sc., 211:232, Feb. 1946.[4]

route of the loss. Table I depicts the composition of fluids withdrawn at different levels of the gastro-intestinal tract. The average values as we have found them are shown together with the extreme range of values which we have encountered in the course of an eighteen-month study of surgical patients. One must guard against assignment of absolute significance to any of these figures because a given lesion rarely drains fluid exclusively from one segment of the gastro-intestinal tract; for example, in an obstructing lesion of the upper jejunum, the vomitus will contain considerable amounts of succus entericus, bile, and pancreatic juice, along with gastric juice. It therefore becomes essential in proper clinical management of such patients to determine the actual concentrations of electrolytes both in the plasma and in the vomitus or other drainage fluid and in the urine as well. Still further information may be obtained through the hematocrit reading, through measurement of the hourly volume flow of urine, and through determination of the plasma volume by the Evans blue-dye technique. The latter determination will be of less value as an absolute depiction of the

TABLE IA—G.I. TRACT LOSSES M.Eq. PER LITER

	Na	*K*	*Cl*
GASTRIC	60.4	9.2	84.0
(Fasting)	9-116	0.5-32.5	7.8-154.5
SMALL BOWEL	111.3	4.6	104.2
(MA Suction)	82.-147.9	2.3-8.0	43-137
ILEOSTOMY	129.4	11.2	116.2
(Recent)	105.4-143.7	5.9-29.3	90-136.4
ILEOSTOMY (Adapted)	46	3.0	21.4
CAECOSTOMY	52.5	7.9	42.5
FORMED STOOL	<10	<10	<15

Electrolyte composition of gastro-intestinal fluids. (Upper figure indicates average; lower figure indicates range of observed values.)

TABLE IB—BILE AND PANCREATIC FISTULAE

	Na	*K*	*Cl*
BILE	148.9	4.98	100.6
	131-164	2.6-12	89-117.6
PANCREAS	141.1	4.6	76.6
	113-153	2.6-7.4	54.1-95.2
URINE Normal	40-90	20-60	40-120
URINE Path.	0.5-312	5-166	5-210
TRANSUDATES	130-145	2.5-5.0	90-110

(Upper figure indicates average; lower figure indicates range of observed values.)

degree of reduction in plasma volume than as a baseline upon which to evaluate the adequacy of subsequent rehydration. Also the determination of the total red cell mass as calculated from hematocrit and plasma volume is of considerable value in determining the volume of blood transfusion which should be administered in conjunction with efforts at rehydration. Performance of these biochemical and physiological tests imposes a severe strain on the professional and technical staff of any hospital, but they have become an integral part of surgical management and success in dealing with severe problems of electrolyte imbalance in surgical patients cannot be attained simply by guess-work.

However, there are a few simple principles the observance of which will keep to a minimum the volume of laboratory work required and, more important, will help to keep the surgeon and his patient out of trouble. The balance of this paper will be devoted to emphasis of such points.

1. *Changes in the weight of the patient from day to day are a very useful index of over-all changes in hydration.* Although every effort should be made to measure and record accurately on the hospital chart the total volumes of both intake and output of everything which enters into daily fluid balance, there are often inaccuracies in such measurements. The total insensible loss and loss through perspiration can only be estimated very crudely, and drainage fluids and urine are frequently lost on dressings and bed clothes. The practice of early ambulation makes it possible to record daily patient weights even during the immediate postoperative period. A set of scales with a limit of accuracy of ½ pound is sufficient to obtain the relatively crude appraisal which is all one seeks by this method. In the case of a dehydrated patient it is possible to trace a successful effort at rehydration by progressive weight gain—which in a critical situation might be as much as 3 or 4 kilograms in 24 hours. On the other hand, the patient whose fluid regimen requires alteration because of the development of edema should undergo progressive weight loss if the new regimen has been well designed. Sudden changes in weight must always be accounted for, and unless other obvious causes exist, diurnal variations in excess of one half a kilogram are almost certainly attributable to loss or retention of body water. Attention then turns immediately toward meeting any pathological losses or gains by supplying more or less of whatever type of fluid is concerned.

2. *Every effort should be made to administer fluids by mouth in preference to parenteral routes* whenever the patient's disorder does not contraindicate use of the gastro-intestinal tract. The patient's actual needs for a substance such as salt are likely to be met more accurately by the dictates of his taste for salt than by the calculations of even the most solicitous surgeon, especially if accurate laboratory data are not continuously at hand. Furthermore, there is much less danger of having to meet the consequences of over-treatment if advantage is taken of the "intelligence" of the normally functioning gastro-intestinal tract. When we give sodium chloride solution as the sole source of electro-

lytes, we are failing to provide the significant amounts of potassium, magnesium, calcium, and other electrolytes present in natural foods, and, as will shortly be seen, knowledge is only beginning to catch up with the role of these inorganic ions in metabolism.

3. *Sodium chloride is a potentially dangerous drug, which is frequently indispensible in preserving life, and should be used with respect on both counts.* The normal intake of sodium chloride is generally given as about 2 to 4 grams per day and is approximately the amount excreted daily by the kidneys. This would be equivalent to 250 to 500 cc. of the usual so-called "normal saline" solution. Only under severe conditions of exposure to heat, such as might be encountered in a South African diamond mine, would the physiological requirement of salt for a healthy individual rise to equal the amounts which are often given to surgical patients in 2 or 3 liters of saline solution. Where there is an inability of the kidneys to retain sodium, as in Addison's disease, or where there is an extensive external loss of body fluids which contain sodium, the requirements of NaCl replacement are necessarily increased correspondingly and might even equal the quantities cited.

Specifications of proper requirements of sodium chloride for surgical patients have followed several swings of the pendulum between the extremes of inadequate and excessive salt therapy. However, much of the difficulty which surgeons have encountered has been due to over-reliance on sodium chloride alone in meeting electrolyte deficits. In 1938 Coller and his associates[5,6] proposed that hypochloremic patients should be given 0.5 gm. of salt per kilogram of body weight for each 100 mgms. that the plasma chloride level needs to be raised to reach the level of 560 mgms. per cent. Application of this rule might call for the administration of as much as 70 gms. of sodium chloride to a large individual who had a reduction of plasma chloride to a level of 360 mgms. per cent. The authors recognized that the need for sodium might not be identical with the need for chloride but stated that the normal kidney was perfectly capable of excreting sodium chloride given in excess of that actually required and that therefore it was desirable to err on the side of too much rather than of too little. However, in 1944 Coller[7] and his associates published an article on postoperative salt intolerance in which they retracted this clinical rule for salt administration and called attention to the inability of the kidney to excrete sodium chloride during the immediate postoperative period. They reported a number of cases in which the application of their previously enunciated rule had resulted in serious over-hydration. Coller's new recommendation was that no saline solution of any kind be given during the day of operation and during the subsequent two postoperative days. It was further recommended that if a significant loss of extracellular fluid occurred during this three-day period, it should be replaced with 0.5 per cent sodium chloride solution containing 5 per cent glucose. It was his impression that at least 48 hours were required for the recovery of the kidney from the effects of the operative procedure and that during this interval great care should be exercised in the administration of salt. Administration of sodium chloride above that so required seemed prone to predispose to atelectasis, pulmonary edema, and intestinal dysfunction. Attention was called to the importance of careful observation of the physiological response of the dehydrated patient to test doses of salt solution rather than to reliance exclusively on laboratory determinations of the various electrolytes and other plasma constituents. Further emphasis on the significance of postoperative salt retention was supplied by Van Slyke and his colleagues[8] who pointed out that significant changes in renal function took place following periods of reduced renal blood flow such as might occur during the course of any major surgical procedure. Numerous students of the physiological mechanisms of cardiac failure have emphasized the effect of altered renal blood flow on salt retention and have even gone so far as to suggest that the edema of cardiac failure is due to renal dysfunction rather than to simple dynamic considerations, as had been previously assumed. Borst[9] suggests that salt retention by the kidney may be a protective mechanism designed to assist in the maintenance of plasma volume in shock and hemorrhage or in any situation in which cardiac output is decreased, a view similar to that originally held by Starling. Our own observations have confirmed the presence of marked impairment of renal blood flow during operative procedures and the subsequent tendency toward transient retention of sodium. One recent patient of ours excreted only traces of sodium for a period of 11 days during which the volume output of water and of chloride ion was approximately normal. The plasma sodium level was kept within normal limits only by rigidly excluding all sodium chloride from her fluid regimen. This case illustrates an important limitation of the Fantus test for urine chloride, as recently

TABLE II—COMPOSITION OF PARENTERAL FLUIDS
M.Eq. Per Liter

	Na	*K*	*Cl*	*Effective HCO_3*
0.85% NaCl	146	0	146	0
.9 % NaCl	154	0	154	0
110 Na+30 K	110	30	140	0
1/6M Na Lactate	166	0	0	166
NH_4Cl*	0	0	100	0
Dextrose+KCl**	0	30	30	0
Darrow's Solution	120	35	105	50
Hartman's Solution***	136	5.3	112	33
Dextrose in Water	0	0	0	0
Amigen	34	......	34	......
NORMAL Plasma	140.8	4.28	103	27.6

* 0.5% NH_4Cl+5% Dext.
** 0.223% KCl+5% Dext.
*** 3.6 meq/1Ca++

Electrolyte content of certain parenteral fluids compared with that of normal plasma.

repopularized by Van Slyke and Evans.[10] It is important to call attention to the fact that the kidney may retain sodium and yet excrete chloride in nearly normal amounts, so that the patient's need for sodium may be quantitatively quite different from his need for chloride ion. The results of a test for chloride in the urine may not reflect the condition of sodium balance. Our choice of fluids for electrolyte replacement must therefore be sufficiently flexible to separate these two requirements as necessary in special circumstances. Except when confronted with the problem of correcting or preventing an obvious deficit in body water, a patient should not be given more than his normal 2 to 4 gms. of salt a day or 250 to 500 cc. of saline. Additional requirements of fluid should be met with 5 per cent dextrose in water and additional amounts of salt should be given only upon clearcut indications therefor.

Electrolyte losses from the different levels of the gastro-intestinal tract may be compensated by the administration of fluids better designed than plain sodium chloride solution to meet the deficiencies likely to occur. In Table I is shown how the electrolyte composition of the various gastro-intestinal secretions varies in respect to sodium.

TABLE III—PARENTERAL FLUID REPLACEMENT

	Dext./W	*Dext./Sal*	*M/6Na Lact.*
GASTRIC	33%	67%	....
SMALL INT.	20%	70%	10%
ILEOSTOMY	10%	75%	15%
BILIARY	....	67%	33%
PANCREATIC	....	50%	50%

Above solutions employed for volume-for-volume replacement of calculated losses. Basal intake should be 1500-2500 cc. with not more than 500 cc. saline.

Formulae which approximate average requirements in volume for volume replacement of gastro-intestinal fluid losses.

Table II shows by contrast the composition of some of the fluids which are available from our own Solution Room. Of these, only Hartman's solution approximates the electrolyte composition of extracellular fluid (plasma). Since it is convenient to replace the volume of fluid lost with a similar volume of replacement solution, it is suggested that the formulae indicated in Table III be employed. All three solutions are readily available in any hospital. When compensating for losses from the stomach on a volume-for-volume basis, it is wise to dilute "normal" saline solution with dextrose in water. When the drainage is from the small bowel such a mixture contains too much chloride, and a small part of 1/6 molar sodium lactate is added. The proportions of lactate increase progressively in the cases of ileostomy drainage, biliary and pancreatic fistulae, respectively. Since the ratio of sodium to chloride loss in pancreatic fistulae is approximately two to one, the appropriate mixture for the latter is equal parts of sodium chloride and sodium lactate. If these mixtures are given in amounts equal to volume of loss and the basal fluid intake is provided as indicated on the table, it is possible to anticipate and avoid some of the most troublesome sequelae of dehydration and over-hydration.

An especial word of caution is needed in regard to salt therapy in patients with low plasma protein levels. The tendency of the hypoproteinemic individual to hold extra water in the extracellular fluid is particularly aggravated in the presence of normal or high levels of plasma sodium. Although hypoproteinemic edema can be partially combatted by simply withholding salt and permitting the sodium level to fall, the ideal treatment is to administer a high protein diet, and to meet the immediate protein deficit with transfusions of blood, plasma, or albumin. Otherwise, correction of the edema is gained at the expense of a reduced circulating blood volume which is in itself a serious handicap to the patient. It is in the hypoproteinemic patients that improper salt therapy is most likely to result in severe gastro-intestinal and pulmonary edema with marked dysfunction of both systems. Rhoads and his colleagues[11] at the Memorial Hospital encountered intractable hypochloremia in hypoproteinemic subjects and were able to correct this hypochloremia with sodium chloride until steps had been taken to restore the plasma protein level to normal. The question may now be raised as to whether these workers were dealing with simple chloride deficits or whether they were in fact confronted with associated potassium deficiencies, a syndrome which we now suspect may be frequently encountered in surgery.

4. *Severe dehydration is associated with loss of intracellular potassium and the patient cannot be restored to health until this potassium deficit is corrected.* Several years ago Darrow[12] called attention to the potassium deficits existing in infants after severe diarrhea and demonstrated that rehydration of these infants must be accomplished with fluids containing potassium as well as sodium. Very substantial reduction in mortality occurred when a combined electrolyte solution was administered in comparison with the mortality rate in patients treated with sodium chloride alone. When the flame photometer became available to us eighteen months ago, we commenced a study of the implications of Darrow's work in surgical patients with results which have been of considerable interest to us. According to Darrow's balance studies, there is a considerable loss of intracellular potassium consequent to the withdrawal of intracellular water in patients whose dehydration has gone beyond simple depletion of extracellular fluid. If sodium chloride solution is then given in amounts sufficient to rehydrate the individual, sodium moves into the cell to replace the lost intracellular potassium. This tends to produce intracellular edema and probable interference with many of the normal metabolic functions of the cell. However, the intracellular sodium can in turn be displaced and returned to its normal extracellular position if sufficient amounts of potassium are given before irreversible changes have occurred. In surgical patients

who are sometimes dependent for many days on parenteral fluids, a potassium deficiency can apparently occur even without the appearance at any time of marked dehydration. This is due to the fact that excretion of potassium by the kidneys goes on at a fairly regular rate of 10 to 20 milliequivalents per liter even in the absence of any potassium intake, the source being entirely endogenous. When the patient's balance requirements of calories and proteins are not being met, as is usually the case in surgical patients, a portion of this potassium loss reflects the nitrogen losses due to tissue catabolism. Furthermore, potassium is present in significant amounts in gastro-intestinal secretions and is especially high in pancreatic juice and bile. Therefore, if a draining fistula is present or if the patient is on gastro-intestinal intubation drainage, such additional losses of potassium will be added to those in the urine. A normal diet would ordinarily contain more than enough potassium to offset such losses. However, the patient who continues to be dependent on parenteral fluids for several days will tend to build up a cumulative potassium deficit equal to many times the normal potassium content of extracellular fluid, a total of only about 50 milliequivalents.

Although the clinical picture of potassium deficiency cannot yet be clearly defined, these patients are usually markedly asthenic and listless and in extreme cases will show myasthenia similar to that occurring in familial periodic paralysis, another potassium deficiency syndrome. Many of these patients give evidence of intestinal and gastric atony, and they are unable to eat adequate amounts of food. Blood chloride levels are normal or low, blood sodium levels are normal or high, the bicarbonate concentrations vary reciprocally with the chloride but are usually high in spite of the co-existence of an acid urine.[13] We now recognize that many patients who formerly did badly after major operative procedures, and who eventually succumbed, were probably suffering from this basic disorder in metabolism. Fortunately, the response of patients with potassium deficiency to adequate potassium therapy is prompt and frequently dramatic. Immediately after commencement of replacement therapy with a solution containing 30 milliequivalents per liter of potassium chloride, the patient displays an improvement in strength and appetite and usually within three to four days there is a marked diuresis with the excretion of a considerable quantity of sodium, presumably that which had become displaced from its unphysiological intracellular depot. We have seen several patients become transformed within five to seven days and restored to full health after having previously been in a condition where recovery was despaired of. Caution must always be exercised in administering potassium-containing solutions because of the dangerous consequences of inducing an increase in plasma potassium to levels as high as 9 or 10 milliequivalents per litter, when heart block may occur. However, we have not observed such consequences in the patients we have studied, even though we have given as much as 120 milliequivalents of potassium, or 9 grams, within a twenty-four hour period to patients in whom a serious demonstrated deficiency existed. The specific contraindications of intensive potassium therapy are in those states where blood potassium levels are already high—namely, acute dehydration, severe burns in acute phase, intestinal obstruction, severe renal insufficiency, and during the first twenty-four hours after a severely traumatizing operative procedure. In these conditions the administration of potassium becomes safer after steps toward rehydration have become effectively under way. It is possible that the inclusion of a small amount of potassium, say 5 milliequivalents per liter, or .04 per cent, in all parenteral fluids might be the best means of preventing the development of such severe deficiencies as, once developed, would require therapy with more concentrated potassium solutions. Certainly no danger would exist from giving potassium in such amounts even to patients who did not actually need this ion.

Although much work remains to be done in correlating changes in plasma potassium with changes in potassium content of red cells and muscle tissue, we can now express confidence that the ability to recognize and to deal effectively with this syndrome represents a substantial improvement in the postoperative care of surgical patients.

Summary

The management of problems of water and electrolyte balance is of major importance in surgery because of the numerous instances of dehydration with which the surgeon must deal, and because of the frequent necessity to rely on parenteral fluid therapy for fairly long periods. In meeting these problems the surgeon should be conversant with modern terminology on matters of water exchange and ion equivalents and must receive the benefit of adequate laboratory assis-

tance in following losses and gains of these metabolites. Special considerations of importance are: 1) the usefulness of studying day-to-day changes in weight; 2) the importance of employing natural routes of feeding whenever possible in preference to parenteral routes; 3) the dangers inherent in excessive therapy with sodium chloride, particularly during periods of postoperative and post-traumatic renal dysfunction; 4) the syndrome of potassium deficiency is likely to occur in patients who are given excessive sodium during treatment or prevention of severe dehydration, and in patients carried exclusively on potassium-free fluids for several days.

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