

MAINTENANCE OF FLUID BALANCE*

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IN previous discussions of fluid balance^{1,2,3} emphasis has always been placed upon individualizing the treatment to fit the needs of the patient, and further experience has more firmly established the soundness of this view. If a patient can take fluids by mouth there is generally no problem concerning the maintenance of a good fluid balance, and much of the material in this article has no bearing on such cases. Unfortunately often in emergency situations, for one reason or another, the patient cannot take fluids by mouth and the proper parenteral therapy is in the hands of the physician.

Emergency surgery commonly involves patients who are well up to the time of an acute trauma, and there are often no long standing deficiencies to deal with. In traumatic injuries, shock is of rather common occurrence and its prevention and treatment have been well discussed in the preceding article by Cressman and Blacklock,⁴ who, among other things, point out the dangers of administering large amounts of glucose or saline solutions when shock is present. This will be referred to later, but it here serves well to point out that the administration of fluids in emergency situations requires thought based on facts if one is to select the proper kind and amount of fluid to give.

Considering the kind of fluid to use, the choice is between the saline and glucose solutions, and the important point is that there is possible harm with the use of the saline and practically none with the glucose. The relation of sodium chloride to edema is common knowledge and yet several liters of physiologic saline or

Ringer's solution may be given daily to patients who can ill afford the edema of salt on top of the edema of trauma. Accordingly, a few references to this possible harmful effect of saline solutions are in order.

SALINE SOLUTIONS

White, Sweet, and Hurwitt⁵ studied the water balance of neurosurgical patients in order to be able to maintain them in a slightly dehydrated condition. In their article they state that "edema from too much salt solution is a very real danger. For this reason we recommend limiting the use of glucose in saline to the period of operation, during which there is a considerable loss of sodium chloride. Thereafter, fluids can usually be taken by mouth in adequate volume by neurosurgical patients. Saline solutions should only be used when the serum electrolytes are seriously depleted by prolonged vomiting or diarrhea, and then in limited amounts." In their summary White, Sweet and Hurwitt⁵ state: "postoperatively fluid must be replaced much more accurately in neurosurgical than in general surgical patients. While the latter may be given a moderate excess of fluid with impunity, a slightly deficient state of hydration is safer after operations on the brain, in order to minimize cerebral edema. In the absence of vomiting or diarrhea, 5 per cent glucose in distilled water appears to be a better solution for prolonged intravenous administration than when combined with normal saline, because the addition of saline increases the risk of edema." This reasoning holds equally well for patients with cranio-

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cerebral injuries. Temple Fay⁶ has long been an ardent supporter of dehydration therapy for such patients.

Beard and Blalock⁷ studied the composition of the blood of dogs undergoing continuous trauma to the intestines when no fluid was injected and when fluid was injected continuously. A copious weeping of fluid from the peritoneal surface resulted from the trauma. This fluid had the same protein content as that of the blood plasma, the result being a loss of protein and therefore a diminished osmotic pressure of the blood. The effects of the injection of various fluids on the reduced protein content of the blood of these dogs, which were in shock, is most important. With the continuous injection of 0.9 per cent salt solution there was a decrease in the total volume of blood plasma and a marked reduction in the percentage of protein per unit volume of serum, the calculated entire amount of protein in the blood stream being generally one-half of the original values. It was the impression of Beard and Blalock⁷ that if the injection of salt solution was stopped the blood pressure of the animals declined more rapidly than if no fluid had been introduced. With 3.0 and 6.0 per cent saline solution the results were essentially the same. From these experiments there is little to expect from the treatment of shock due to blood plasma loss by the use of physiologic saline solution. Beard and Blalock state "that they do not mean to imply that if a patient is in shock as a result of an injury and no donor is available that saline or similar solutions should not be injected. However, in the absence of a favorable response in blood pressure after a considerable amount of solution had been injected, almost certainly the further administration of the same fluid intravenously would diminish the chances of recovery."

Another warning concerning too much salt solution arises from a study by Jones and Eaton⁸ on postoperative nutritional edema. Their thirty-four patients were all seriously ill, chiefly with lesions of the

gastrointestinal tract, producing anorexia and undernutrition. Clinical edema was present in twenty-six of the patients, five had definite edema of the lungs, and eight on whom a gastroenterostomy had been done were considered to have edema of the stomach, of the gastroenterostomy stoma or of the adjacent intestine sufficient to produce partial obstruction at the stoma. Among the several factors thought to be responsible for the edema was the administration of excessive amounts of water and salt.

Jones, Eaton and White⁹ then produced edema in cats and considered the factors responsible to be important in the following order: nitrogen starvation, general malnutrition, sepsis, the administration of excessive amounts of water and sodium chloride, serous drainage, major surgical procedures and general anesthesia. Mecray, Barden and Ravdin¹⁰ showed experimentally in dogs that obstruction at the pylorus and at gastroenterostomy stomas could be produced as a result of edema incident to low plasma proteins and that gastric emptying time improved as the proteins increased. Their study emphasized that while edema is clinically an observation of excess fluid in the subcutaneous tissue, it is but an external manifestation of a general process with very definite harmful effect on internal organs.

The ease with which salt solutions are retained by seriously ill surgical patients was further demonstrated by Collier, Dick and Maddock,¹ who provided intravenously about 3500 c.c. of fluid daily to their patients under investigation, using 5 per cent glucose in either physiologic saline or Ringer's solution. At present in their patients selected for study, many seriously ill surgical patients have one or more of the important features setting the background for the retention of water, that is, nitrogen starvation, general malnutrition, sepsis, serous drainage, hemorrhage, impaired hepatic or renal function. But even with these it takes water and sodium ions for the edema to develop,^{11,12} and it was the

impression of Coller, Dick and Maddock¹ that an excess of saline solution had been the precipitating factor in patients seen by them with postoperative edema. In their study group, twelve of the thirteen patients receiving salt solution retained water and gained weight although they were receiving insufficient calories and should have lost weight.

This common error of giving excessive amounts of salt solution to seriously ill patients when sodium chloride is not needed, is one to avoid. It is thoughtless as to the requirements of the patient; the excess amount of salt administered may easily amount to from 30 to 50 or more grams which must be excreted by the kidneys; and finally, the edema fluid is known to impair various functions and be harmful. The surgical staff may well feel guilty in some instances when patients come to autopsy with water-logged tissues.

The discussion so far on saline solutions has pointed out their possible harmful effects. However, everyone realizes that saline solutions must be given to some patients, but they are essentially for patients who have or have had abnormal losses of fluids containing sodium chloride. The most serious of these abnormal losses occur through severe diarrhea, dysentery, and vomiting. The first two are uncommon among surgical patients, while vomiting is the most frequent form of losing substantial amounts of body electrolytes. Other losses from the gastrointestinal tract may occur through biliary or intestinal fistulae, and recently there has been added the valuable therapy of continuous gastro-duodenal suction.¹³ When appreciable amounts of body electrolytes, chiefly sodium and chloride ions, have been lost through any one of these channels, they must be replaced. Evidences of even moderate deficiency are lethargy, depression, weakness, fatigue, anorexia, nausea, dehydration, drowsiness and stupor. With marked hypochloremia several patients at the University Hospital^{14, 15} and elsewhere¹⁶ have shown the complete clinical picture

of shock. The problem is how to restore sodium chloride adequately to these patients without giving too much salt.

At the University Hospital an attempt has been made to keep saline solution therapy on a simple basis, which on repeated studies has been shown to be as accurate as possible and still practical. The problem is divided into two groups, the first covering patients who are in the hospital and while under observation are losing important amounts of electrolytes through vomiting, gastro-duodenal suction, intestinal or biliary fistulae, etc. The second group is composed of those patients who lost their sodium chloride before entering the hospital and on admission are found, after blood chemistry studies, to have low chlorides. There is, of course, some overlapping of these groups, since a patient who has been vomiting before admission to the hospital, may continue to vomit while in the hospital, but then the two methods of treatment are simply combined and both used as needed. They can be considered as follows:

Patients losing important amounts of gastrointestinal secretions while in the hospital have these losses measured. This is not difficult. Bile drained from the common duct or gall-bladder through tubes is readily collected in bottles. Suction is applied to intestinal fistulae and the drainage collected in siphon bottles. Patients who vomit more than once or twice have a Levine tube inserted through the nose and gastro-duodenal suction started, and the amount of fluid withdrawn is readily measured. Also, the use of this gastro-duodenal suction which has been shown by Wangenstein and his associates¹³ to be so effective in intestinal obstruction, is applied to many patients to forestall vomiting or to keep the stomach and intestines decompressed after gastric and intestinal or other operations.

There is thus a frequent need for replacing daily abnormal losses of sodium chloride. Our treatment is based upon the fact that there is less of this salt in the gastro-

intestinal secretions lost than in an equal volume of physiologic saline or Ringer's solution. Data showing the sodium chloride concentrations in the various fluids are presented in Table I, from which it is

TABLE I
CONCENTRATION OF SODIUM CHLORIDE IN VARIOUS FLUIDS

	Variation in NaCl Concentration Gm/L.	Average NaCl Concentration Gm/L.	Reference
Vomitus.....	1.2-6.2	3.3	Dick, Coller and Maddock ¹⁷
Gastroduodenal drainage (Wangensteen suction).	1.9-7.9	5.7	Bartlett, Bingham, and Pedersen ¹⁶ (Analysis of 100 twenty-four-hr. specimens)
Hepatic bile.....	3.5-6.4	5.1	Bartlett, Bingham and Pedersen ¹⁶ (Analysis of 30 twenty-four-hr. specimens)
Intestinal fistula drainage.	3.1-6.6 } 4.7-7.9 } 3.0-8.8 }	5.2	Bartlett, Bingham and Pedersen ¹⁶ Welch et al. ¹⁸
Diarrheal stools.....	3.7-5.2	4.3	Karr and Abbott ¹⁹ Bartlett, Bingham and Pedersen ¹⁶
Physiologic saline solution.....		8.5	U.S.P.
Ringer's solution.....		9.0	University of Michigan Hospital
Ringer's solution.....		7.0	Abbott's Laboratories

apparent that if a patient has a liter of gastroduodenal drainage a liter of physiologic saline or Ringer's solution will replace the water and more than the sodium chloride loss by a fair margin. This volume-for-volume rule is the replacement method used at the University Hospital in such cases. In actual performances two other ideas are incorporated into the procedure. The first is that when gastroduodenal suction is being used, a liter of Ringer's solution is given during the first twenty-four hours, in this way lessening an initial drop in plasma chlorides during this period.^{14,15} For the second twenty-four hours the amount of Ringer's solution given equals the amount of gastroduodenal drainage for the first day, and this volume-for-volume replacement continues with

the addition of the second idea, which is that a minimum of 500 c.c. of Ringer's solution is given daily, even if the drainage for the preceding day is less than this amount. It has been found for general surgical patients having gastroduodenal tube drainage, biliary and intestinal tube drainage that satisfactory plasma chloride and carbon dioxide combining power levels can be maintained by this seemingly rational procedure.^{14,15,20}

For the second group of patients, those with low plasma chlorides when first encountered, the clinical formula^{14,15} for restoring sodium chloride is used. This formula states that: for each 100 mg. that the plasma chloride level needs to be raised to reach the normal (560 mg. per cent) the patient should be given 0.5 Gm. salt per kilogram of body weight. Examples of the use of this formula in three hypothetical cases are given in Table II. Studies have

TABLE II
USE OF CLINICAL FORMULA FOR CORRECTING SODIUM CHLORIDE DEFICIENCY

Wt. of Patient, Kg.	Initial Plasma Chlorides, Mg. per 100 C.c.	Calculation of NaCl Needed, Gm.
60	460	0.5 × 60 = 30
60	410	1.5 × 0.5 × 60 = 45
60	360	2.0 × 0.5 × 60 = 60

been continued on the use of this formula in a large series of general surgical patients, determinations being carried out on the plasma chlorides, plasma carbon dioxide combining power, fluid intake and output, urine chloride excretion, gastrointestinal tract and other fluid chloride losses, and changes in the patient's weight. From these studies several facts are apparent. First and most important is that the clinical formula provides enough salt to restore the plasma chlorides to normal. All patients, however, do not handle the provided salt in a normal manner. The best response, which is a prompt return of the plasma

chlorides to normal and an appreciable excretion of chloride in the urine, is obtained by patients who have not been sick very long but who have suffered a recent or acute loss of electrolytes, as through acute intestinal obstruction or a recent period of prolonged vomiting from any cause. The second group of patients with depleted chlorides often fail to have their plasma chlorides return to the expected level, and either excrete some of the salt given or add it to their body with water and gain weight. These patients generally have had a long standing illness associated with sepsis or general malnutrition or any one of the other factors previously mentioned as predisposing to the retention of water. Carcinoma of the gastrointestinal tract is one of the rather common initial lesions among these patients. Repeated case analyses have shown that giving more salt than the formula calculation fails to increase the plasma chloride level materially and simply adds to the retention of water, as often shown later by evident subcutaneous edema and ascites. In the most recent studies²⁰ it was found to be definitely a mistake to give more salt.

This failure of the plasma chlorides to come up to the level of normal individuals in some instances when disease is present has been noted before. McLean²¹ found that the average renal threshold for chlorides in fever was 542 mg. and in diabetes mellitus 512 mg., instead of his average of 562 mg. per 100 c.c. of plasma found for normal individuals. Davidson²² found that plasma chlorides in burned patients often remain well below normal despite a good daily intake of sodium chloride. The reasons for these alterations are not clear, but in the University Hospital patients^{15, 20} it was the rule that if they improved in general and began to eat, then the abnormally retained salt readjusted and the plasma chlorides approached normal. The clinical formula has been found to be usable by the general staff members of the University Hospital, and along with the volume-for-volume rule has sufficed to

provide adequate amounts of salt for patients needing salt and at the same time has avoided the dangers of excess administration.

Besides the failure to recognize that postoperative edema is frequently initiated by too much salt solution, there are two other reasons why in the past the danger from salt solution has not been more apparent. One is that intravenous fluids are often only needed for one or two days and then the patient is able to take water by mouth. If there had been any retention of fluids as a result of the salt solutions, the administration was for too short a time for it to become apparent. The second reason is that patients who do not have the factors predisposing to the retention of water—general malnutrition, sepsis, etc.—do not retain fluids when given salt solution¹ but excrete the salt and a fair volume of urine just as is done within limits by normal individuals.²³ There are many patients not seriously ill who receive fluids parenterally for a day or two, patients whose general condition was good up to the time of the operation and is good after the operation, but who are temporarily upset and need to be given fluids other than by mouth. The excretion of the sodium chloride is an unnecessary load on the kidneys and the salt solution is a poor choice of fluids for these patients. As emphasized, the real danger from salt solution is with the seriously ill patient and facts and ideas on this subject have been presented in previous paragraphs.

In this discussion the need for sodium chloride has been considered in terms of chloride. This works out practically because in surgical patients significant losses of electrolytes generally occur through loss of fluid from the upper part of the gastrointestinal tract. In such instances the loss of chloride ions is generally greater than, and only occasionally equalled by, the loss of sodium ions. Since in correcting a deficiency of these ions the solutions commonly used, physiologic saline or Ringer's solution, have an equal number of both

ions,* the deficiency of both can be corrected. Gamble²⁴ has emphasized that with a good supply of available water the kidneys can be depended upon to excrete the less needed ion.

An occasional case is encountered among surgical patients in which the loss of sodium has been appreciably greater than the loss of chloride ions. Two recent examples were, first, in a patient with marked drainage from an ileostomy done because of chronic ulcerative colitis, and secondly, in a patient with prostatism and severe renal damage. In both these patients a solution providing an excess of sodium, Hartmann's²⁵ sodium lactate, was given. One must be on the watch for, and understand, these less common lesions in surgical practice.

WATER AND GLUCOSE

Glucose solutions are valuable because they supply readily available water and carbohydrates. Water comprises 65 per cent of the total body weight and most living organisms are dependent upon a rather frequent ingestion of water to balance up for its daily loss. As in normal individuals these daily losses for surgical patients are mainly for two processes (1) the water used for vaporization from the skin and lungs as part of the heat dissipating mechanism and (2), the water for kidney function. In the operation of these processes it is quite apparent that the heat dissipating mechanism has prior rights over kidney function for available water, the latter using for excretion what is left after the former has taken what it needs. On the surgical services of the University of Michigan Hospital, the staff is encouraged to think of the water requirements, and to order the glucose solution which provides the water on this basis: so many cubic centimeters for vaporization and so many more cubic centimeters for

urine output. The figures to have in mind are arrived at as follows:

Vaporization from the skin and lungs for normal adults in comfortable environmental conditions varies from about 1000 to 1500 c.c. daily,²⁶ the larger figure being for the larger or more active individuals. These same figures have been found to be true for surgical patients who have no tax upon their heat dissipating mechanism. On the other hand, patients with fever or with hyperthyroidism, or when the environment is hot and humid, have the additional factor of sweating and more water is thus lost by vaporization.²⁷ Wassel²⁸ investigated the vaporization loss in patients when the weather was particularly hot and humid and obtained figures from 2,068 to 5,034 c.c. daily. However, for any case complicated by some tax on the heat dissipating mechanism, the vaporization loss can be estimated at 2000 c.c. daily. More will be necessary with the extremes of fever and heat.

The amount of urine put out by the kidneys is a matter over which the physician has some control. Just what is a minimum permissible daily urine output and what is a satisfactory amount? Lashmet and Newburgh²⁹ have furnished information in this regard by making a comparative study of the excretion of water and solids by normal and abnormal kidneys. From their data Table III was composed and shows the amount of water needed to excrete 35 Gm. of waste material, which is about an average daily amount.

From Table III it can be seen that about 500 c.c. of urine is the very minimum daily amount, and is obtained only when normal kidneys are working at maximum concentrating ability. With volumes appreciably below this amount one may expect retention of waste materials, as shown by an increased blood nonprotein nitrogen. With diseased kidneys more water is needed, until with a concentrating ability down to a specific gravity of 1.014 to 1.010 approximately 1500 c.c. of urine is needed to do what the normal can accomplish with

* There are a few less sodium ions than chloride ions in Ringer's solution because of the presence of a small amount of KCl and CaCl₂ in that solution.

500 c.c. On the surgical services at the University Hospital it is considered desirable for the more seriously ill patients—those with sepsis, with severe biliary disease, etc., to put out 1500 c.c. of urine per day. For other patients 1000 c.c. is a good volume, since under the conditions of Table III, 1000 c.c. can be seen to cover all but the most seriously diseased kidneys.

TABLE III
MINIMUM AMOUNT OF WATER NEEDED BY KIDNEYS TO
EXCRETE 35 GRAMS OF WASTE MATERIALS

Condition of Kidneys as Shown by Maximum Concentrating Ability	Sp. Gr. Urine	Water Needed, C.c.
Normal.....	1.032-1.029	473
Diseased*.....	1.028-1.025	595
	1.024-1.020	605
	1.019-1.015	850
	1.014-1.010	1439

* Chronic nephritis, pyelonephritis, renal tuberculosis, etc.

Other opinions have been given as to a satisfactory urine volume. Wangenstein¹³ looks for an output of from 700 to 1000 c.c. per day. White, Sweet and Hurwitt⁵ consider 800 to 1000 c.c. per day as best for neurosurgical patients. Graham,³⁰ in discussing the fluid requirements of patients needing surgical procedures for gastric or duodenal ulcer, asks for a urine output of at least 900 c.c. daily.

A summary of the discussion on the volume of water needed daily to maintain a normal water balance is shown in Table IV. The amounts are those generally accepted as suitable throughout the country. Here they are simply broken up so that one can know their component parts and deal with them as conditions demand. If sweating has been profuse, more fluid must be allowed for the vaporizing process or the urine output will be decreased. If there have been abnormal losses, such as by vomiting, saline solutions must be given following the previously discussed methods, or again the urine output will be low. One

should always remember that a satisfactory water balance is shown by a satisfactory urine output, and conversely, a low urine output, particularly of high specific gravity—which means that the kidneys have good functional capacity and are working hard at the job of excreting waste materials in solution—signifies insufficient available water. It is a sign of progress that one

TABLE IV
DAILY WATER REQUIREMENTS

	Cc.
Uncomplicated Case:	
For vaporization.....	1000-1500
For urine.....	1000
	2000-2500
Complicated Case (sepsis, hyperthyroidism, hot humid weather, etc.)	
For vaporization.....	2000
For urine.....	1000-1500
Abnormal losses (vomitus, etc.).....	
	3000-3500

now sees less of the old phrase "toxic suppression of the kidney function." There are many simpler reasons for no or little urine output and the commonest one is no or little available water.

Glucose solutions are not only valuable because of their ready supply of available water but also because they provide food for energy requirements, and they protect the liver. Also, they prevent ketosis, and studies have shown that 50 Gm. per day is sufficient to accomplish this in the normal adult.³¹ Five per cent glucose in distilled water is close to being isotonic. Winslow³² found that an average of 98 per cent of the glucose was retained by a group of surgical patients given three liters daily at the rate of from 300 to 500 c.c. per hour. This rate easily permits the administration of from 2000 to 3500 c.c. in a few hours, and it should be given during the day, so that the night is left more comfortable for sleeping. Ten per cent glucose is hypertonic to blood and at the University Hospital it seems to be more frequently associated with phlebitis at the site of the injection than is the 5 per cent solution. However Winslow³² found that 95 per cent of the

glucose in three liters of the 10 per cent solution given at the rate of 300 to 500 c.c. per hour, was retained daily by a group of surgical patients, who thus obtained 93 per cent more carbohydrate than if they had received an equal volume of the 5 per cent solution. The water of the 10 per cent solution appeared to be as readily available for all purposes as that of the 5 per cent solution. In patients needing more than just a moderate supply of carbohydrates, those with liver damage, with severe hyperthyroidism, with malnutrition and cachexia, the 10 per cent solution is particularly valuable. In its use it is important to remember that a slow rate of administration, about 150 to 200 c.c. per hour, provides continuous food and the least amount of glycosuria.

In conclusion one may well express appreciation for the availability and comparative safety of the different solutions on hand for the parenteral administration of water, glucose and salt. In the small as well as in the large hospitals this therapy is serving its purpose to carry the more seriously ill patients over periods of acute crises, and the best results are being obtained by thoughtful consideration of the needs of the individual patient.

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WATER was never prescribed by ancient man *qua* water, but Plain Water, Well Water, Salt Water, Spring Water, and Cake Water, all vie in popularity with Water-from-the-Bird-Pond, Water-from-the-Rain-of-the-Heavens, and most potent of all, Water-in-which-the-Phallus-has-been-Washed.