THE REPLACEMENT OF SODIUM CHLORIDE IN SURGICAL PATIENTS*

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THE IMPORTANCE of replacing the sodium chloride and water which may be lost from the body by such abnormal ways as vomiting, gastroduodenal suction, diarrhea, drainage from biliary and intestinal fistulae has been emphasized since the investigations of O'Shaughnessy,[1] Hartwell and Hoguet,[2] MacCallum, Lintz, Vermilye, Leggett, and Boas,[3] Haden and Orr,[4, 5, 6, 7, 8] Gamble and Ross,[9] and many others,[10, 11, 12] showed the value of such therapy. In practice, when a salt deficiency exists the amount of sodium chloride given has been largely empiric, one to five liters of saline solution being administered and the sodium chloride restoration followed by blood chemistry studies. This method has at least two faults. If the sodium chloride needs of the patient have been underestimated, valuable time is lost in restoring the body chemistry to normal; and secondly, if an excessive amount of salt is given, the error will not be shown by the blood chemistry studies and the patient may develop edema.[13, 14, 15, 16, 17, 18] The purpose of this paper is to present briefly‡ data leading to simple accurate rules for: (1) The maintenance of a normal sodium chloride concentration in patients losing sodium chloride while under observation; and (2) the restoration of sodium chloride in patients whose sodium chloride concentration is below normal when first examined.

The Maintenance of a Normal Sodium Chloride§ Concentration.—In actual surgical practice the problem of maintaining a normal sodium chloride level deals mainly with the patient who, while in the hospital, is losing important amounts of water and sodium chloride through loss of gastro-intestinal secretions. In 1937, Dick, Maddock and Coller[19] pointed out that the concentration of sodium chloride in these secretions is almost always less than the concentration of sodium chloride in physiologic saline or Ringer's solution, and they suggested that if one replaced the secretion loss by an equal volume of these solutions, a satisfactory water and salt balance should be maintained.

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‡ A more complete presentation of sodium chloride metabolism in surgical patients will be published subsequently.

§ Throughout the study only the chloride ion was measured and, as is customary, its value was expressed in terms of sodium chloride.

To determine the value of this volume-for-volume rule a series of patients who were losing alimentary tract secretions were studied in the following manner: Immediately after operation each patient was weighed on a special scale, a blood specimen was taken for the determination of the plasma chlorides, a Levine tube was inserted into the stomach and gastroduodenal suction was instituted. Nothing was given by mouth and the water requirements for the day were provided for by the intravenous administration of 5 per cent glucose in distilled water. On the following morning the patient was weighed, the 24-hour specimens of urine and alimentary tract drainage were measured and their chloride content determined, and blood was again taken for a plasma chloride determination. A volume of physiologic saline or Ringer's solution equal to the volume of drainage for the previous 24 hours was then given intravenously, and in addition sufficient 5 per cent glucose in distilled water to provide for the water needs of the body. For the several days that this procedure was carried out, no stools were passed. The salt losses through the skin were not determined, but in no case was there profuse sweating. The

TABLE I

REPLACEMENT OF UPPER GASTRO-INTESTINAL SECRETION LOSSES WITH EQUAL VOLUMES OF PHYSIOLOGIC SALINE SOLUTION

1 Liter = 8.5 Gm. NaCl

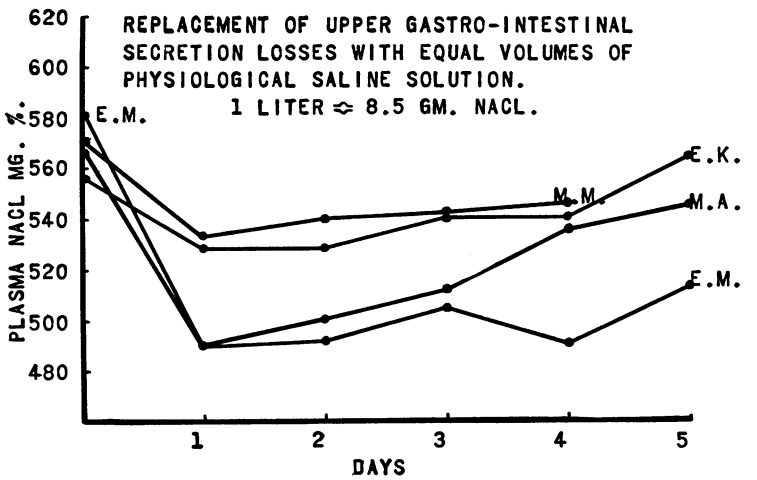
			Secretions Lost				Salt Given			
					Total					
Patient	24 Hours Ending	Body Weight Kg.	G.I. Tract Cc.	Bile T-Tube Cc.	Volume Cc.	NaCl Gm.	Phys. Saline Cc.	Salt Content Gm.	Plasma Chlorides Mg. NaCl/ 100 Cc.	NaCl in Urine Gm.
E. K.....	2-18	—	—	—	—	—	—	—	556	—
	2-19	49.36	320	400	720	2.94	0	0	528	2.45
	2-20	47.86	850	290	1,140	7.50	708	6.03	528	1.10
	2-21	48.26	0	290	290	1.75	1,165	9.90	540	1.06
	2-22	47.67	0	250	250	1.49	287	2.44	540	1.11
	2-23	47.44	0	250	250	1.01	478	4.06	564	1.26
			1,170	1,480	2,650	14.69	2,638	22.43		6.98
E. M.....	3- 9	58.01	—	—	—	—	—	—	582	—
	3-10	59.06	900	0	900	6.46	0	0	490	1.21
	3-11	57.25	840	0	840	4.94	865	7.35	492	1.65
	3-12	56.85	920	0	920	5.69	835	7.01	505	1.51
	3-13	56.30	1,020	0	1,020	5.30	922	7.84	490	0.70
	3-14	56.50	0	0	0	0	1,030	8.76	513	0.80
			3,680	0	3,680	22.39	3,652	30.96		5.87
M. M.....	2-21	42.01	—	—	—	—	—	—	571	—
	2-22	42.62	220	0	220	0.56	990*	5.86	533	6.85
	2-23	41.32	350	0	350	2.23	243	2.07	540	1.42
	2-24	41.65	390	0	390	2.45	354	3.01	541	1.11
	2-25	40.26	0	0	0	0	385	3.27	545	1.53
			960	0	960	5.24	1,872	14.21		10.91
M. A.....	4- 5	54.46	—	—	—	—	—	—	568	—
	4- 6	—	490	160	650	4.12	0	0	490	2.17
	4- 7	53.26	780	240	1,020	6.40	669	5.69	500	3.12
	4- 8	51.29	910	230	1,140	7.63	1,010	8.59	512	1.59
	4- 9	50.87	0	215	215	1.08	1,150	9.78	535	0.98
	4-10	50.92	0	220	220	1.14	393	3.34	545	0.76
			2,180	1,065	3,245	20.37	3,222	27.40		8.62

* 465 cc. physiologic saline solution and 425 cc. of blood.

patients did not gain in weight; therefore it was assumed that an excessive amount of salt leading to the development of water retention had not been given.

In Table I the data from the patients having their sodium chloride losses replaced with physiologic saline solution are given. The resulting plasma chloride levels are shown graphically in Chart I. Three of the patients (M. M., E. K., and M. A.) maintained a satisfactory plasma chloride level and excreted more than 1 Gm. of sodium chloride in the urine daily. Although the plasma chlorides of the fourth case, E. M., did not fall to a seriously low

CHART I



level, nevertheless, they were definitely below normal. This may be a failure of the volume-for-volume rule, or it may be an example of a patient whose plasma chloride level cannot be brought up to normal.*

In Table II are given the data from the patients whose gastroduodenal secretion losses were replaced by equal volumes of a Ringer's solution containing the equivalent of 7.55 Gm. of sodium chloride per liter.† It will be noted that all of the cases studied (W. W., J. B., A. G., and M. L.) maintained a plasma chloride level above 500 mg. NaCl per 100 cc., but in each the daily urinary excretion of sodium chloride fell below 1 Gm., indicating what we, at this time, believe to be an inadequate excess of salt.

In all except one of the cases of Charts I and II (W. W. of Chart II) there is a definite fall in the plasma chloride concentration during the first 24 hours of the gastro-intestinal fluid drainage, no salt being given during this time. A fairly constant plasma chloride level is thereafter maintained by the volume-for-volume replacement, with a tendency in most cases for the

* This inability to raise the plasma chloride level to normal has been observed in a number of patients.

† Ringer's solution, as made by different laboratories, varies in its composition.

TABLE II

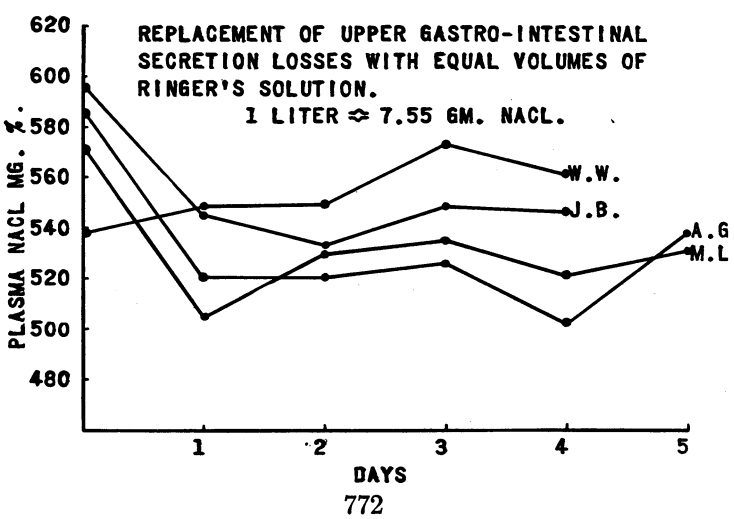
REPLACEMENT OF UPPER GASTRO-INTESTINAL SECRETION LOSSES WITH EQUAL VOLUMES OF RINGER'S SOLUTION

1 Liter ≏ 7.55 Gm. NaCl

Patient	24 Hours Ending	Body Weight Kg.	Secretions Lost: G.I. Tract Cc.	Bile T-Tube Cc.	Total: Volume Cc.	Total: NaCl Gm.	Salt Given: Ringer's Solution Cc.	Salt Given: Salt Content Gm.	Plasma Chlorides Mg. NaCl/ 100 Cc.	NaCl in Urine Gm.
W. W.....	1- 4	81.77	—	—	—	—	—	—	538	—
	1- 5	80.00	960	1,000	1,960	9.97	0	0	548	0.73
	1- 6	78.82	290	810	1,100	6.88	2,035	15.36	549	0.54
	1- 7	77.81	0	315	315	20.3	1,133	8.55	573	2.10
	1- 8	76.96	0	0	0	0	318	2.30	561	0.35
			1,250	2,125	3,375	18.88	3,486	26.21		3.72
J. B.....	1-10	73.00	—	—	—	—	—	—	596	—
	1-11	74.50	480	0	480	2.65	0	0	545	3.86
	1-12	73.23	505	0	505	3.30	485	3.66	533	5.19
	1-13	72.33	280	0	280	1.57	522	3.81	548	0.48
	1-14	72.07	0	0	0	0	318	2.40	546	0.32
			1,265	0	1,265	7.52	1,325	9.87		9.85
A. G.....	1-10	51.64	—	—	—	—	—	—	586	—
	1-11	—	320	190	510	3.51	800*	4.80	520	1.61
	1-12	49.65	775	180	955	7.18	517	3.90	520	1.02
	1-13	48.78	855	130	985	7.49	945	7.13	526	0.49
	1-14	48.25	860	70	930	5.95	963	7.27	502	0.34
	1-15	49.38	0	150	150	0.88	956	7.22	538	0.27
			2,810	720	3,530	25.01	4,181	30.32		3.73
M. L.....	1-24	52.91	—	—	—	—	—	—	571	—
	1-25	52.15	570	290	860	5.60	0	0	505	4.82
	1-26	49.85	540	340	880	4.62	835	6.30	530	0.51
	1-27	49.03	520	250	770	4.41	900	6.79	535	0.17
	1-28	49.76	0	300	300	1.26	787	5.93	521	0.06
	1-29	49.06	0	260	260	1.57	317	2.39	531	0.13
			1,630	1,440	3,070	17.46	2,839	21.41		5.69

* 300 cc. of physiologic saline solution and 500 cc. of blood.

CHART II



level to rise on the last day of the study. In an attempt to eliminate this initial drop and thus to maintain the plasma chlorides at a higher level, a series of four patients were given about 1,000 cc. of physiologic saline solution during the first 24 hours of the study. Then, as in the previous cases, the gastro-intestinal secretion losses were replaced volume-for-volume with physiologic saline solution.

TABLE III

REPLACEMENT OF UPPER GASTRO-INTESTINAL SECRETION LOSSES WITH EQUAL VOLUMES OF PHYSIOLOGIC SALINE SOLUTION PLUS 1,000 CC. PHYSIOLOGIC SALINE SOLUTION DURING THE FIRST 24 HOURS

1 Liter = 8.5 Gm. NaCl

			Secretions Lost				Salt Given			
					Total					
Patient	24 Hours Ending	Body Weight Kg.	G.I. Tract Cc.	Bile T-Tube Cc.	Volume Cc.	NaCl Gm.	Phys. Saline Cc.	Salt Content Gm.	Plasma Chlorides Mg. NaCl/ 100 Cc.	NaCl in Urine Gm.
T. D.....	3-16	—	—	—	—	—	—	—	591	—
	3-17	66.20	120	0	120	0.80	1,050	8.91	561	3.77
	3-18	65.15	110	0	110	0.76	120	1.02	568	1.01
	3-19	63.62	335	0	335	2.27	110	0.93	578	1.33
	3-20	64.03	0	0	0	0	342	2.91	584	0.50
			565	0	565	3.83	1,622	13.77		6.61
E. R.....	3-19	46.56	—	—	—	—	—	—	559	—
	3-20	47.29	630	0	630	4.50	1,010	8.60	563	0.36
	3-21	45.30	1,020	0	1,020	7.53	640	5.36	563	0.46
	3-22	44.11	1,890	0	1,890	12.36	1,020	8.65	553	0.13
	3-23	43.21	2,500	0	2,500	19.28	1,920	16.32	530	0.09
	3-24	43.17	3,000	0	3,000	20.76	2,510	21.33	528	0.14
	3-25	42.54	2,330	0	2,330	15.38	3,080	26.20	611	0.41
			11,370	0	11,370	79.81	10,170	86.46		1.59
L. W.....	3-22	58.09	—	—	—	—	—	—	579	—
	3-23	59.22	320	0	320	1.96	1,060	9.01	543	3.08
	3-24	57.09	310	0	310	1.82	325	2.76	546	9.02
	3-25	54.45	600	0	600	4.01	314	2.67	594	1.97
	3-26	55.46	0	0	0	0	582	4.91	592	0.64
			1,230	0	1,230	7.79	2,281	19.35		14.71
M. L.....	4-12	40.08	—	—	—	—	—	—	602	—
	4-13	40.94	260	220	480	2.87	1,600*	11.41	578	1.33
	4-14	39.08	250	390	640	3.69	486	4.13	568	4.81
	4-15	38.87	0	370	370	2.07	632	5.37	569	1.59
	4-16	37.64	0	390	390	2.17	722	6.14	558	2.12
			510	1,370	1,880	10.80	3,440	17.05		9.85

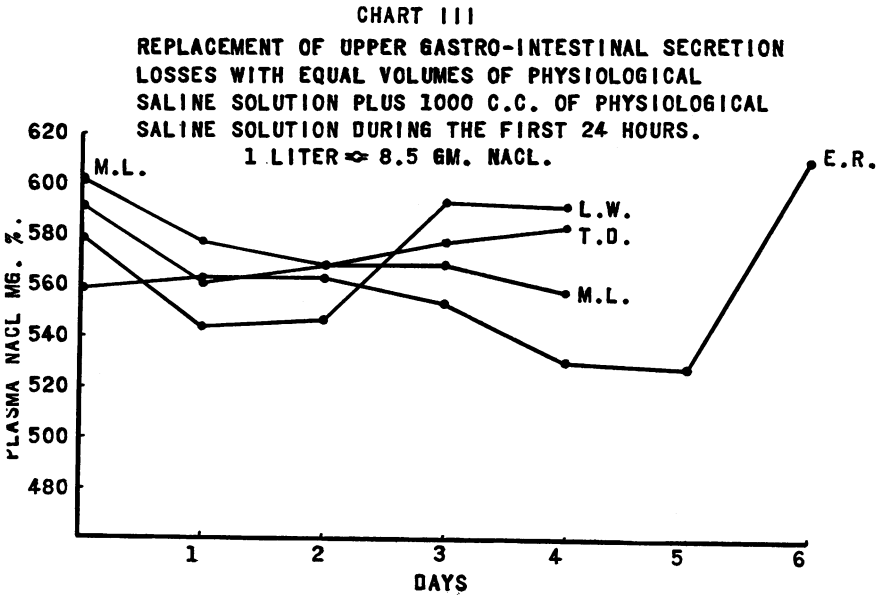
* 1,050 cc. of physiologic saline solution and 550 cc. of blood.

The data from this study are shown in Table III, and graphically presented in Chart III. It will be seen that three of the four cases showed an initial drop in the plasma chloride level in spite of the administration of more than sufficient saline solution to balance the abnormal losses during this period. However, the fall was not as marked as in the cases presented in Tables I and II in which no saline solution was given during the first 24-hour period. Also, the plasma chlorides were maintained at a higher level for the remaining days of the study than was the case for the previous patients.

The maintenance of a satisfactory sodium chloride level in patients losing

significant amounts of gastro-intestinal tract secretions seems to be possible by following the volume-for-volume replacement rule plus the administration of about one liter of physiologic saline solution during the first 24 hours. This latter procedure was added to decrease the initial fall in plasma chlorides which so frequently occurs.

The Restoration of Sodium Chloride.—The idea of putting the sodium chloride needs of patients on a quantitative basis is not new. In 1923, Haden and Orr[7] suggested that in well advanced intestinal obstruction the patient should be given an initial dose of 1 Gm. of sodium chloride per kg. of body weight. Recently, Falconer and Lyall[20] made a further advance in accurate



sodium chloride therapy. They gave known amounts of salt to patients with hypochloremia and determined the resulting rise in the plasma chloride level. From their studies they concluded that "in hypochloremia about 20 grammes (from 15 to 30 grammes) of salt are required on the average to raise the plasma chloride by 100 mg. per 100 cc."

Early in our[21] investigation of the salt requirements of surgical patients, two simple but fundamental principles became apparent: First, it seemed obvious that the salt needs of a 20 Kg. child must be quite different from those of an adult weighing three times that much. Second, it was thought that if one could determine what percentage of the body salt had been lost, it should be possible to calculate accurately the amount of salt that must be given to restore the body chlorides to normal provided the normal salt content of the body is known.

Various estimations of the total chlorine content of the body have been made. Sherman[22] stated the amount to be 0.15 per cent of the body weight.

Expressed as sodium chloride, this amounts to 0.248 per cent of the body weight. On this basis, there are 148.8 Gm. of salt in a 60 Kg. individual and 49.6 Gm. in a 20 Kg. child. The importance of body weight in calculations of salt requirements is thus apparent.

As an index of the state of the total body sodium chloride concentration, the value of the plasma chloride level was considered. It has been shown by White and Bridge[23] that a fall in tissue chlorides is directly proportional to the fall in plasma chloride concentration. From this we assume that the plasma chloride concentration can be used as an index of the chloride concentration throughout the body. On this basis, if the plasma chlorides are 20 per cent below normal it is reasonable to consider that about 20 per cent of the body chlorides have been lost. In the previous paragraph are given data that can be used for calculating the total sodium chloride content of the body. With these data and the plasma chloride level one should be able to calculate the grams of salt necessary to be given to a patient with hypochloremia to restore the chlorides to normal, as follows:

(1) Per cent of body salt lost

$$= \frac{\text{normal plasma chlorides} - \text{actual plasma chlorides}}{\text{normal plasma chlorides}} \times 100$$

(2) Total NaCl content of body = 0.248 per cent of body weight (Gm.)
From (1) and (2):

(3) Number of grams of NaCl needed to restore body chlorides to normal

$$= \text{per cent of body salt lost} \times \text{total NaCl content of body}$$

$$= \frac{\text{normal plasma chlorides} - \text{actual plasma chlorides}}{\text{normal plasma chlorides}} \times 100 \times$$

$$0.248 \text{ per cent of body weight (Gm.)}$$

$$= \frac{560 - \text{actual plasma chlorides}}{560} \times 0.00248 \times \text{body wt. (Gm.)}$$

Applying the last equation to the example of a 60 Kg. patient admitted to the hospital with a plasma chloride level of 410 mg. NaCl per 100 cc., the formula shows the amount of sodium chloride needed to restore the plasma chloride level to 560 mg. per cent,* *i.e.*, $\frac{560 - 410}{560} \times 0.00248 \times 60{,}000 =$ 39.9 Gm.

In order to determine the practical value of this formula, it was applied to a series of individuals with hypochloremia. This group included instances of pyloric and intestinal obstruction, rectal polyp with profuse rectal discharge, paralytic ileus and patients who had been on gastroduodenal suction without accurate replacement of the drainage loss. The patients were given an amount of salt calculated as necessary to restore the plasma chlorides to 560 mg. NaCl per 100 cc. The salt was given intravenously in the form of

* The normal plasma chloride level varies from 560 to 630 mg. per 100 cc. The lower limit was selected for the calculations because many sick patients will not attain a higher level.

physiologic saline or Ringer's solution at the rate of about 500 cc. per hour. During the period of study, 24-hour specimens of urine were collected and the chlorine content determined. If the patient was losing chlorides through some abnormal source during the period of correction of the hypochloremia, these losses were also collected and the salt content determined. These losses in most instances were replaced by the volume-for-volume rule.

TABLE IV

RESTORATION OF BODY CHLORIDES

The formula and clinical calculations are on the basis of a normal plasma chloride concentration of 560 mg. NaCl/100 cc.

Patient	Body Weight Kg.	Initial Plasma Chlorides Mg. NaCl/100 Cc.	Initial Plasma CO_2 Comb. Power Vol. %	NaCl Given Gm.	NaCl Lost During Restoration: Urine Gm.	Upper G.I. Tract Gm.	Stool Gm.	Total Gm.	NaCl Retnd. Gm.	Formula Calculation Gm.	Final Plasma Chlorides Mg. NaCl/100 Cc.	Final Plasma CO_2 Comb. Power Vol. %	Clin. Calculation Gm.
O. M...	63.3	404	57.6	55.8	7.7	7.3	0	15.0	40.8	43.7	559	52.0	49.6
B. S....	39.0	449	53.6	28.4	9.2	1.2	0	10.4	18.0	19.2	493	67.1	21.6
J. C....	65.5	479	45.7	27.5	2.6	1.4	0	4.0	23.5	23.4	586	44.7	26.5
D. C...	60.4	513	59.8	15.8	1.3	0	0	1.3	14.5	12.6	564	53.9	14.2
D. E...	58.1	345	100.0	100.6	6.2	38.1	?	44.3	56.3	55.3	606	73.0	62.5
L. A. D.	62.0	372	75.0	70.1	14.9	5.5	0	20.4	49.7	51.6	566	60.0	58.3
C. K...	48.9	356	48.0	56.8	0.7	1.1	17.9	19.7	37.1	44.1	528	49.8	49.8
S. L....	21.8	479	—	8.7	0.9	0	0.8	1.7	7.0	7.8	536	—	8.8
L. B. D.	54.0	464	—	25.7	5.4	0.3	0	5.7	20.0	22.9	554	—	25.9
B. M...	34.0	437	—	21.3	0.2	0	0	0.2	21.1	18.5	513	—	20.9
T. J....	72.7	427	59.9	40.6	0.0	0	0	0.0	40.6	42.7	564	48.0	48.3
W. P...	67.7	436	57.3	33.7	1.5	0	0	1.5	32.2	37.1	543	58.3	42.0
J. W....	59.8	447	61.4	26.2	1.1	0	0	1.1	25.1	29.7	546	58.9	33.8
S. T....	73.2	436	67.3	42.8	0.5	0	0	0.5	42.3	39.8	554	56.3	45.4
H. A...	76.9	454	49.5	38.2	0.7	0	0	0.7	37.5	35.6	545	60.7	40.8

The data from this study are shown in Table IV. The close correlation between the amount of salt retained and the amount needed as determined by the formula calculation indicates that the principles of salt replacement previously discussed are sound. In most instances the plasma chloride level determined from 12 to 36 hours after the completion of the saline administration was fairly close to 560 mg. NaCl per 100 cc.

Because of important illustrative points, several cases deserve special comment.

Patient B. S. attained a final plasma chloride level of only 493 mg. per 100 cc. However, this seemed to be the highest level the patient could reach at the time, since she excreted 9.2 Gm. of sodium chloride in the urine and further administration of salt failed to raise the plasma chloride level significantly.

Patient C. K. was moribund when first seen. She had a large rectal polyp associated with frequent watery stools and a profuse rectal discharge, the salt content of which was found to be 5.5 Gm. per liter. Before half of the necessary salt was administered she was awake, and within 24 hours was sitting up in bed and mentally alert. One of the characteristic findings in patients recovering from hypochloremia is a definite euphoria as the plasma chlorides

approach normal. The final plasma chloride level in this patient was only 528 mg. per 100 cc., but it will be noted that the actual salt retention fell 7 Gm. short of the calculated need. This was due to the fact that the patient was losing more salt in the rectal discharge than had been anticipated. The rectal polyp was removed and the patient left the hospital cured. If her moribund state had not been recognized as due to hypochloremia, an operation would never have been possible.

Patient L. A. D. illustrates another instructive point. She was a female, age 82, with a strangulated femoral hernia. Her calculated salt requirement was 51.7 Gm. but by mistake she was given 70.1 Gm. Of the excess 19.4 Gm., 5.5 Gm. were lost in gastroduodenal drainage and 14.9 Gm. were excreted in the urine. In general, small excesses of salt are readily eliminated by the kidneys, but, as others have pointed out, large excesses in sick patients tend to cause edema.

Although the formula was found to be accurate, it is cumbersome, and a search was made for a simpler calculation. Using the formula as a basis, several simple approximations were found, the following being considered the most satisfactory: For each 100 mg. per cent that the plasma chlorides need to be raised to reach the normal of 560 mg. NaCl per 100 cc., the patient should be given 0.5 Gm. of sodium chloride per Kg. of body weight.* Example: For a 60 Kg. patient with a plasma chloride concentration of 410 mg. per cent, the amount of sodium chloride needed is $1.5 \times 0.5 \times 60 = 45.0$ Gm. The figures in the last column in Table IV were calculated on this basis and when compared to the formula calculation they show the adequacy of this simple clinical rule. By its use a slight excess of salt will be given, a desirable feature, without danger.

Discussion.—The clinical syndrome presented by patients with depleted body chlorides is worthy of special comment: They are definitely depressed. There is marked lassitude, weakness, and fatigue. The patient's mentality is dulled, and, in the most severe cases, there may even be stupor and coma. The gastro-intestinal symptoms include, first, a dulling of the sense of taste,[24] followed by anorexia, nausea, and vomiting. Muscular cramps also often

* For those who are accustomed to expressing body weight in terms of pounds rather than kilograms, the following rule, which provides for slightly less salt than the clinical calculation, has been formulated: For each 100 mg. per cent that the plasma chlorides need to be raised, the patient should be given 0.2 Gm. of sodium chloride per pound of body weight.

In some laboratories whole blood chlorides rather than plasma chlorides are determined. Using 450 mg. NaCl per 100 cc. as the normal for whole blood, the formula calculation would be:

$$\text{Gm. NaCl needed} = \frac{450 - \text{actual blood chlorides}}{450} \times 0.248 \text{ per cent of body weight (Gm.)}$$

A clinical rule derived from this formula is as follows: For each 100 mg. per cent that the whole blood chlorides need to be raised, the patient should be given 0.6 Gm. of sodium chloride per Kg., or 0.25 Gm. per pound of body weight.

occur. Dehydration, characterized by a dry tongue, sunken eyes, and dry inelastic skin almost invariably accompanies hypochloremia. A low pulse pressure has also been observed; two of our patients presented the clinical picture of shock. Alkalosis with slow respirations and tetany, or inorganic acidosis with deep respirations, may or may not be associated with the chloride depletion.

In the consideration of sodium chloride maintenance and restoration we have dealt with the chloride ion only because, for clinical purposes, its determination is easier than that of sodium. Indirect information concerning the plasma sodium concentration derived from the estimation of the carbon dioxide combining power is always relative to the chloride concentration at that time. For example, gastroduodenal drainage usually contains about equivalent amounts of sodium and chlorine. The loss of a significant volume of these secretions will deplete the body of about equal amounts of sodium and of chlorine, and while the plasma chloride concentration will be definitely lowered, the carbon dioxide combining power will usually be within normal limits. By our use of the plasma chloride determination no implication was intended that chloride is more important than sodium. Undoubtedly the sodium ion is as important, if not more important, than the chloride ion. This was stressed by Gamble and Ross.[9] In actual surgical practice, the correction of the chloride depletion with sodium chloride also corrects the sodium deficiency which always exists in some degree when gastro-intestinal secretions have been lost. This was emphasized by Gamble,[25] who pointed out that sodium chloride given with an abundance of water will correct either alkalosis or inorganic acidosis, the kidneys excreting the unnecessary ion.

It is important to remember that salt is always lost from the body together with water in concentrations which are always less than that of physiologic saline solution. It is apparent, therefore, that salt used for the restoration of body chlorides should be given in isotonic or hypotonic solutions. Hypertonic solutions have the disadvantages that they further dehydrate the patient, and they tend to produce inaccuracies in salt administration by causing salt losses in diarrheal stools. In this study it has been found that physiologic saline or Ringer's solution, given at the rate of 400 to 500 cc. per hour, is retained and corrects sodium chloride deficiency and dehydration. The additional water needed for the daily output of urine and vaporization should be given in the form of 5 per cent glucose in distilled water.

SUMMARY AND CONCLUSIONS

The replacement of sodium chloride lost from the body by vomiting, gastroduodenal drainage, drainage from biliary and intestinal fistulae, diarrhea, wound drainage, and occasionally profuse sweating is a practical problem frequently encountered by the surgeon. Serious depletion of the body sodium chloride will lead to death unless the condition is corrected.

To maintain the normal sodium chloride content of the body in surgical patients losing sodium chloride abnormally while under observation, the fol-

lowing procedure was found to be satisfactory: Administer a volume of physiologic saline solution equal to the volume of the abnormal fluid losses. This procedure has a very practical application when inlying, gastroduodenal suction is employed. In addition to the volume-for-volume rule, in this instance it has been found advisable to give 1,000 cc. of physiologic saline solution during the first day of the drainage period in order to lessen the initial fall in plasma chlorides which commonly occurs.

To restore to normal the sodium chloride content of a patient depleted of these substances, the following clinical rule was found to be effective: For each 100 mg. per cent that the plasma chlorides need to be raised to reach the normal (560 mg. NaCl per 100 cc.) the patient should be given 0.5 Gm. of sodium chloride per Kg. of body weight.

BIBLIOGRAPHY

[1] O'Shaughnessy, W. B.: Letter to London Med. Gazette, **9**, 486, 1831–1832.

[2] Hartwell, John A., and Hoguet, J. P.: Experimental Intestinal Obstruction in Dogs with Especial Reference to the Cause of Death and the Treatment by Large Amounts of Normal Saline Solution. J.A.M.A., **59**, 82, 1912.

[3] MacCallum, W. G., Lintz, Joseph, Vermilye, H. N., Leggett, T. H., and Boas, E.: The Effect of Pyloric Obstruction in Relation to Gastric Tetany. Bull. Johns Hopkins Hosp., **31**, 1, 1920.

[4] Haden, Russell L., and Orr, Thomas G.: The Effect of Sodium Chloride on the Chemical Changes in the Blood of the Dog After Pyloric and Intestinal Obstruction. J. Exper. Med., **38**, 55, 1923.

[5] Haden, Russell L., and Guffey, D. C.: A Case of Pernicious Vomiting of Pregnancy with Low Blood Chlorides and Marked Response to Sodium Chloride Therapy. Am. J. Obstet. and Gynec., **8**, 486, 1924.

[6] Haden, Russell L., and Orr, Thomas G.: The Use of Sodium Chlorid in Treatment of Intestinal Obstruction. J.A.M.A., **82**, 1515, 1924.

[7] Haden, Russell L., and Orr, Thomas G.: Chemical Changes in the Blood of Man After Acute Intestinal Obstruction. Surg., Gynec. and Obstet., **37**, 465, 1923.

[8] Orr, Thomas G., and Haden, Russell L.: Chloride Treatment of Intestinal Obstruction. Southern Med. J., **19**, 300, 1926.

[9] Gamble, James L., and Ross, S. Graham: The Factors in the Dehydration Following Pyloric Obstruction. J. Clin. Invest., **1**, 403, 1925.

[10] Dixon, C. F.: The Value of Sodium Chlorid in the Treatment of Duodenal Intoxication. J.A.M.A., **82**, 1498, 1924.

[11] Raine, Forrester, and Perry, Margaret C.: Intestinal Obstruction—Experimental Studies on Toxicity, Intra-Intestinal Pressure and Chloride Therapy. Arch. Surg., **19**, 478, 1929.

[12] Walters, Waltman, Kilgore, Alan M., and Bollman, Jesse L.: Changes in the Blood Resulting from Duodenal Fistula. J.A.M.A., **86**, 186, 1926.

[13] Matas, R.: The Continued Intravenous "Drip." ANNALS OF SURGERY, **79**, 643, 1924.

[14] Jones, Chester M., and Eaton, Frances B.: Post-Operative Nutritional Edema. Arch. Surg., **27**, 159, 1933.

[15] Jones, Chester M., Eaton, Frances B., and White, James C.: Experimental Post-Operative Edema. Arch. Int. Med., **53**, 649, 1934.

[16] Ravdin, I. S., and Rhoads, J. E.: Certain Problems Illustrating the Importance of a Knowledge of Biochemistry by the Surgeon. Surg. Clin. North Amer., **15**, 85, 1935.

[17] Coller, Frederick A., Dick, Vernon S., and Maddock, Walter G.: Maintenance of Normal Water Exchange with Intravenous Fluids. J.A.M.A., **107**, 1522, 1936.

[18] Curphey, W. C., and Orr, T. G.: Edema in Surgical Patients. Surgery, **1**, 589, 1936.

[19] Dick, Vernon S., Maddock, Walter G., and Coller, Frederick A.: Sodium Chloride Content of Gastro-Intestinal Secretions. Proc. Soc. Exper. Biol. and Med., **37**, 318, 1937.

[20] Falconer, M. F., and Lyall, A.: The Requirements of Sodium Chloride. Brit. Med. J., 1116, December 4, 1937.

[21] Bartlett, Robert M., Bingham, Dermid L. C., Pedersen, Svend, Maddock, Walter G., and Coller, Frederick A.: Quantitative Studies on the Replacement of Body Chlorides. Proc. Soc. Exper. Biol. and Med., **38**, 89, 1938.

[22] Sherman, Henry C.: Chemistry of Food and Nutrition. Macmillan Co., New York, 242, 1937.

[23] White, James C., and Bridge, Edward M.: Loss of Chloride and Water from the Tissues and Blood in Acute High Intestinal Obstruction. Boston Med. and Surg. J., **196**, 893, 1927.

[24] McCance, R. A.: Experimental Sodium Chloride Deficiency in Man. Proc. Royal Soc. of London, Series B, **119**, 245, 1935.

[25] Gamble, James L.: Dehydration. New Eng. J. Med., **201**, 909, 1929.

DISCUSSION.—DR. THOMAS G. ORR (Kansas City, Kans.): In 1925, Gamble and Ross made the statement that "sodium chloride is the only one of a long list of salts containing both of the ions specifically required for plasma repair." Potassium chloride, calcium chloride, magnesium chloride and ammonium chloride have no value in plasma repair.

The treatment of patients with sodium chloride is a logical and simple type of chemotherapy, being merely a substitution of a body chemical lost by disease. To supply sodium chloride in hypochloremia is comparable to the transfusion of blood for anemia and is just as essential to life.

In addition to the physiologic properties of sodium chloride already mentioned, it may play a rôle in growth, bactericidal power of the blood and maintenance of bowel tone. The prompt response of peristalsis when sodium chloride is given to some patients with distention and hypochloremia leads to the belief that the chloride balance affects the intestinal tone.

We have found, in some recent experiments upon dogs, that sodium chloride is absorbed from the stomach and upper intestine when the jejunum is obstructed 25 cm. below the ligament of Treitz. Animals permitted to drink 0.6 per cent sodium chloride live twice as long as animals drinking tap water. The blood chlorides show relatively little change in the group receiving the salt as compared to those drinking water.

How much water and how much salt to give a sick patient has long been a practical problem. Before the work of Coller and his associates the needs of the patient were estimated by his clinical appearance and the estimation of the blood chlorides. If this is done with understanding, it is quite satisfactory. However, one only needs to observe his own patients and particularly those of his confreres who are not familiar with chloride metabolism to realize the gross inaccuracies of such treatment and the desirability of having some quantitative estimate upon which treatment with water and salt may be based. Everyone who has been interested in sodium chloride therapy in its clinical and experimental aspects realizes the wide margin of safety of this treatment. It is equally well known that too much or too little sodium chloride will cause definite symptoms which mean serious consequences unless corrected. The normal patient or experimental animal will tolerate enormous quantities of sodium chloride without apparent harm, but the sick patient, particularly those who have undergone a starvation period with a reduction

in blood protein, frequently develops an edema which may involve the parenchymatous organs.

From a practical standpoint the method of estimating the quantity of salt needed by equation seems much preferable to measuring the fluids lost and replacing them with the same quantity of physiologic sodium chloride solution. Part of the value of the gastric suction treatment is the pleasure and comfort afforded the patient by drinking water. Any liquid swallowed would upset the balance of measured gastric intake and output. The practical value to the average surgeon of Coller's quantitative method of administering sodium chloride is quite obvious.

DR. FREDERICK A. COLLER (closing): We all realize the importance of restoring the biochemical balance of the sick patient. The present communication is another effort on our part to furnish the clinician with practical working quantitative methods for accomplishing this. Previously, we have reported other studies showing that water losses are the measurable losses from the body, plus an average loss of two liters from the skin and lungs; that enables one to maintain water balance with sufficient accuracy. We have reported our observations showing that the clinical picture of dehydration was produced by the loss of 6 per cent of the body weight in water, and have emphasized the need of replacing fluid and electrolyte losses by the proper fluid; emphasizing the danger of employing saline solutions routinely as a vehicle.

In the present communication we hope to have demonstrated a sound method for replacing sodium chloride losses in an accurate way, simple enough to have an easy clinical application. Hypochloremia is not uncommonly seen in the sick patients in the surgical wards. The symptoms and signs of hypochloremia are not infrequently attributed to the disease causing the loss of body chlorides and often are not recognized as being due primarily to the altered body chemistry. The findings most commonly encountered in this condition are marked lassitude, weakness and a sense of great fatigue. There are dulling of the mentality, drowsiness verging toward stupor and coma, dulling of the sense of taste, anorexia, nausea and vomiting—with occasionally muscle cramps. There are signs of dehydration—dry tongue, sunken eyes, dry inelastic skin and a low pulse pressure. The final proof of the diagnosis rests with the determination of the plasma chloride concentration. Not infrequently alkalosis or inorganic acidosis is also present; alkalosis if the chloride losses are from the stomach. The carbon dioxide combining power as determined shows the acid-base balance and may show alkalosis or inorganic acidosis or be normal with a marked hypochloremia.

In actual surgical practice, the correction of the chloride depletion with sodium chloride almost invariably corrects any disturbance in the acid-base balance. This has been emphasized by Gamble, who pointed out that sodium chloride given with an abundance of water will correct either alkalosis or an inorganic acidosis, the kidneys excreting the unnecessary ion. It is important to remember that salt is always lost from the body together with water in concentrations always less than that of physiologic saline. It is apparent, therefore, that salt used for the restoration of body chlorides should be given in isotonic or hypotonic solutions. In this study, it has been demonstrated that physiologic saline or Ringer's solution given intravenously at the rate of 400 to 500 cc. per hour is retained, and corrects both sodium chloride deficiency and dehydration. The additional water needed for the daily out-

put of urine and for vaporization should be given in the form of 5 per cent glucose in distilled water.

One should emphasize that death may occur when the plasma chlorides fall to approximately half the normal level. Symptoms are usually present when the plasma chlorides fall to a point below 500 mg./100 cc., and that they become serious when they get as low as 400 mg./100 cc. We have been on the lookout for this condition; nevertheless we have nearly lost four patients this year from hypochloremia. In every patient who has lost, or is losing fluid from any part of the gastro-intestinal tract, one must keep careful check of the plasma chlorides, and if they are low they can be replaced with sufficient accuracy by using the formula presented.