MEASUREMENT OF TOTAL WATER EXCHANGE

L. H. Newburgh, … , Margaret Woodwell Johnston, Mark Falcon-Lesses

J Clin Invest. 1930;8(2):161-196. https://doi.org/10.1172/JCI100259.

MEASUREMENT OF TOTAL WATER EXCHANGE[1]

By L. H. NEWBURGH, MARGARET WOODWELL JOHNSTON AND MARK FALCON-LESSES

(From the Department of Internal Medicine, Medical School, University of Michigan, Ann Arbor)

(Received for publication July 1, 1929)

As a rule when the terms, "water balance" or "water exchange," occur in clinical literature, the writer has in mind merely a comparison between the water which enters the body as food and drink with the water which leaves it as urine. Sometimes the water of the stool is also included. A statement that includes merely these increments of water is inaccurate and liable to be misleading, since it fails to take into account (1) the large amount of water that is evaporated from the skin and lungs; (2) the water that is formed by oxidation of the food; (3) water physically held as part of the protoplasm, but set free when the organism derives some of its energy by burning its own tissues.

I

We propose to describe a system which permits the observer to obtain an accurate account of all the sources and the total amount of water that becomes available for the organism on the one hand; and of the amount of water that leaves the organism on the other hand.

In working out a plan for dealing with all the increments of water, it is helpful to think of them under two separate headings: (1) Those that may be measured by standard laboratory methods; and (2) those whose value is obtained indirectly by calculation. The first group includes the water that the subject drinks as such, and the water contained in the food, urine and stool. The second group consists of the water evaporated from the skin and lungs, the water that is a byproduct of the combustion of materials, and water made free when body tissue is burned.

[1] Aided by a grant from The Fellowship Corporation.

In order to determine whether the organism has gained or lost water, it is necessary to classify the above mentioned portions of water under two headings. On one side of the balance sheet are gathered together all those increments of water that have become available as free water for the first time during the period. They include not only the water that enters the organism from the outside, but also the water formed by oxidation of the metabolic mixture,[2] and the water that is freed when body tissues are burned (preformed water). On the other side of the balance sheet all the fractions of water that have been given off by the organism, are brought together. They are the water of the urine and stool and the water that has been given off by

TABLE 1

Water exchange

Available water	grams	Water given off	grams
A. Water drunk	——	E. Water of urine	——
B. Water of food	——	F. Water of stool	——
C. Water of oxidation	——	G. Insensible water	——
D. Preformed water	——		
Total	——	Total	——
Difference ——			

the skin and lungs[3] (insensible water). Table 1 is a water balance form that was found useful.

The weights of each of these seven items of water were obtained in the following manner:

A. The subject drank water as desired from a "thermos bottle" fitted with a rubber stopper containing a glass drinking tube. The stoppered bottle filled with cold water was weighed at the beginning of the period and again at the end on a balance accurate to one gram. Less than one gram of water evaporated from the bottle in twenty-four hours.

B. Several different diets were used. The best results were obtained when only milk and sucrose was fed. During this period, the

[2] The metabolic mixture consists of all the materials burned by the organism during the period and thus often includes body tissues.

[3] This water is chiefly or entirely removed from the body by evaporation, but it also includes any water lost as liquid sweat.

desired composition was secured by mixing appropriate amounts of cream (40 per cent), whole milk and skim milk. After thorough mixing a sample was removed. Its water content was determined by freezing and desiccation in vacuo (1). The sucrose was considered to be dry.

At other times the diet included bread, butter and bananas in addition to the milk mixture and sugar. Samples of banana were frozen and desiccated. The water content of the bread was determined by drying in the oven. Since the butter contained, at most, two grams of water, its water was not regularly determined. Fifteen per cent of its weight was allowed for water.[4]

Finally we were interested to know what results could be obtained when the usual types of food were employed instead of the highly

TABLE 2

Insensible water

I		II	
	grams		*grams*
Subject at beginning	—	Subject at end	—
Food	—	Urine	—
Drink	—	Stool	—
Oxygen	—	Carbon dioxide	—
Total	—	Total	—

restricted diets just described. Accordingly the standard vegetables, fruits, meats, milk, eggs, bread and butter, cooked in the customary way, were fed. Complicated desserts and salad dressings were omitted. Since it seemed hopeless to obtain a fair sample from such a complicated mixture, the water content was determined as follows: A dietitian prepared two diets as nearly alike as she could. All that the subject was to receive at any meal was placed on a tray and the whole weighed. After the subject had eaten, the tray and dishes were weighed again. The duplicate diet was also placed on a tray which was then weighed. The food was next scraped into an enameled can of known weight, and the covered can was placed in a refrigerator.

[4] In order to get accurate knowledge of the composition of the diet, a sample of the milk mixture was analysed for nitrogen (Kjeldahl), fat by the Babcock method, and ash. Samples of the dry bread and bananas were analysed for nitrogen.

The subject received three meals daily and the duplicate diet was also served in three portions, weighed and collected in the can. The latter was then weighed with the whole wet duplicate diet in it and placed on a steam bath whose temperature varied from 50° to 70°C. It took about two weeks to reach its final weight. The loss was assumed to have been caused entirely by evaporation of water. However such "dry" diets[5] lost an additional small amount of weight after being in a desiccator over sulphuric acid.

TABLE 3

Constants to obtain oxygen absorbed and carbon dioxide given off

Oxygen	
Multiply protein	by 1.38
Multiply fat	by 2.86
Multiply carbohydrate	by 1.13
Carbon dioxide	
Multiply protein	by 1.46
Multiply fat	by 2.78
Multiply carbohydrate	by 1.54

C. The weight of the water that arises from protein, fat or carbohydrate when they are oxidized by the organism, has been determined by several students. We used the following values (2).

100 grams protein	yields 41 grams H_2O
100 grams fat	yields 107 grams H_2O
100 grams carbohydrate	yields 60 grams H_2O

It is, however, necessary to know the metabolic mixture before this increment of water can be calculated. The method of calculating the former has already been described (3).

D. To obtain the preformed water the diet and the metabolic mixture are compared. When the former contains more energy than the latter and when no body protein is destroyed or when the caloric value of the two is the same, no preformed water is released. When, however, a submaintenance diet is fed, the destruction of body tissues frees the water that was physically held by them. But under

[5] All of the dry duplicate diet collected during a period was ground and a sample analysed for nitrogen.

TABLE 4

Weight of oxygen added to body to complete oxidation of metabolic mixture

A. *Protein* (Muscle protein)

Composition (4)

$C = 51$ per cent $\begin{cases} \text{Respiratory 40 per cent} \\ \text{Urine and feces 11 per cent} \end{cases}$

H to form water = 4.8 per cent

O = 21 per cent

1 gram C requires 2.66 grams O to form CO_2

1 gram C requires 1.33 grams O to form urea

1 gram H requires 8.0 grams O to form water

therefore

(a) Protein × (0.40 × 2.66) = O to form CO_2

(b) Protein × (0.11 × 1.33) = O to form urea

(c) Protein × (0.048 × 8.0) = O to form H_2O

(d) Protein × 0.21 = intramolecular O

(a + b + c) − (d) = 1.384, hence

Protein × 1.38 = Oxygen added

B. *Fat* (tripalmitin)

Composition

C = 76 per cent

H = 12 per cent

O = 12 per cent

(a) Fat × (0.76 × 2.66) = O to form CO_2

(b) Fat × (0.12 × 8.0) = O to form H_2O

(c) Fat × 0.12 = intramolecular O

(a + b) − (c) = 2.86, hence

Fat × 2.86 = Oxygen added

C. *Carbohydrate* (sucrose)

Composition

C = 42 per cent

H = 6.5 per cent

O = 51.5 per cent

(a) CH × (0.42 × 2.66) = O to form CO_2

(b) CH × (0.065 × 8.0) = O to form H_2O

(c) CH × 0.515 = intramolecular O

(a + b) − (c) = 1.125, hence

Carbohydrate × 1.13 = Oxygen added

Weight of carbon dioxide yielded by the metabolic mixture

A. *Protein*

Protein × (0.40 × 3.66) = CO_2

B. *Fat*

Fat × (0.76 × 3.66) = CO_2

C. *Carbohydrate*

CH × (0.42 × 3.66) = CO_2

these circumstances the total amount of preformed water released can not be calculated while glycogen is being destroyed, since it is not known how much water it binds. In the previous paper (3) we pointed out the ways by which we believed we had selected periods during which no glycogen (or a very few grams) was being oxidized.

Comparison between the ingoing and outgoing nitrogen shows whether body protein has been destroyed. It is customary to allow three grams of preformed water for every gram of protein. The remainder of the calories furnished by the body come from fat. Its preformed water is considered to be about ten per cent of its weight.

E. The water content of the urine was obtained by freezing and desiccating, in vacuo, duplicate samples of each twenty-four hourly amount, by means of the same technique employed for milk.

F. The subject defecated directly into a weighed enameled container by means of a commode. After recording the weight of the container plus the wet stool, the whole was placed on the steam bath without transfer. The loss of weight, which was complete in three or four days, was assumed to be entirely due to evaporation of water.[6]

G. We have obtained the weight[7] of the insensible water by adding

[6] All of the feces formed while any single diet was being used was mixed, ground and analysed for nitrogen. When the subject received only the milk mixture and sugar, fat and fecal ash was also determined.

[7] Since the time of Sanctorius (1614) it has been known that there is a continuous loss of gaseous material from the body. Later studies have shown that this consists of carbon dioxide and water vapor. The combined weight of these two is greater than the weight lost by the organism as determined by the scales. (The terms "Insensible loss" or "Insensible perspiration" refer to the latter.) This is true because the loss of weight caused by the outward passage of carbon dioxide and water, is, in part, compensated for, by the weight of the oxygen absorbed.

Isenschmid (5) has expressed this relationship thus:

$$\text{Insensible loss} = H_2O + CO_2 - O_2.$$

If carbohydrate alone were being burned the weight of oxygen absorbed would equal the weight of the oxygen contained in the carbon dioxide given off. Under these conditions the insensible loss would equal the weight of the water plus carbon.

When, as is usually the case, fat and protein are burned, some of the oxygen absorbed is used to complete the oxidation of hydrogen as well as carbon. Then the insensible loss may be thought of as made up of water, carbon and hydrogen. Schwenkenbecher and Inagaki (6) pointed out this relationship in 1905.

Because of this varying relationship it is not possible to determine the total the weight of everything that entered the body during the period to its weight at the beginning; and by adding the weights of everything that left the body during the period, other than water vapor, to its weight at the end of the period. The difference between the two sums is clearly the weight of the water lost insensibly. Table 2 shows what weights need to be used. The manner of obtaining the weights of the subject, food, drink, urine and stool, has already been described.

The weight of the oxygen is obtained by calculating how much of it had to be added to the body to complete the oxidation of the metabolic mixture; and the weight of the carbon dioxide is derived by means of the same type of calculation. The time required for these cumbersome calculations may be greatly reduced by means of numerical constants.

Table 3 shows the constants[8] we have used. These constants were obtained by the calculations shown in table 4.

II

When it was desired to obtain the day to day water exchange of an individual we proceeded as follows:

1. The mean twenty-four hourly heat production was determined (3).

2. The metabolic mixture was calculated from this value, the composition of the diet and the outgoing nitrogen.

3. Next the weights of the oxygen absorbed and carbon dioxide given off on the basis of this mixture were obtained, and the oxygen value subtracted from that for carbon dioxide.

4. The subtraction of this latter difference from each twenty-four hourly insensible loss gives the weight of the water lost insensibly during each twenty-four hours.

5. The water formed by oxidation of the metabolic mixture was calculated.

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insensible water by merely deducting the weight of the carbon of the metabolic mixture from the insensible loss. The oxygen and carbon dioxide may be determined directly or calculated from the metabolic mixture. With the weights of the insensible loss, the carbon dioxide and oxygen, the insensible water may be obtained from Isenschmid's Equation.

[8] Lusk (Science of Nutrition, 3rd ed., p. 28) states that it requires 133.43 grams oxygen to burn 100 grams meat protein; 288.5 grams oxygen for 100 grams fat; and 118.5 grams oxygen for 100 grams starch.

6. The diet was compared with the metabolic mixture and the differences used to calculate preformed water, if body tissue was being oxidized; or if tissue was being added to the body, the appropriate amount of water (stored by it) was subtracted from the total available water.

The use of an average metabolic mixture for the period instead of calculating one for each twenty-four hours has two advantages. It tends to compensate for any irregularities of absorption and oxidation and so probably gives a better statement of what has been metabolized. Further, it greatly reduces the time required for calculation.

III

A concrete example of the way in which water exchange was determined will now be given.

The normal subject and the general conduct of the study have already been described (3). From January 3 to January 8, 1929, his life and diet were unrestricted. The evening of January 8 he went to bed in the special room, and the next morning began to receive a milk mixture and sugar in amounts which were expected to be close to his requirement for maintenance.

The water exchange was determined for five consecutive days beginning January 11. During this time the milk mixture was found by analysis to contain 69 grams of protein, 83 grams of fat and 112 grams of carbohydrate, per day. In addition he received 155 grams of sucrose daily. The average twenty-four hourly heat production was 1907 calories. The diet yielded 2091 calories; and he destroyed 11.88 grams of body protein daily. The subtraction of the out-going calories from the calories of the diet plus those of the body protein, left 232 calories to be stored. For purposes of calculation it is assumed that they are stored as fat. This represents the storage of 24 grams of fat; or an addition to the body weight of 26 grams. On the other hand he lost 11.9 grams of protein from the body daily, which, with its water, represents a loss of 48 grams. Therefore, he should lose 22 grams of weight daily. His metabolic mixture was 81 grams protein (diet plus body protein); 267 grams carbohydrate (it is assumed that all the carbohydrate of the diet was burned); and 57 grams of fat (to supply the difference between the outgoing calories and the sum of the calories derived from the protein and carbohydrate oxidized). From the above it is evident that there was released the water which was held by the 11.9 grams of body protein destroyed daily. That is an addition of 36 grams to the available water. On the other hand he stored 24 grams of fat which holds 2 grams of water; so that we may consider that 34 grams of preformed water became available.

The water formed by the oxidation of this metabolic mixture (obtained by means of the constants mentioned above) was 254 grams.

By means of the constants in table 3 it is found that the oxygen absorbed to complete the oxidation of the metabolic mixture weighed 576.5 grams and the carbon dioxide produced weighed 687.9 grams. The difference is 111 grams. The subtraction of this value from the twenty-four hourly insensible loss gives the daily insensible water.

Since the diet was unusual it was thought that the standard method of calculating the available calories of the diet might not be sufficiently accurate. For this reason the calories actually lost in the stool were determined by the oxy calorimeter of Benedict and Fox[9] (7). The calories lost in the urine were calculated by multiplying the urinary N by 8, (following the custom of the Carnegie Institution). The caloric value of the stool was 4.35 calories per gram of dry weight. The total calories lost in the stool and urine for the period were 979 or 196 per day. The full heat value of the diet was obtained by multiplying protein by 5.65; fat by 9.54 and carbohydrate by 4. To this value was added the calories derived from body protein, making a total of 2317 daily. From this must be substracted the calories lost in urine and stool, leaving 2121 calories for metabolic disposal. The twenty-four hourly calories determined by insensible loss were 1907.

Since the full heat value has been assigned to the materials oxidized, the calories of the metabolic mixture in this case must consist of the total heat production plus the potential heat lost in the urine and stool, that is, $1907 + 196 = 2103$. The metabolic mixture would accordingly be protein 81 grams, fat 61 grams and carbohydrate 267 grams. The only difference between the metabolic mixtures calculated by the two methods is four grams of fat. With the latter mix-

[9] We are indebted to Dr. T. M. Carpenter of the Nutrition Laboratory of the Carnegie Institution for this determination.

TABLE 5

Data used in calculation of water exchange

Date	Weight of subject 8:40 a.m.	Water	Milk*		Urine			Stool			Insensible loss	Heat production
			Total	Water	Total	Solids	N	Total	Solids	N		
1928	*grams*	*grams*	*grams*	*per cent*	*grams*	*grams*	*grams*	*grams*	*grams*	*grams*	*grams*	*calories*
January 11.	59,520	268	2,299	87.8	1,527	45	12.04	122	17.5	0.72†	1,213	2,040
January 12.	59,385	724	2,200	87.5	2,182	49.6	12.33	0		0.72	1,073	1,860
January 13.	59,210	300	2,198	87.5	1,194	44.6	12.69	0		0.72	1,078	1,870
January 14.	59,590	368	2,201	87.5	1,376	41.7	11.76	22	6.5	0.72	1,175	1,990
January 15.	59,740	407	2,200	87.3	1,504	42.6	11.60	205	55	0.72	1,009	1,775
January 16.	59,785											

* To obtain total weight of food, add 155 grams daily for sucrose.

† Total mixed stool analysed in duplicate for N and apportioned per day.

TABLE 6

Water exchange of a normal subject. Diet more than maintenance

Date	(1) Drink	(2) Food water	(3) Preformed water	(4) Oxidation water	(5) Water of urine	(6) Water of stool	(7) Insensible water	(8) Available water	(9) Outgoing water	(10) Water balance
Available energy of diet calculated by standard method										
	grams	*grams*	*grams*	*grams*	*grams*	*grams*	*grams*	*grams*	*grams*	
January 11..............	268	2,018	34	254	1,482	105	1,102	2,574	2,689	−115
January 12..............	724	1,925	34	254	2,132		962	2,937	3,094	−157
January 13..............	300	1,923	34	254	1,149		967	2,511	2,116	+395
January 14..............	368	1,926	34	254	1,334	16	1,064	2,582	2,413	+169
January 15..............	407	1,921	34	254	1,461	150	898	2,616	2,509	+107
Available energy of diet calculated from full heat value of food, stool and urine										
January 11..............	268	2,018	34	259	1,482	105	1,101	2,579	2,688	−109
January 12..............	724	1,925	34	259	2,132		961	2,942	3,093	−151
January 13..............	300	1,923	34	259	1,149		966	2,516	2,115	+401
January 14..............	368	1,926	34	259	1,334	16	1,063	2,587	2,412	+175
January 15..............	407	1,921	34	259	1,461	150	897	2,621	2,508	+113

ture the predicted daily loss of weight would be 24 grams instead of 22 grams as in the former case.

The remaining data needed to obtain the water exchange are shown in table 5. With this information at hand, the values set forth in table 6 were secured. Columns 1, 2, 3 and 4 show the amounts of the various increments that make up the available water (column 8). Columns 5, 6 and 7 are the separate items of outgoing water, brought together in column 9. Finally column 10 shows how much water has been retained or lost by the organism during each 24 hours. The table also shows the effect on water exchange of each of the two ways of calculating the heat value of the diet. It is clear that the differences are not significant.[10]

IV

In order to estimate the degree of accuracy of this method for obtaining water exchange, a prediction of the water retention or loss for this same period has been made. This was done by comparing the actual change in weight with the theoretical loss of weight and assuming the difference to be water. See table 7. In the upper section of the table, the caloric value of the diet is calculated by means of the usual heat values assigned to food. In the lower section the caloric value of the diet is obtained by subtracting the calories lost in urine and stool from the full heat value of the diet. It is noticeable that a marked discrepancy between the predicted and determined water balance exists on the last day, but by both methods of calculation the agreement is surprisingly good for the other four days. One may conclude from this comparison that the usual caloric values assigned to food are sufficiently accurate to give excellent values for water balance. The reason for the error on the last day is not evident, but it has been consistently noticed that on days when an unusually large stool was voided the largest errors in water balance have occurred. It should be pointed out, however, that the total error for the five days was 44 grams or a little more than 8 grams per day.

Table 8 gives a comparison between the predicted and determined water balance when the normal subject was receiving a somewhat more complicated diet than the one just dealt with. In addition to the milk mixture and sucrose he was given bread, butter, bananas and

[10] The heat value of the stool calculated from determinations of nitrogen, fat, ash and carbohydrate by difference, was 4.4 calories per gram of dry weight. This checks well with the value, 4.35 obtained by the oxy calorimeter.

grape-nuts. This diet, like the one taken during the period represented by table 7, also contained more energy than the maintenance requirement. This period followed one during which the subject was living under the special conditions of the investigation except that he was allowed the "house diet." The data for calculating the water balance of this period will be found in table 1 of the appendix.

The water balance of a third period of moderate overnutrition is shown in table 9. The diet contained milk, sucrose, bread, butter

TABLE 7

Comparison between predicted and determined water balance based on data in table 6

Date	Change in subject's weight	Theoretical loss	Water balance		
			Predicted	Determined	Error
	grams	*grams*	*grams*	*grams*	*grams*
January 11..	−135	22	−113	−115	2
January 12	−175	22	−153	−157	4
January 13	+380	22	+402	+395	7
January 14..	+150	22	+172	+169	3
January 15	+45	22	+67	+107	40
Totals			+375	+399	
January 11	−135	24	−111	−109	2
January 12	−175	24	−151	−151	0
January 13	+380	24	+404	+401	3
January 14	+150	24	+174	+175	1
January 15	+45	24	+69	+113	44
Totals			+385	+429	
Error for period 44					

and bananas, but the "grape-nuts" were not used. This period followed one of undernutrition during which there had apparently been a depletion of glycogen since the fasting respiratory quotient had fallen to 0.72 from the earlier level of 0.82. When the higher diet of this third period of overnutrition was taken by the subject, his quotient again rose to 0.82, indicating that he had replaced the glycogen destroyed in the preceding period. However, when calculating the metabolic mixture used in compiling table 9, it was assumed that the extra calories of the diet were stored as fat. It is instructive to see how much difference in water exchange would be caused by using a metabolic mixture based on the assumption that all the extra calories were stored as glycogen. The metabolic mixture in the first case was: protein 66 grams; fat 76 grams; carbohydrate 270 grams. In the second case it would be: protein 66 grams; fat 88 grams; carbohydrate 243 grams. The change in metabolic mixture would affect the water of oxidation, the insensible water and the preformed water. Since the preformed water held by glycogen is not known, we have left

TABLE 8

Comparison between determined and predicted water balance in overnutrition

Date	Change in subject's weight	Theoretical loss	Water balance		
			Predicted	Determined	Error
1928	*grams*	*grams*	*grams*	*grams*	*grams*
November 13	−475	22	−453	−433	20
November 14	−175	22	−153	−161	3
November 15	−470	22	−448	−402	46
November 16	+415	22	+437	+423	14
November 17	+85	22	+107	+133	26
November 18	−20	22	+2	−31	33
November 19	−350	22	−328	−275	53
November 20	+225	22	+247	+255	8
November 21	−10	22	+12	+7	5
November 22	+190	22	+212	+229	17
November 23	−125	22	−103	−106	3
Totals			−468	−361	
Error for period 107					

all of the preformed water out of the following calculation. While this obviously fails to give a true statement of the water exchange, it does not affect the relationship between the predicted and determined water balance. This is true because the predicted loss of weight as ordinarily calculated includes the preformed water which also makes up part of the available water. This fact comes out clearly when the two balances are compared by means of algebraic equations:

(1) Predicted water balance = (Solids + Preformed Water) ± (Change in weight).

(2) Determined water balance = (Preformed water + Drink + Food Water + Oxidation water) − (Outgoing water).

If our predicted and determined balances are correct, then

Predicted water balance = Determined water balance

Therefore

(Solids + Preformed water) ± (Change in weight) = (Preformed water + Drink + food water + Oxidation water) − (Outgoing water)

Hence

(Solids) ± (Change in weight) = (Drink + Food water + Oxidation water) − (Outgoing water)

TABLE 9

Comparison between determined and predicted water balance when glycogen is being stored

Date	Change in subject's weight	Theoretical loss	Water balance		
			Predicted	Determined	Error
1928	*grams*	*grams*	*grams*	*grams*	*grams*
December 3	+145	−15	+160	+173	13
December 4	+520	−15	+535	+527	8
December 5	−150	−15	−135	−118	17
December 6	−50	−15	−35	−7	28
December 7	−25	−15	−10	−26	16
December 8	−80	−15	−65	−52	13
Totals			−497	−450	
Error for period 47					

A detailed statement of the water exchange for the period under consideration, showing the effect of each metabolic mixture, will be found in table 10. Consideration of table 10 brings out several points of interest: (1) If one is trying to account for the difference between the actual weight of an individual and what he would be expected to weigh as the result of any given diet, the discrepancy, due to retention or loss of water, may be determined as successfully when preformed water is left out of the account as when it is included.

TABLE 10

Water exchange

A. When the extra calories of the diet are stored as fat and the metabolic mixture is protein 66 grams; fat 76 grams; carbohydrate 270 grams

Date	Food water	Drink	Pre-formed water	Oxida-tion water	Availa-ble water	Water of urine	Water of stool	Insensi-ble water	Out-going water	Deter-mined balance	Actual change in weight	Pre-dicted change in weight	Pre-dicted balance
	grams	*grams*	*grams*	*grams*	*grams*	*grams*	*grams*	*grams*	*grams*	*grams*	*grams*	*grams*	*grams*
December 3	1,484	552	19	270	2,326	1,100	143	909	2,152	+173	+145	−15	+160
December 4	1,484	838	19	270	2,612	1,060	0	1,024	2,084	+527	+520	−15	+535
December 5	1,491	455	19	270	2,236	1,205	75	1,073	2,353	−118	−150	−15	−135
December 6	1,491	962	19	270	2,743	1,474	124	1,151	2,749	−7	−50	−15	−35
December 7	1,490	502	19	270	2,282	1,171	0	1,136	2,307	−26	−25	−15	−10
December 8	1,484	612	19	270	2,390	1,070	110	1,261	2,441	−52	−80	−15	−65
										+497			+450

B. When the extra calories of the diet are stored as glycogen and the metabolic mixture is protein 66 grams; fat 88 grams; carbohydrate 243 grams

Date	Food water	Drink	Pre-formed water	Oxida-tion water	Availa-ble water	Water of urine	Water of stool	Insensi-ble water	Out-going water	Deter-mined balance	Actual change in weight	Pre-dicted change in weight	Pre-dicted balance
December 3	1,484	552		267	2,303	1,100	143	909	2,164	+139	+145	+20	+125
December 4	1,484	838		267	2,589	1,060	0	1,024	2,096	+493	+520	+20	+500
December 5	1,491	455		267	2,213	1,205	75	1,073	2,365	−152	−150	+20	−170
December 6	1,491	962		267	2,720	1,474	124	1,151	2,761	−41	−50	+20	−70
December 7	1,490	502		267	2,259	1,171	0	1,136	2,319	−60	−25	+20	−45
December 8	1,484	612		267	2,367	1,070	110	1,261	2,453	−87	−80	+20	−100
										+292			+240

A. Preformed water is included in the calculation in the usual manner.

B. Preformed water is not included in either the available water or in the predicted loss of weight.

This is demonstrated in figure 1, which represents that period[11] in the study of the normal subject, when the preformed water was the largest; namely 65 grams daily. The solid line (*A*) is the predicted weight when the predicted loss is only the weight of protein and fat destroyed; and the broken line (*B*) is the predicted weight when the

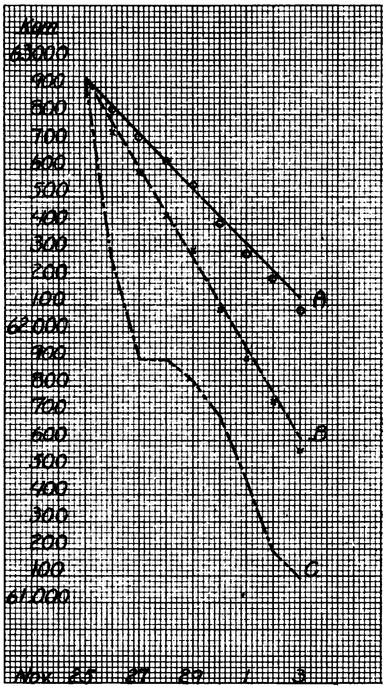

FIG. 1

C, actual weight of subject. *B* – –, and *B* x x; predicted and corrected weight obtained in usual way. *A* –, and *A* o o; predicted and corrected weight when no preformed water is included in the calculation.

predicted loss of weight includes the preformed water in addition to the protein and fat. The circles and crosses indicate the subject's real weight (*C*) corrected each day by adding or subtracting the amount of water that had been held or lost by the subject. But in

[11] Not the same period as used for Table 10. It was the first period of undernutrition and immediately preceded that presented in table 10.

the case of the corrections represented by the circles, the water balances used to make the corrections were the differences between the outgoing water and the available water when the latter did not include the preformed water. Hence both the predicted loss of weight (A) and the water balance are reduced to the same degree. This corrected weight is as close to the predicted weight when preformed water is not considered as when it is. The difference between the determined and predicted water balance is, in each case, 46 grams for the whole period of 8 days.

TABLE 11

Comparison between predicted and determined water balance in undernutrition

Date	Change in subject's weight	Theoretical loss	Water balance		
			Predicted	Determined	Error
1929	*grams*	*grams*	*grams*	*grams*	*grams*
January 16	−525	100	−425	−404	21
January 17	−25	100	+75	+78	3
January 18	−235	100	−135	−135	0
January 19	−235	100	−135	−138	3
January 20	−30	100	+70	+64	6
January 21	−235	100	−135	−124	11
January 22	−175	100	−75	−76	1
January 23	+45	100	+145	+129	16
January 24	−330	100	−230	−214	16
January 25	−250	100	−150	−166	16
Totals			−985	−966	

Error for period 19 grams

(2) It is also desirable to realize that the errors in water balances found in table 10 are largely attributable to something other than an incorrect statement of the metabolic mixtures, since the errors between the predicted and determined balances are essentially the same even though the fat and carbohydrate values of the two metabolic mixtures are different.

The period represented in figure 1, was the first period of undernutrition in which water exchange was studied. The data will be found in table 3 of the appendix. That the underfeeding caused destruction of glycogen is clearly indicated by the fall of ten points in the respiratory quotient. It was, however, assumed, when constructing the metabolic mixture, that all of the endogenous calories came from protein and fat. The water balance thus obtained indicates that the organism lost 695 grams of water during the first two days. Most of this water was presumably released by the destruction of glycogen. If the latter has the same hydrophylic coefficient as protein, the water loss would indicate that about 200 grams of glycogen had been destroyed.

The next period, like the one represented by figure 1, also shows the effect of the first days of undernutrition with a probable destruction of glycogen. It also followed an interval during which the subject

TABLE 12

Comparison of three periods of undernutrition in which carbohydrate in diet differed

Period	Date	Protein	Fat	Carbo-hydrate	Diet calories	Total nitrogen out	Heat produc-tion	Average fasting R.Q.
		grams	*grams*	*grams*	*calories*	*grams*	*calories 24 hours*	
A	November 25–December 2	60	44	126	1,185	12.56	2,000	0.73
B	January 16–26	63	26	148	1,078	11.1	1,746	0.76
C	December 9–24	57	22	178	1,138	10.55	1,813	0.77

was receiving more than the requirement for maintenance. The respiratory quotient fell from 0.83 during the maintenance period to 0.76. Nevertheless glycogen was not included in the metabolic mixture for reasons pointed out above. The water balance will be found in table 11, and the analytical data are brought together in table 4 of the Appendix. The discrepancy between the determined and predicted water balance is only 19 grams for the ten days, even though no allowance is made for the (presumable) destruction of glycogen.

It will be interesting to compare a period of undernutrition during which the diet was relatively high in carbohydrate with the two periods just discussed (fig. 1 and table 11) in which the carbohydrate was sufficiently low to (presumably) cause the organism to burn glycogen. The three periods are compared in table 12 and figure 2. While the metabolic conditions are not strictly comparable in the three periods, it will be noted that in period A in which the greatest caloric deficit exists, the dietary carbohydrate is lowest. This would imply the greatest demand upon the glycogen reserve. In period B and period C the only significant difference is in the dietary carbohydrate. This relationship between carbohydrate in the diet and the destruction of glycogen appears to be confirmed by the trend of the fasting respiratory quotient.

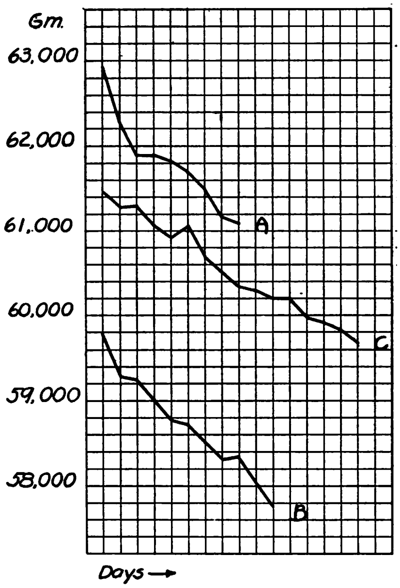

FIG. 2. WEIGHT CURVES DURING THREE PERIODS OF UNDERNUTRITION

The steep initial fall in (*A*) suggests a large destruction of glycogen, whereas the relative smoothness of (*C*) suggests that little or no glycogen was destroyed. The small but definitely steep initial fall in (*B*) suggests a condition intermediate between (*A*) and (*C*).

The rapid fall in weight in period A (fig. 2) also indicates a considerable destruction of glycogen whereas in period C, the relatively smooth curve indicates that there was no significant destruction of glycogen. The weight curve in period B suggests an intermediate condition in regard to glycogen.

The water balance of this third period of undernutrition, when the dietary carbohydrate was relatively high and little or no glycogen was destroyed, will be found in table 13. The metabolic data for the period are brought together in table 5 of the Appendix.

The water exchange during a fourth period of undernutrition is presented next in table 14. Ten days before the beginning of this period a low calory diet consisting solely of milk and sugar was instituted and continued without change. It is probably true that the

TABLE 13

Comparison between predicted and determined water balance in undernutrition

Date	Change in subject's weight	Theoretical loss	Water balance		
			Predicted	Determined	Error
1928	*grams*	*grams*	*grams*	*grams*	*grams*
December 9	−165	114	−51	−49	2
December 10	+20	114	+134	+156	22
December 11	−260	114	−146	−155	9
December 12	−120	114	−6	+6	12
December 13	+110	114	+224	+221	3
December 14	−355	114	−241	−227	14
December 15	−165	114	−51	−61	10
December 16	−170	114	−56	−60	4
December 17	−45	114	+69	+66	3
December 18	−105	114	+9	+68	59
December 19	±0	114	+114	+104	10
December 20	−230	114	−116	−128	12
December 21	−50	114	+64	+76	12
December 22	−105	114	+9	0	9
December 23	−140	114	−26	−33	7
December 24	+130		+244	+243	1
Totals			+174	+227	

Error for period 53 grams

destruction of glycogen had ceased before the period began, and that all the endogenous calories came from protein and fat. Since there was a falling heat production during this long period, two metabolic mixtures were calculated.

The data needed to obtain the water exchange will be found in the Appendix, tables 6 and 7. The former is for the first metabolic mixture and the latter for the second mixture.

We come now to the study of water exchange in patients. We have selected from our series what we consider to be an average example. The subject was a girl aged fourteen years, of low mentality, and who

TABLE 14

Comparison between predicted and determined water balance in undernutrition

Date	Change in subject's weight	Theoretical loss	Water balance		
			Predicted	Determined	Error
1929	*grams*	*grams*	*grams*	*grams*	*grams*
January 26	+50	127	+177	+175	2
January 27	−115	127	+12	+33	21
January 28	−285	127	−158	−147	11
January 29	+25	127	+152	+139	13
January 30	+15	127	+142	+129	13
January 31	+35	127	+162	+175	13
February 1	−270	127	−143	−153	10
February 2	−430	127	−303	−293	10
Totals			+41	+58	
February 3	+285	97	+382	+369	13
February 4	−225	97	−128	−105	23
February 5	+65	97	+162	+149	13
February 6	−125	97	−28	−41	13
February 7	+115	97	+212	+198	14
February 8	−345	97	−248	−201	47
February 9	−150	97	−53	−55	2
February 10	−90	97	+7	−4	11
February 11	−35	97	+62	+48	14
February 12	−350	97	−253	−215	38
February 13	+20	97	+117	+101	16
February 14	−5	97	+92	+75	17
February 15	−310	97	−213	−176	37
Totals			+108	+143	
Grand Totals			+149	+201	

Error for period 52 grams

had an endocrine disturbance that had caused gigantism and precocious sexual development. Her basal metabolic rate was about 25 per cent below normal. She did not cooperate well with us. She was fed a mixed diet of the type described on page 163; and the water content of the food was accordingly obtained by means of the duplicate diet as described on page 163. The duplicate diet was analysed for nitrogen but not for fat or carbohydrate. The food table values were used for the latter two. The urine solids were obtained by dessication in a partial vacuum over sulphuric acid. We found this method much less satisfactory than the procedure of Shackell (1).

The subject was allowed to be out of bed in a wheel chair several hours daily, but was not permitted to leave the room unless she was to be brought to the laboratory.

When the period was over it was found that the daily record of the insensible loss was unsatisfactory since the heat production obtained from it was repeatedly less than the basal metabolic rate. Upon looking back we recalled that the patient often sat in the wheel chair with bare legs in a room that, at times, was distinctly cool. The small insensible loss was apparently caused by chilling the lower extremities.

In order to compensate for this error we proceeded as follows: A few weeks after the period just described had ended, the patient was strictly confined to bed under continuous guard. Bathing was ommitted. Under these conditions the total heat production for three consecutive days was 1900, 1930, and 1930 calories. A number of determinations of the basal metabolic rate, preceding and following this special interval of three days, gave an average of 1506 calories. The total calories when the patient was continuously confined to bed were accordingly 27 per cent more than the basal calories. During the earlier period, when the insensible loss was irregular, twenty-one determinations of the basal metabolic rate gave an average of 1604 calories for 24 hours. If the total calories at this time had been 27 per cent greater, they would have been 2037. But since the patient had been more active during those days we inferred that 100 calories should be added for such factors. This gave us the final value of 2137 as the total twenty-four hourly heat production.

Before presenting the water balances for the long period when 2137 calories was assumed to be the average heat production, it is desirable to see what results were obtained during the special three day period when the heat production was so uniform. (See table 15 and Appendix, table 8.) The large error of the second day was, as usual, on a day when the patient had a very large stool. The considerable errors on the other two days are largely attributable to the complicated diet.

The water balances of the long period when the heat production was estimated to be 2137 calories for each twenty-four hours, are presented in table 16. (The data will be found in table 9 of the Appendix.)

In spite of the greater likelihood of larger errors for the reasons given above, the results are fairly satisfactory. From February 25th to March 12th the patient should have lost 2996 grams of weight,

TABLE 15

Water balance in a patient confined to bed but receiving a complicated diet

Date	Change in subject's weight	Theoretical gain	Water balance		
			Predicted	Determined	Error
1928	*grams*	*grams*	*grams*	*grams*	*grams*
April 24	−157	7	−164	−134	30
April 25	−565	7	−572	−517	55
April 26	+129	7	+122	+100	22
Totals			−614	−551	
Error for period 63 grams					

but her weight fell only 10 grams during these sixteen days. The predicted retention of water was 2886 grams and the data showed a retention of 2672 grams. Accordingly, in spite of the complicated diet and the doubt regarding the figure obtained for heat production, the determined retention of water was only 7 per cent less than the prediction.

Following the large retention of water there was an excessive output of water. During the nine days from March 12 to March 21 the patient should have lost 1629 grams. Since her weight fell 3995 grams, the difference, 2366 grams, was the predicted water loss. The determined loss was 2266 grams. In this case the determined loss was only 4 per cent less than the prediction.

TABLE 16

Water balances when complicated diet is fed and subject is up in a chair during the day

Date	Change in subject's weight	Theoretical loss	Water balance		
			Predicted	Determined	Error
1928	*grams*	*grams*	*grams*	*grams*	*grams*
February 25	0	181	+181	+157	24
February 26	−85	181	+96	+66	30
February 27	−480	181	−299	−249	50
February 28	+300	181	+481	+448	33
February 29	+280	181	+461	+428	33
March 1	−350	181	−169	−144	25
March 2	−230	181	−49	−39	10
March 3	−110	181	+71	+42	29
March 4	+500	181	+681	+650	31
March 5	−290	181	−109	−48	61
March 6	−110	181	+71	+44	27
March 7	+260	181	+441	+396	45
March 8	−360	181	−179	−210	31
March 9	+170	181	+351	+338	13
March 10	−225	181	−44	−79	35
March 11	+720	181	+901	+872	29
Totals			+2,886	+2,672	
March 12	−665	181	−484	−411	73
March 13	−90	181	+91	+71	20
March 14	−640	181	−459	−434	25
March 15	−300	181	−119	−107	12
March 16	−700	181	−519	−486	33
March 17	−195	181	−14	−48	34
March 18	−875	181	−694	−673	21
March 19	−150	181	+31	+13	18
March 20	−380	181	−199	−191	7
Totals			−2,366	−2,266	
Grand Totals			+520	+406	

Error for period 114 grams

V

There remains now the discussion of the degree of accuracy of the water balance obtained by the above methods. We have dealt with this question by comparing the predicted balance with the determined balance. This implies that the prediction is absolutely correct. But the information at hand does not warrant such an assumption to its full extent, since the predicted balance is derived from the

TABLE 17

Error in determination of water balance

Period number	Date	Daily error			Error for period per day	Notes
		Maximal	Minimal	Average		
		grams	*grams*	*grams*	*grams*	
1	January 26–February 15	47	2	17	2.5	Diet completely analysed. Undernutrition. No destruction of glycogen
2	December 9–24	57	2	12	3.3	Diet completely analysed. Undernutrition. Little or no destruction of glycogen
3	January 16–25	21	0	9	1.9	Diet completely analysed. Undernutrition. Moderate destruction of glycogen
4	November 25–December 2	37	4	12	5.7	Diet completely analysed. Undernutrition. Much glycogen destroyed
5	December 3–8	28	8	16	7.8	Diet completely analysed. Overnutrition. Much glycogen stored
6	November 13–23	53	3	21	9.7	Diet completely analysed. Overnutrition. No data regarding glycogen
7	January 11–15	40	2	11	4.8	Diet completely analysed. Overnutrition. No data regarding glycogen
8	April 24–26	55	22	36	21.0	Only nitrogen of diet determined. Duplicate diet used. Overnutrition. Period only three days
9	February 25–March 20	73	7	30	4.6	Only nitrogen of diet determined. Duplicate diet used. Undernutrition. Small destruction of glycogen

metabolic mixture and it usually is not possible to avoid small inaccuracies in the latter. Accordingly the error, as the term is used in table 17, is not a final measure of the method; but is an approximation, approaching nearest to the truth when the statement of the metabolic mixture is most nearly correct.

In period 1 of table 17, the conditions were most suitable for obtaining a satisfactory statement of the materials burned. The values for period 1 may, therefore, be accepted as the probable error of the method.

The conditions for period 2 are only slightly different from those of period 1; so that the error is nearly the same.

It will be seen that the average error is only about 15 grams per day, but that a mistake of 50 grams may occur on any single day. Since the water that the subject had to deal with from day to day was about 2100 grams, the average error made in accounting for it was less than 1 per cent; and, what is more important, the maximal error was less than 3 per cent.

Interestingly the errors for periods 3 and 4, when the metabolic mixture cannot be correct because it does not include the glycogen that was destroyed, are no greater. Likewise, in the three periods of overnutrition, periods 5, 6 and 7 in the table, when the same doubt exists regarding glycogen, the error is of only slightly greater magnitude than in period 1.

The two periods 8 and 9, when the conditions were not so simple nor so satisfactory, gave results that are better than anticipated.

The last column of table 17 deals with the error in water balance for whole periods, expressed in 24 hourly amounts. This is not the same as the average error, since the daily differences tend to counteract each each other and so reduce the discrepancy. The error in determining the water balance for the period was always less than 0.5 per cent of the water to be dealt with, except in period 8 where the period is too short to be of much value in this regard.

BIBLIOGRAPHY

1. Shackell, L. F., Am. J. Physiol., 1909, xxiv, 325. An Improved Method of Desiccation with Some Applications to Biological Problems.
2. DuBois, E. F., Basal Metabolism in Health and Disease, 2nd ed., Lea & Febiger, Philadelphia, 1927, pp. 24, 29, 216.
3. Johnston, M. W., and Newburgh, L. H., J. Clin. Invest., 1929, viii, 147. The Determination of the Heat Eliminated by the Human Being.
4. Lusk, G., Elements of the Science of Nutrition, 3rd ed., W. B. Saunders Co., Philadelphia, 1917, p. 39.

5. Isenschmid, Med. Klin., 1918, xiv, 1128. Die Bestimmung der wasserbilanz am Krankenbett.
6. Schwenkenbecher, A., and Inagaki, Arch. fur Exper. Path., u., Pharmacol., 1906, liv, 168. Ueber den Wasserwechsel des fiebernden Menschen.
7. Benedict, F. G., and Fox, E. L., J. Biol. Chem., 1925, lxvi, 783. A Method for the Determination of the Energy Values of Foods and Excreta.

APPENDIX

TABLE 1

Normal subject: overnutrition. November 13–23, 1928

Date	Weight of subject 8:40 a.m.	Water	Milk		Bread		Bananas		Grapenuts*	Butter*	Sucrose	Urine			Stool		Insensible loss	Heat production
			Total	Water	Total	Water	Total	Water				Total	Solids	N	Total	Solids		
	grams	*grams*	*grams*	*per cent*	*grams*	*per cent*	*grams*	*per cent*	*grams*	*grams*	*grams*	*grams*	*grams*	*grams*	*grams*	*grams*	*grams*	*calories*
November 13	64,010	491	1,312	85.0	100	39.1	197	75.5	61	16	99	1,116	46.5	11.03	111	23	1,524	2,450
November 14	63,535	19	1,297	84.7	103	40.4	197	75.4	61	16	98	727	44.2	11.38	0		1,239	2,080
November 15	63,360	2	1,312	85.8	100	42.5	201	77.4	60	16	102	727	45.3	11.25	154	37	1,383	2,275
November 16	62,890	591	1,312	84.9	101	42.0	198	76.6	63	16	109	622	44.8	12.05	0		1,352	2,220
November 17	63,305	1,122	1,310	85.3	103	38.8	202	73.6	60	16	109	1,389	44.8	12.39	177	43	1,271	2,100
November 18	63,390	669	1,304	84.7	100	33.8	198	73.5	61	15	112	1,396	44.6	11.20	0		1,087	1,880
November 19	63,370	571	1,312	84.5	100	39.4	198	73.7	58	15	111	921	40.7	10.56	606	82	1,190	2,020
November 20	63,020	504	1,310	85.4	98	37.0	198	73.8	61	15	100	816	41.3	10.85	136	17	1,109	1,920
November 21	63,245	400	1,307	85.1	101	40.0	198	74.2	60	15	99	919	42.5	11.30	0		1,270	2,110
November 22	63,235	548	1,304	84.8	102	40.0	197	74.6	59	16	98	734	41.2	11.02	147	26	1,252	2,100
November 23	63,425	765	1,311	85.3	101	38.8	199	74.5	60	16	98	1,574	43.7	10.79	0		1,100	1,900
November 24	63,300																	

Diet: Protein 63 grams; fat 94 grams; carbohydrate 309 grams.

Stool N: Average 1.7 grams per day.

Metabolic mixture: Protein 77 grams; fat 63 grams, carbohydrate 309 grams.

* The average of several samples gave 2.5 per cent water for grapenuts and 13.8 per cent for butter.

TABLE 2

Normal subject: Overnutrition. December 3–8, 1928

Date	Weight of subject 8:40 a.m.	Water	Milk		Bread		Bananas		Sucrose	Butter*	Urine			Stool		Insensible loss	Heat production
			Total	Water	Total	Water	Total	Water			Total	Solids	N	Total	Solids		
	grams	*grams*	*grams*	*per cent*	*grams*	*per cent*	*grams*	*per cent*	*grams*	*grams*	*grams*	*grams*	*grams*	*grams*	*grams*	*grams*	*calories*
December 3	61,095	552	1,508	86.0	100	38.7	198	74.8	98	11	1,139	38.7	11.6	162	19	1,019	1,795
December 4	61,240	838	1,506	86.0	100	39.3	197	76.1	98	11	1,096	36.4	10.3	0		1,134	1,930
December 5	61,760	455	1,511	86.1	101	40.3	198	76.6	100	10	1,240	34.9	12.7	101	26	1,183	2,025
December 6	61,610	962	1,507	86.4	100	40.0	197	75.6	100	9	1,514	40.0	10.3	150	26	1,261	2,100
December 7	61,560	502	1,513	85.8	101	40.3	200	76.2	99	10	1,204	32.6	8.9	0		1,246	2,085
December 8	61,535	616	1,513	85.6	101	39.2	197.	75.7	100	10	1,106	35.8	9.7	140	30	1,371	2,240
December 9	61,455																

Diet: Protein 59 grams; fat 88 grams; carbohydrate 270 grams.
Stool N: Average 0.63 gram per day.
Metabolic mixture: Protein 66 grams; fat 76 grams; carbohydrate 270 grams.
* 1.5 grams daily was allowed for water contained in the butter.

TABLE 3

Normal Subject. Undernutrition. November 25–December 2, 1928

Date	Weight of subject 8:40 a.m.	Water	Milk		Bread		Butter*	Urine			Stool		Insensible loss	Heat production
			Total	Water	Total	Water		Total	Solids	N	Total	Solids		
	grams	*grams*	*grams*	*per cent*	*grams*	*per cent*	*grams*	*grams*	*grams*	*grams*	*grams*	*grams*	*grams*	*calories*
November 25	62,935	310	1,502	88.8	102	38.2	15	1,216	42.8	10.8	140	20	1,248	2,085
November 26	62,260	378	1,484	88.7	100	37.9	16	1,157	45.3	12.2	0		1,180	2,000
November 27	61,900	587	1,498	88.5	100	41.3	15	874	45.0	12.7	0		1,331	2,190
November 28	61,895	564	1,502	88.4	100	39.9	16	987	43.4	12.8	0		1,275	2,115
November 29	61,815	479	1,500	88.4	100	40.3	15	803	42.6	12.8	205	46	1,206	2,035
November 30	61,695	715	1,501	88.4	101	39.7	13	1,436	44.4	11.5	102	14	1,022	1,800
December 1	61,465	819	1,500	88.7	101	40.9	16	1,684	43.2	12.2	0		1,027	1,800
December 2	61,190	547	1,501	88.3	100	40.5	16	1,004	42.0	11.9	101	27	1,153	1,965
December 3	**61,095**													

Diet: Protein 60 grams; fat 44 grams; carbohydrate 126 grams.
Stool N: Average 0.45 gram per day.
Metabolic mixture: Protein 79 grams; fat 131 grams; carbohydrate 126 grams.
* Two grams daily was allowed for the water contained in the butter.

TABLE 4

Normal subject. Undernutrition. January 16–25, 1929

Date	Weight of subject 8:30 a.m.	Water	Milk		Sugar	Urine			Stool		Insensible loss	Heat production
			Total	Water		Total	Solids	N	Total	Solids		
	grams	*grams*	*grams*	*per cent*	*grams*	*grams*	*grams*	*grams*	*grams*	*grams*	*grams*	*calories*
January 16	59,785	290	1,999	89.5	45	1,585	42.8	10.24	187	33	1,087	1,880
January 17	59,260	234	2,000	89.5	44	1,176	39.1	10.01	131	18	995	1,760
January 18	59,235	202	2,001	89.6	44	1,382	38.7	10.79	107	15	993	1,760
January 19	59,000	143	2,000	89.7	46	1,301	36.7	10.14	124	15	998	1,760
January 20	58,765	474	2,001	89.9	45	1,557	41.0	11.24	0	0	992	1,745
January 21	58,735	197	2,000	89.7	45	1,340	37.9	10.48	162	27	974	1,730
January 22	58,500	103	2,001	89.6	46	1,270	37.1	9.99	119	17	935	1,680
January 23	58,325	173	1,999	89.7	45	1,163	38.4	10.37	0	0	1,008	1,760
January 24	58,370	310	2,001	89.7	45	1,650	39.3	10.72	159	28	877	1,610
January 25	58,040	223	1,998	89.7	46	1,514	39.3	11.06	0	0	1,003	1,760
January 26	57,790											

Diet: Protein 63 grams; fat 26 grams; carbohydrate 148 grams.
Stool N: Average per day 0.6 gram.
Metabolic mixture: Protein 69 grams; fat 24 grams; carbohydrate 148 grams.

TABLE 5

Normal subject. Undernutrition. December 9–25, 1928

Date	Weight of subject 8.40 a.m.	Water	Milk		Bread		Butter	Sugar	Urine			Stool		Insensible loss	Heat production
			Total	Water	Total	Water			Total	Solids	N	Total	Solids		
1928	*grams*	*grams*	*grams*	*per cent*	*grams*	*per cent*	*grams*	*grams*	*grams*	*grams*	*grams*	*grams*	*grams*	*grams*	*calories*
December 9	61,455	187	1,397	90.5	130	40.6	11	40	852	37.6	9.49	0	0	1,077	1,870
December 10	61,290	761	1,400	90.0	131	41.0	11	40	1,146	37.1	10.25	90	27	1,086	1,880
December 11	61,310	502	1,399	89.9	129	37.7	11	40	1,202	36.5	9.82	0	0	1,138	1,930
December 12	61,050	353	1,399	90.0	130	38.8	10	40	913	38.0	10.47	53	19	1,087	1,880
December 13	60,930	673	1,403	90.3	130	39.0	10	40	1,150	36.4	10.38	0	0	995	1,760
December 14	61,040	316	1,402	90.1	130	41.0	10	40	1,208	37.4	10.65	51	17	994	1,760
December 15	60,689	366	1,404	90.1	130	39.3	10	40	1,176	34.4	9.09	0	0	939	1,690
December 16	60,520	450	1,403	89.9	130	40.9	10	40	1,229	37.6	10.58	0	0	973	1,730
December 17	60,350	558	1,400	90.1	129	39.3	10	40	1,212	37.7	10.44	0	0	970	1,730
December 18	60,305	704	1,399	90.0	130	41.5	10	40	957	35.1	9.90	321	62	1,107	1,900
December 19	60,200	417	1,396	90.1	130	37.0	10	40	1,016	34.4	9.66	0	0	977	1,740
December 20	60,200	194	1,401	90.0	129	39.8	10	40	906	30.9	10.32	0	0	1,098	1,890
December 21	59,970	335	1,399	89.8	130	37.8	9	39	789	32.8	10.45	110	28	1,063	1,850
December 22	59,920	448	1,400	90.1	129	38.6	10	40	855	32.9	10.70	0	0	1,276	2,115
December 23	59,815	67	1,403	90.0	130	40.4	11	41	718	37.7	9.85	0	0	1,074	1,860
December 24	59,675	255	1,398	90.6	128	36.7	10	40	644	37.0	9.94	0	0	1,058	1,840
December 25	59,805														

Diet: Protein 57 grams; fat 22 grams; carbohydrate 178 grams.

Stool N: Average per day 0.43 gram.

Metabolic mixture: Protein 66 grams; fat 93 grams; carbohydrate 178.

TABLE 6

Normal Subject. Undernutrition. January 26–February 2

Date	Weight of subject 8:40 a.m.	Water	Milk*		Urine			Stool			Insensible loss	Heat production
			Total	Water	Total	Solids	N	Total	Solids	N†		
	grams	*grams*	*grams*	*per cent*	*grams*	*grams*	*grams*	*grams*	*grams*	*grams*	*grams*	*calories*
January 26	57,790	75	1,997	90.1	1,108	39.2	11.07	0		0.6	958	1,715
January 27	57,840	283	2,000	89.7	1,350	41.2	11.21	113	29	0.6	979	1,730
January 28	57,725	119	2,000	89.6	1,156	37.9	11.25	147	25	0.6	1,145	1,950
January 29	57,440	68	2,000	89.7	959	38.2	10.95	0		0.6	1,128	1,930
January 30	57,465	159	2,015	89.7	1,206	39.1	11.73	0		0.6	998	1,760
January 31	57,480	193	2,023	89.7	1,111	38.5	11.33	105	27	0.6	1,010	1,780
February 1	57,515	147	1,997	89.7	1,422	40.2	11.38	0		0.6	1,037	1,815
February 2	57,245	0	2,001	89.7	1,334	39.8	10.66	85	20	0.6	1,057	1,840

Diet: Protein 63 grams (N × 6.25); fat 26 grams (Babcock); carbohydrate 148 grams (by difference—sucrose 45 grams).
Metabolic mixture: Protein 74 grams; fat 103 grams; carbohydrate 148 grams.

* To obtain total weight of diet add 45 grams for sucrose.

† The stool from January 26 to February 15 was mixed and analysed in duplicate for N. The value obtained was apportioned per day.

TABLE 7

Normal subject. Undernutrition. February 3–15, 1929

Date	Weight of subject 8:40 a.m.	Water	Milk		Urine	Stool		
			Total	Water		Total	Solids	N
1929	*grams*	*grams*	*grams*	*per cent*	*grams*	*grams*	*grams*	*grams*
February 3	56,815	166	2,000	89.7	905	0		0.6
February 4	57,100	88	2,000	89.7	1,236	188	37	0.6
February 5	56,875	74	2,002	89.7	985	0		0.6
February 6	56,940	121	2,000	89.7	1,340	0		0.6
February 7	56,815	249	2,000	89.7	1,257	0		0.6
February 8	56,930	200	2,001	89.7	1,360	300	62	0.6
February 9	56,585	134	1,999	89.7	1,303	60	10	0.6
February 10	56,435	430	2,001	89.7	1,696	0		0.6
February 11	56,345	73	2,000	89.7	1,274	0		0.6
February 12	56,310	86	2,001	89.7	1,180	361	53	0.6
February 13	55,960	0	2,001	89.7	1,132	0		0.6
February 14	55,980	117	1,999	89.7	1,326	0		0.6
February 15	55,975	43	1,990	89.7	1,106	288	44	0.6
February 16	55,670							

Diet and stool N: The same as in table 6.

Metabolic mixture: Protein 69 grams; fat 91 grams; carbohydrate 148 grams.

TABLE 8

Overnutrition with mixed diet. April 24–26, 1928

Date	Weight of subject 8:25 a.m.	Water	Patient's diet	Duplicate diet		Urine			Stool		Insensible loss	Heat production
				Total	Dry	Total	Solids	N	Total	Solids		
1928	*grams*	*grams*	*grams*	*grams*	*grams*	*grams*	*grams*	*grams*	*grams*	*grams*	*grams*	*calories*
April 24	90,927	1,202	1,568	1,593	420	1,652	56	12.12	179	38	1,096	1,900
April 25	90,770	1,235	1,527	1,503	381	1,579	55	12.19	620	73	1,128	1,930
April 26	90,205	1,327	1,466	1,445	384	1,540	54	12.65	0		1,124	1,930
April 27	90,334											

Diet (food tables): Protein 85 grams; fat 100 grams; carbohydrate 186 grams.
N, in; $85 \div 6.25 = 13.6$ grams. N, out; 12.3 (urine) + 10 per cent for stool = 13.5 grams.
Metabolic mixture: Protein 85 grams; fat 93 grams; carbohydrate 186 grams.

TABLE 9

Undernutrition with mixed diet. February 25 to March 20, 1928

Date	Weight of subject 8:45 a.m.	Water	Patient's diet	Duplicate diet		Urine			Stool		Insensible loss
				Total	Dry	Total	Solids	N	Total	Solids	
1928	*grams*	*grams*	*grams*	*grams*	*grams*	*grams*	*grams*	*grams*	*grams*	*grams*	*grams*
February 25	94,200	797	1,056	1,052	192	1,111	32.7	9.97	0		742
February 26	94,200	928	1,050	1,034	196	1,304	42.2	13.88	0		759
February 27	94,115	1,255	1,050	1,055	193	905	23.8	7.62	467	75	1,413
February 28	93,635	1,252	1,035	1,024	188	1,077	26.9	9.43	0		910
February 29	93,935	1,343	984	974	200	1,354	38.0	11.47	0		693
March 1	94,215	1,042	1,089	1,085	200	1,131	26.8	7.60	401	63	949
March 2	93,865	788	1,024	1,034	181	1,177	41.6	13.02	0		865
March 3	93,635	1,891	965	957	200	2,086	40.4	11.88	0		880
March 4	93,525	1,366	1,023	1,019	201	1,148	35.1	11.36	0		741
March 5	94,025	1,152	1,066	1,064	197	1,220	36.3	10.43	432	85	856
March 6	93,735	1,036	1,026	1,018	199	1,448	40.6	11.18	0		724
March 7	93,625	1,611	1,061	1,052	207	1,293	31.6	9.70	0		1,119
March 8	93,885	1,062	1,062	1,056		1,138	18.7?	6.08	0		1,346
March 9	93,525	1,435	1,038	1,036	187	1,255	35.7	10.05	0		1,048
March 10	93,695	754	976	967	201	1,096	36.4	10.07	0		859
March 11	93,470	1,632	1,005	1,004	211	854	44.1	10.43	0		1,063
March 12	94,190	1,151	1,087	1,072	205	1,466	38.5	10.66	434	115	1,003
March 13	93,525	1,306	986	992	202	1,602	37.0	9.38	0		780
March 14	93,435	1,101	1,033	1,025	192	1,708	41.8	11.21	199	44	867
March 15	92,795	1,735	971	957	192	1,305	26.4	6.60	390	53	1,311
March 16	92,495	1,519	1,065	1,047	179	1,815	38.3	9.36	554	53	915
March 17	91,795	1,900	1,013	1,012	223	1,937	50.5	11.21	0		1,171
March 18	91,600	1,281	969	961	189	1,798	37.7	10.08	339	41	988
March 19	90,725	1,316	1,089	1,087	215	1,440	37.8	11.07	202	21	913
March 20	90,575	1,409	1,030	1,023	201	1,268	35.5	10.25	385	41	1,166
March 21	90,195										

Diet: Protein 64.5 grams (N × 6.25); fat 40 grams (food table); carbohydrate 74 grams (food table).
Stool N: Average daily 1.32 grams.
Metabolic mixture: Protein 73 grams; fat 172 grams; carbohydrate 74 grams.