BODY COMPOSITION IN PROTEIN-CALORIE MALNUTRITION

J. D. L. HANSEN, G. L. BRINKMAN AND M. D. BOWIE, *Departments of Child Health and Medicine, University of Cape Town*

The term 'protein-calorie malnutrition' is one used to embrace the following syndromes under a single heading:[1] (1) kwashiorkor; (2) incomplete mild kwashiorkor; (3) nutritional marasmus, and (4) nutritional dwarfing (or underweight for age). In each of these the nutritional background is one of protein deficiency, but with varying levels of intake of calories especially in the form of carbohydrate. The syndromes of protein-calorie malnutrition are common in developing or under-developed communities where the death rate among children in the 1 - 4 year age group may be 20 - 50 times as high as in affluent societies.[2, 3] In the planning of more effective preventative and curative measures to meet this public health problem a better understanding is needed of the effect of protein-calorie malnutrition on body composition and function.

With regard to body composition it is known that total body water (TBW) is increased in malnourished children[4-6, 26] and that the extracellular water (ECW) is also increased.[7-11] In only one instance[6] has the TBW and ECW been measured simultaneously and this was done in 'kwashiorkor' children before and after loss of oedema.

In the investigation to be reported here the TBW and ECW of cases of nutritional marasmus and nutritional dwarfing (underweight) have been measured. This has been done to determine whether the subjects suffering from these variants of protein-calorie malnutrition differ in body water composition from cases of kwashiorkor. In addition the changes that occur in body composition from the time of admission to hospital with kwashiorkor until complete recovery have been observed in 2 subjects by doing serial determinations over a period of 2 - 5 months.

CASE MATERIAL

This consisted of 32 non-White male pre-school children, 17 of whom were admitted to hospital with kwashiorkor and 7 with nutritional marasmus. The 8 other children were of low weight for age, i.e. below the 3rd Boston percentile in weight, but were otherwise asymptomatic and apparently healthy. The children with kwashiorkor all had oedema on admission. Their clinical details are to be presented elsewhere.[26] Two of these cases were kept in a convalescent home for 2 and 5 months respectively where they reached 96% of their expected weight for age (the 50th percentile line of growth charts of the Harvard School of Public Health, Boston[12] was used as expected weight). They were then assumed to be fully recovered and equivalent to 'normal control' subjects. The cases with marasmus were extremely wasted and underweight for age but had no clinical oedema.

PROCEDURE AND METHODS

Body water determinations (TBW and ECW) were performed on the kwashiorkor cases within 6 days of admission and again after loss of clinical oedema and not longer than 20 days after the first test. The average interval between tests was 10 days. The children with marasmus and the low-weight children were tested once only. An ECW estimation was not performed on the low-weight children.

Total body water was measured by determining the dilution in the serum of an intramuscular injection of tritiated water allowing 5 hours for equilibration.[13] Extracellular water was measured with sodium thiosulphate.[14]

RESULTS

The results are summarized in Tables I - IV and Figs. 1 - 5.

(a) *Weight*. The children with marasmus were extremely underweight for age averaging only 47% (±4·9) of expected weight. This is considerably less than the kwashiorkor cases (70% ± 6·4) and the 'low-weight' children (71·8% ± 3·1). The recovered 'normal control' cases averaged 96% expected weight (Table I).

TABLE I. BODY WATER COMPOSITION

		Age mths.	Weight (kg.)	% Expected weight	TBW % Body-weight	ECW % Body-weight	Solids (kg.)
Recovered kwashiorkor 'controls'	A.R.	20	11·51	98	59	24	4·74
	W.C.	21	11·22	94	58	25	4·76
Average	±S.D.	20·5	11·36 ±0·21	96 ±2·8	58·5 ±0·7	24·5 ±0·7	4·75 ±0·05
Low weight	J.U.	39	10·37	70	66		3·53
	B.E.	31	9·03	67	69		2·80
	A.S.	22	9·09	75	66		3·09
	J.W.	30	9·87	74	59		4·05
	D.A.	26	9·13	71	66		3·11
	M.D.	15	7·73	72	69		2·39
	R.M.	31	10·20	76	64		3·67
	I.A.	25	8·77	69	67		2·89
Average	±S.D.	27·4	9·27 ±0·86	71·8 ±3·1	65·8 ±3·2		3·19 ±0·53
Marasmus	J.W.	18	5·02	44	85	42	0·75
	B.S.	21	5·94	50	77	31	1·37
	E.A.	15	4·88	45	74	36	1·27
	J.C.	31	7·32	54	70	29	2·19
	S.M.	27	6·45	49	71	28	1·87
	C.M.	10	3·69	39	80	36	0·74
	D.A.	9	4·42	49	81	37	0·84
Average	±S.D.	18·7	5·39 ±1·25	47·1 ±4·9	76·9 ±1·8	34·1 ±5·0	1·29 ±0·57
Kwashiorkor* Average	±S.D.	17 cases					
With oedema		19·9	8·19 ±1·38	70 ±6·4	69·9 ±6·7	33·2 ±3·6	2·52 ±0·90
After loss of oedema			7·80 ±1·24	66·8 ±6·7	68·1 ±5·2	26·8 ±4·0	2·52 ±0·69

*Individual information to be given elsewhere.[26]

(b) *Total body water*. As a percent of body weight the total body water increased with the degree of underweight. Thus the children with marasmus had the highest TBW of all—77%. The kwashiorkor children had a TBW

TABLE II. INTRACELLULAR WATER

		TBW l.	ECW l.	ICW l.	ICW % body-weight
Recovered 'controls'	A.R.	6·77	2·81	3·96	34
	W.C.	6·47	2·78	3·69	33
	Mean	6·62	2·79	3·83	34
Low weight	Mean	6·04 ± 0·45	—	—	—
Marasmus	Mean	4·09 ± 0·74	1·81 ± 0·289	2·28 ± 0·521	42
Kwashiorkor					
Oedema		5·67 ± 0·748	2·73 ± 0·528	2·95 ± 0·521	36
No oedema		5·29 ± 0·756	2·05 ± 0·343	3·24 ± 0·594	42
		$p < 0·01$	$p < 0·001$	$p < 0·05$	

of 69·9% and 68·1% respectively before and after loss of oedema, the low-weight children 66% and the 'controls' 58% (Table I). This phenomenon is illustrated in Fig. 1 where it can be seen that there is a significant negative correlation between percent expected weight and percent TBW ($r = -0·72$, $p < 0·001$). Since the children in this investigation were all in the same age group a similar significant correlation is found ($r = -0·73$, $p < 0·001$) if absolute weight instead of percent expected weight is used on the X axis (Fig. 2). In Fig. 2 the values before and after oedema are included showing that the oedematous

TABLE III. REDUCTION IN BODY SOLIDS

	% Ideal solids	% Ideal weight
Recovered kwashiorkor ..	104	96
Low weight	63	72
Marasmus	28	47
Kwashiorkor	55	70

cases appear to be little different from the non-oedematous in total body water composition. Expressing water as ml. water/G of solids gives a similar picture (Fig. 3).

(c) *Extracellular water*. As a percent of body weight the ECW was significantly less after loss of oedema in the kwashiorkor cases (33% and 27%, $t = 4·88$, $p < 0·001$) (Table I). This decrease was absolute as well as relative,

TABLE IV. CHANGES DURING RECOVERY

	Age (months)	Weight (kg.)	TBW l.	TBW % body-weight	ECW l.	ECW % body-weight	Solids (kg.)	Time between first and second estimations
A.R.	15	6·17	5·00	81	2·10	34	1·17	13 days
	15	5·34	4·13	77	1·42	27	1·21	
	20	11·51	6·77	59	2·81	24	4·74	
W.C.	19	8·27	5·49	66	2·52	30	2·78	6 days
	19	8·34	5·41	65	1·86	22	2·93	
	21	11·22	6·47	58	2·78	25	4·76	

2·73 l. cf. 2·05 l. ($p < 0·001$) (Table II). As with the TBW, the ECW was related to weight (Fig. 4), i.e. the lightest children (marasmus patients without oedema) had the highest percentage of ECW (34·1% ± 5·0) (Table I). In Fig. 4 it can be seen that the ECW of the oedematous cases is in general higher for their weight than the non-oedematous cases. The 2 recovered children had an ECW of 25% of the body weight which is in good agreement with literature values for children of their age.[14]

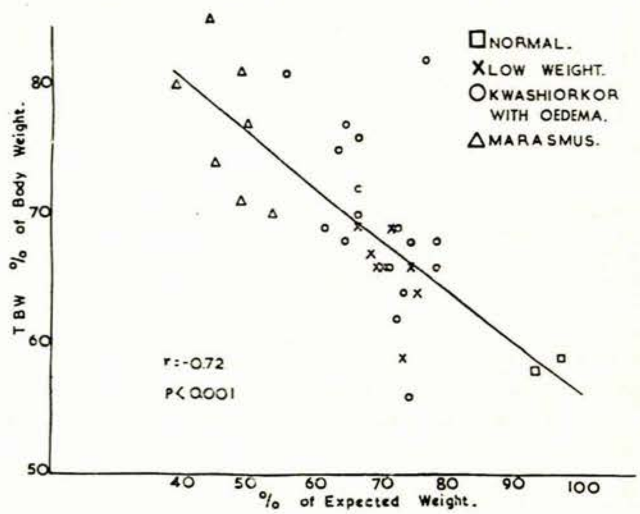

Fig. 1. Significant negative correlation between percent expected weight and percent TBW.

(d) *Intracellular water*. The derived figures (TBW - ECW) for the ICW compartment are summarized in Table II. In the kwashiorkor cases the ICW space increased from 36% to 42% of body weight as oedema was lost.

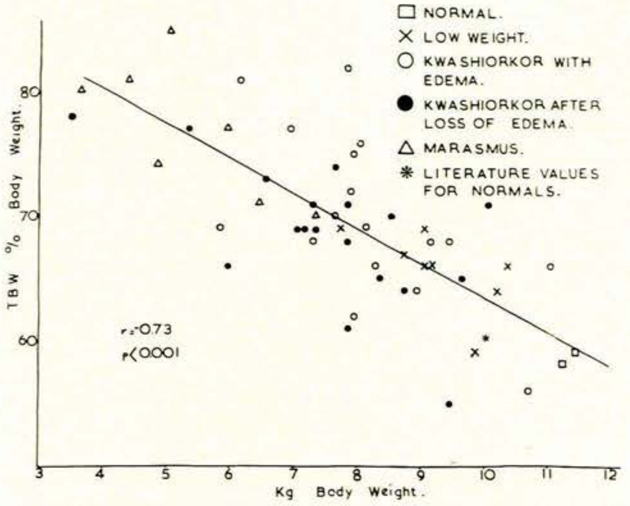

Fig. 2. Significant negative correlation between actual weight and percent TBW.

There was a significant increase of absolute value of ICW ($p<0 \cdot 05$) which, when coupled with the loss of ECW volume, suggests that there was a shift of some ECW to the intracellular compartment. The ICW space is slightly higher in the oedema-free kwashiorkor cases and children with marasmus than in the recovered 'control' cases (42% cf. 34%).

(e) *Body solids*. Body solids = body weight-total body water. Necessarily the body solids show a reciprocal decrease with an increase of TBW. Using a total body water of 60% as an average normal figure for this age group, the ideal body solids for a particular individual can be calculated.[4] The reduction in body solids in the groups under investigation is depicted in Table III. The degree of body solid deficit is much greater than the weight deficit particularly for the marasmus group where there is a 72% reduction in solids as opposed to a 53% reduction in weight.

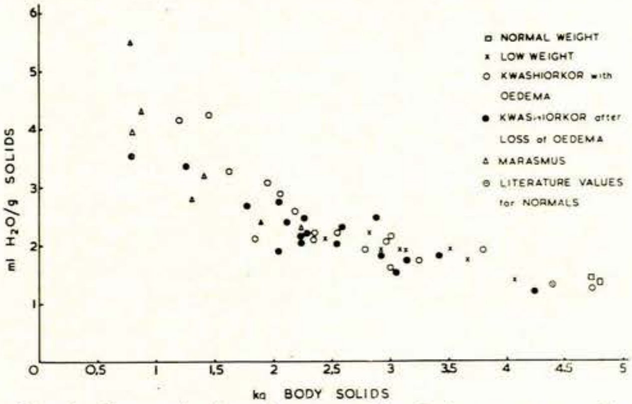

Fig. 3. Shows similar picture as Fig. 2 (water expressed as ml. water/G of solids).

(f) *Changes during recovery*. In Fig. 5 the changes from admission with oedema to complete recovery are depicted for 2 children, A.R. and W.C. Each child had 3 estimations done, the first two being done before and after

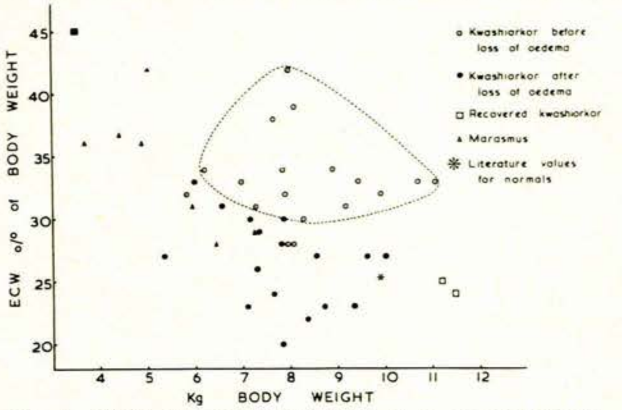

Fig. 4. ECW of oedematous cases is in general higher for their weight than the non-oedematous cases.

loss of oedema (Table IV). A.R. was grossly underweight for his age of 15 months. With loss of oedema there was a shift of water from the extracellular to the intracellular compartment. At this time he had the weight (50th Boston percentile) and composition of a normal child of 3 months of age.[15] Five months of feeding in a convalescent home restored his weight and composition to that of a normal child of his own age (20 months). The changes, shown in Fig. 5 and Table IV, were particularly great in body solids. While the weight had nearly doubled, the body solids had increased by 4 times from the time of admission.

The second case, W.C., was less underweight for his age on admission. However, at 19 months he had the weight and composition of a child of 8 months. Recovery to normal weight and composition took only 2 months. As with A.R., the relative increase of solids was greater (1·7 times) than the increase of weight (1·35 times).

DISCUSSION

From the data presented it appears that in the protein-calorie malnutrition syndromes of pre-school children, the

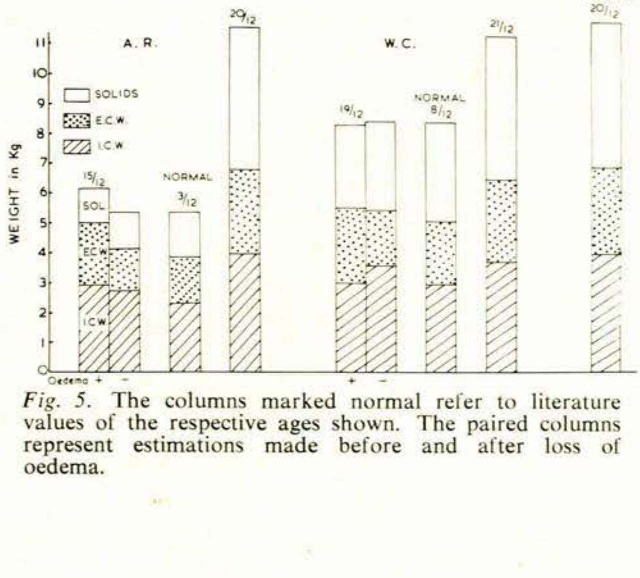

Fig. 5. The columns marked normal refer to literature values of the respective ages shown. The paired columns represent estimations made before and after loss of oedema.

body water composition is related more to the degree of underweight than any other factor. The correlation of TBW as a percent of body weight with the degree of deviation from the expected weight for age is very close. This finding gives an explanation for the fact that in one reported series of oedematous kwashiorkor cases the TBW (estimated by the same method) was considerably higher[4] (84·5%) than in our own series (70%). In the former the children were more underweight for their age than the group in Cape Town.

As far as ECW is concerned, the same relationship to the degree of weight deficit is clearly demonstrable—an observation already made by Kerpel-Fronius and Kovach.[7] These malnourished children thus have the weight and the body water composition of much younger infants, e.g. at a mean age of 18 months the group with marasmus weighed 5·39 kg. and had a TBW of 76·9% of body weight and an ECW of 34%. These figures would apply to normal infants of 1 - 3 months of age.[15] The hypothesis[16, 17] that undernutrition causes a reversal of body composition to that of an earlier stage of development is thus supported by the present findings. These children are not only underweight but have an abnormal or immature body composition for their age.

The changes that occur with recovery illustrate this point (Fig. 5). Both children on admission to hospital had the weight and composition of much younger children. Proper feeding restored each to normal in a relatively short time.

Oedema *per se* does not seem to be related to TBW, a fact noted previously.[4, 26] However, it is closely related to ECW volume and the present data support the suggestion of Kerpel-Fronius[18] that there is an absolute increase of ECW in oedema. With resolution of oedema the ECW is still relatively increased in accordance with the degree of deviation from expected weight. Thus all children who are severely underweight for age can be expected to have a relatively increased ECW but only in those with oedema will there be an absolute increase. Because this increase is absolute the diuresis that occurs with resolution of the oedema results in a loss of weight. Sometimes there is no diuresis or loss of weight as oedema resolves. In these instances it is possible that most of the excess ECW in the oedematous areas is redistributed to relatively less hydrated intra- and extracellular spaces.[6] It has, for example, been observed that oedema of feet and at the same time dehydration of the upper trunk can occur together in cases of kwashiorkor.[16, 19]

In the marasmus group the mean ECW was 34% of the body weight. This high figure represented 1·81 litres of fluid (Table II). For a normal child of comparable age (18 months) the figures would be 25% and 2·97 l. respectively.[14] The relative increase in marasmus is apparently due to the great loss of solids. A similar phenomenon is discernible in wasted adults[20] where the high ECW volume is considered to be essentially relative rather than absolute.

The body water compartment measurements *in vivo* are in line with data obtained from direct tissue analysis. For example, in skin and muscle biopsies of malnourished children Frenk *et al.*[21] reported equally high water contents in oedematous, non-oedematous and atrophic subjects. The atrophic subjects were extremely underweight for age (a mean of 39% expected weight) and on current evidence this would account for the high water content of the muscle biopsies.

It has been found also that in whole body analysis after death, the TBW was increased in a malnourished infant of 3 months as compared to a newborn infant of the same weight.[22]

With normal development and age the accumulation of tissue solids (lean tissue, minerals and fat) causes a steady decrease of the percentage TBW.[15] It is therefore understandable that with protein depletion and the subsequent wasting of muscle and other tissues the percent of TBW increases. In the marasmic children where there is also loss of fat, TBW is likely to be very high, as was indeed found. The present study supports the conclusion that the degree of loss of tissue solids is usually greater than the loss of weight would indicate.[4]

The cause of the excessive accumulation of ECW that results in the appearance of clinical oedema is not as yet satisfactorily explained. The phenomenon is undoubtedly complicated by hormonal and electrolyte imbalance, cellular function, salt intake, venous pressure, serum protein concentration and numerous other factors which may be acting singly or in combination in a particular individual.

The ambulant underweight group of children were very close to the kwashiorkor cases in their TBW composition. This indicates a considerable reduction in body solids. Stress of any kind, whether it be infection, diarrhoea or psychological, might be expected to deplete the tissue reserves of these children further and precipitate them into one of the clinical syndromes of malnutrition.

Clinical cases of kwashiorkor come from this population of underweight children.[23] It is in this group also that mortality and morbidity from gastroenteritis and other childhood diseases is so high.[24, 25] There is thus an inescapable link between weight-for-age, body composition and over-all child health. Deviation from expected growth and weight gain is an indication of changing body composition and susceptibility to the effects of disease. It is thus evident that every effort must be made to ensure, with adequate nutrition, patterns of growth within normal limits. With the use of acceptable growth charts this can be done with great ease at home, clinic and school.

SUMMARY

Body water composition in the various manifestations of protein-calorie malnutrition has been studied using tritiated water for measurement of total body water (TBW) and sodium thiosulphate space as a measure of extracellular water (ECW). An increase of TBW as a percentage of body weight was found in kwashiorkor, marasmus and children who were underweight for age but asymptomatic. The increase of TBW appears to correlate well with the degree of weight deficit, being highest in the marasmus cases. The presence of oedema appeared to bear no relation to the TBW.

ECW was also increased in protein-calorie malnutrition and bore a close relation to the weight deficit. However, in oedematous cases ECW was still further expanded.

Children with protein-calorie malnutrition thus have an abnormal or immature body composition for their age in addition to their growth failure.

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