LONG-TERM CHANGES IN GROSS BODY COMPOSITION OF PARAPLEGIC AND QUADRIPLEGIC PATIENTS[1]

By ROBERT M. GREENWAY, Ph.D., HAROLD B. HOUSER, M.D., OLGIERD LINDAN,[2] M.D., Ph.D., and DAVID R. WEIR, M.D.

Metabolic Ward, Department of Medicine, Highland View Hospital, and Departments of Medicine and Preventive Medicine, Case Western Reserve University Sshool of Medicine, Cleveland, Ohio, U.S.A.

INJURY to the spinal cord and the ensuing extensive paralysis of skeletal muscle is known to give rise to many metabolic changes (Cooper and Hoen, 1952; O'Connell and Gardner, 1953; Arieff *et al.*, 1960). Some of these changes are generally reversible, such as the catabolic reaction resulting in marked loss of nitrogen, potassium and calcium (Cooper, *et al.*, 1950), impairment of bromsulfalein clearance (Cooper and Hoen, 1952) and development of gynecomastia in males. These abnormalities may disappear in the course of a few months, especially with modern treatment (Arieff *et al.*, 1960). On the other hand, some changes seem to be essentially permanent and these include disturbance of the distribution of serum proteins (Robinson, 1954; Arieff *et al.*, 1960), a tendency to creatinuria and decreased creatine tolerance (Pollock *et al.*, 1954), a lowered excretion of creatinine and subnormal serum glutamic-oxalacetic transaminase levels (Arieff *et al.*, 1960).

The aim of the present work is to determine to what extent the gross body composition of spinal cord injured patients is altered as a result of such metabolic changes. The patients available in this hospital for the care and rehabilitation of the chronically ill were treated elsewhere during the acute post-injury phase. Consequently only the effects of relatively long-term metabolic changes would be apparent from these studies.

In one approach, observations made on groups of paraplegic and quadriplegic patients were compared with those from groups of other chronically ill patients in this hospital in order to delineate differences specifically due to spinal cord injury. Comparison with data from the literature on healthy normal controls was also possible. In a second approach, in which the patient served as his own control, periodic observations were made on spinal cord injured subjects over a period of up to 51 months in order to follow *changes* in their body composition. Previous work on the variability in measurement of the selected parameters allowed assessment of the statistical significance of the changes observed in the latter study (Greenway *et al.*, 1965).

METHODS

Patient Selection. All patients were chronically ill, but in no acute distress. The spinal cord injured patients had no large decubitus ulcers and were all either

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[2] Address requests for reprints to Dr. O. Lindan, Metabolic Ward, Highland View Hospital, Cleveland, Ohio 44122.

undergoing active rehabilitation therapy or had already reached their rehabilitation plateau.

The following four groups of patients were studied (up to four at a time) following admission to the Metabolic Ward:

Spinal-cord injured (see Table I):

Group 1. Fourteen male *paraplegics*, having cord lesions from T3 to T12, studied at 1 to 25 months after injury and ages 17 to 41 years (mean 28).

Group 2. Six *quadriplegic* patients, including five males with cord lesions at C4 to C6 incurred 3 to 62 months previously, and of ages 15 to 48 years (mean 31). The 24-year-old female was injured 85 months before study at the C5 level.

Chronically-ill controls (see Tables 2A and 2B):

Group 3. Twenty-two chronically ill males judged clinically to be '*well-nourished*', aged 28 to 75 years (mean 60).

Group 4. Twenty-three chronically ill males judged similarly to be '*poorly-nourished*', otherwise similar to those of group 3 with respect to age, race and diagnosis. Ages were 33 to 80 years (mean 66).

Some of the patients in groups 3 end 4 have been described elsewhere (Houser *et al.*, 1963) as part of a study to determine the effect of nutritional status on chronic illness. The group consisted of patients with diagnoses of: stroke (13 in group 3, 10 in group 4), multiple sclerosis (five in group 3, three in group 4), hip fracture (two in group 3, six in group 4), rheumatoid arthritis (two in each group), and parkinsonism (one in each group).

Where appropriate, observations on these groups were compared with data published by Moore *et al.* 1963*a*) on a group of 10 *normal* males ages 23 to 54 (mean 37).

In the longitudinal study of body composition changes, measurements were made on four paraplegics from group 1 and three quadriplegics from group 2 at varying intervals of time when the patients were available for study. These observations covered periods of time from 15 to 51 months and included 4 to 12 independent measurements of body composition per patient.

Experimental Procedures. Two experimental schedules were set up to perform the following series of measurements in a single day: body weight and height, skinfold thickness, total body water, sodium space, blood and plasma volumes, blood haemoglobin and serum total protein and albumin levels.

The earlier ('*Schedule Antip.*') utilised the dilution of antipyrine for the measurement of total body water, and has been described in detail previously (Greenway *et al.*, 1965). In this procedure, which was used for most of the present work, 1 g. antipyrine and 35 μc. sodium^{24} (carbonate form[1]) were first injected in 50-ml. saline and blood samples after equilibration (3, 4, 5 and 6 hours after injection) assayed chemically for antipyrine and in a well-scintillation counter for sodium^{24}. Following the 6-hour sample, 5 μc. of I^{131}-radioiodinated serum albumin (RISA[2]) in 20 ml. saline were injected and a final blood sample taken after allowing 10 minutes for RISA equilibration. Iodine^{131}-activity was measured in the well counter, using a Packard Auto-Gamma spectrometer to minimize the

[1] Union Carbide Nuclear Co., Oak Ridge, Tenn.
[2] E. R. Squibb and Sons, New Brunswick, N.J.

TABLE I

Basic Body Composition Measurements in Spinal Cord Injured Patients

Subject	Injury level	Duration of injury (mo.)	Age (yrs.)	Hgt. (in.)	Wgt. (kg.)	Lean body mass (kg.)	Body water (l.)	Sod. space (l.)	Blood vol. (l.)	Plas. vol. (l.)	Blood hgb. (g.%)	Ser. alb. (g.%)	A/G ratio	Sum of skinfold (mm.)
Group 1.	PARAPLEGICS													
P1	T12-L1	8	17	72	60·0	58·5	42·1	23·4	4·60	2·78	12·2	4·0	1·06	13·0
P2	T7	3	19	70	59·8	51·2	36·8	19·5	4·92	2·62	14·3	3·1	0·96	16·5
P3	T4-5	8	19	73	64·9	57·3	41·2	19·7	5·12	2·87	15·9	3·7	0·95	13·5
P4	T5	10	21	70	64·7	56·4	40·6	24·1	5·00	2·95	15·3	3·1	0·77	11·5
P5	T11	16	22	75	88·7	52·0	37·4	24·4	5·04	2·79	13·7	3·6	1·06	28·5
P6	T3-4	3	24	70	65·1	51·3	36·9	19·3	5·14	3·17	12·5	3·4	1·27	23·5
P7	T10	39	26	71	48·1	43·8	31·5	19·1	5·02	2·69	15·9	3·8	1·13	13·5
P8	T3-4	2	30	70	68·1	56·7	40·8	22·7	5·98	3·43	13·4	3·0	0·70	19·0
P9	T5	3	30	70	54·8	46·6	33·5	21·4	4·95	3·19	12·2	3·1	0·71	12·0
P10	T9	25	32	78	72·8	51·8	37·3	17·1	4·68	2·57	17·0	4·8	1·66	25·0
P11	T5	1	35	71	58·6	54·1	38·9	23·1	5·14	3·15	12·2	4·2	1·15	14·5
P12	T12	18	38	72	78·0	50·3	36·2	21·6	4·43	2·47	13·9	3·7	1·09	49·0
P13	T10	2	40	69	80·4	52·7	37·9	26·2	5·59	3·43	12·9	3·7	1·52	—
P14	T10-11	5	41	68	62·4	51·4	37·0	23·2	5·11	2·84	13·0	3·6	0·70	16·5
MEAN		10	28	71	66·2	52·4	37·7	21·8	5·05	2·93	13·9	3·6	1·05	19·7
Group 2.	QUADRIPLEGICS													
Q1	C4-5	8	15	69	48·5	39·8	28·6	17·1	5·39	3·06	13·7	4·2	1·73	—
Q2†	C5	26	19	68	74·2	42·4	30·5	16·9	—	—	13·4	3·6	1·17	—
Q3†*	C6	85	24	60	51·9	28·5	20·5	11·1	—	—	13·0	3·0	0·99	—
Q4†	C5	6	33	74	83·3	57·3	41·2	—	4·98	3·01	12·5	2·9	0·91	—
Q5	C5	62	46	72	73·4	47·5	34·2	18·0	6·05	3·27	14·0	3·1	0·76	—
Q6	C6	3	48	72	72·4	56·7	40·8	29·0	5·89	3·73	11·2	3·2	0·82	—
MEAN		32	31	69	67·3	45·4	32·6	18·4	5·58	3·27	13·0	3·3	1·06	—

* Female, others male.

† By 'Schedule HTO', others by 'Schedule Antip'.

TABLE IIA

Basic Body Composition Measurements in Chronically-ill Control Subjects

Group 3. 'WELL-NOURISHED'

Case No.	Age (yrs)	Height (in.)	Weight (kg.)	Lean body mass (kg.)	Body water (l.)	Sodium space (l.)	Blood vol. (l.)	Plasma vol. (l.)	Blood hgb. (g.%)	Serum dlbumin (g.%)	A/G ratio	Sum of skinfold (mm.)
6	28	69	81·6	64·2	46·2	22·5	5·84	3·58	15·3	4·0	1·25	36·0
38	36	69	70·6	64·2	46·2	17·9	5·71	2·92	15·8	3·8	1·36	24·0
50	41	73	90·2	60·7	43·7	19·8	7·07	3·79	14·0	3·4	1·23	19·0
2	46	69	69·5	47·5	34·2	16·9	3·70	2·02	14·1	4·1	1·13	35·0
4	46	64	51·3	44·2	31·8	15·3	3·27	1·76	14·1	3·7	1·30	16·0
20	48	67	68·6	48·2	34·7	16·0	5·15	2·48	16·9	2·9	1·11	28·0
30	51	64	67·7	61·4	44·2	18·2	5·10	2·80	16·0	3·3	0·76	22·0
42	55	67	77·9	56·6	40·7	19·9	5·70	2·85	16·9	3·6	1·05	16·5
40	60	62	62·1	47·8	34·4	16·4	5·44	2·62	16·3	3·4	0·93	16·0
14	62	70	60·8	49·8	35·8	18·4	5·39	3·10	13·5	3·5	0·96	13·0
44	65	68	71·5	57·3	41·2	19·8	6·10	3·47	13·9	2·9	0·88	22·5
48	65	68	81·8	66·6	47·9	21·7	6·79	3·61	13·6	3·1	0·92	23·5
16	66	63	65·6	46·0	33·1	18·2	5·80	2·93	13·6	3·1	0·81	20·5
18	69	60	58·8	39·6	28·5	15·5	4·51	2·55	12·8	3·4	0·92	26·5
36	70	61	57·4	37·0	26·6	14·4	3·72	1·90	15·8	3·5	0·95	30·0
46	70	67	79·3	53·1	38·2	20·0	6·76	3·88	13·4	2·8	0·62	31·0
24	71	63	68·9	46·4	33·4	17·4	4·71	2·70	12·1	2·6	0·58	26·0
34	72	65	70·5	55·9	40·2	17·7	5·31	2·98	14·8	3·3	0·71	40·5
12	73	63	59·3	41·0	29·5	16·0	3·36	1·79	12·3	3·0	0·79	34·0
32	73	65	61·2	58·1	41·8	18·7	5·05	3·12	11·8	4·2	1·44	18·0
8	75	66	72·4	54·5	39·2	21·7	4·55	2·59	12·5	3·2	1·06	24·5
10	75	68	64·7	42·5	30·6	19·6	4·98	2·71	11·2	3·2	0·94	19·0
MEAN	60	66	68·7	51·9	37·4	18·3	5·18	2·82	14·1	3·4	0·99	24·6

Table IIb

Basic Body Composition Measurements in Chronically-ill Control Subjects

Group 4. 'Poorly-nourished'

Case No.	Age (yrs)	Height (in.)	Weight (kg.)	Lean body mass (kg.)	Body water (l.)	Sodium space (l.)	Blood vol. (l.)	Plasma vol. (l.)	Blood hgb. (g.%)	Serum albumin (g.%)	A/G ratio	Sum of skinfold (mm.)
5	33	68	49·6	33·1	23·8	15·4	4·36	2·67	9·8	2·7	0·60	15·5
3	44	68	47·4	46·8	33·7	16·4	3·54	2·12	13·2	3·7	1·14	10·5
19	46	65	38·8	33·1	23·8	14·2	4·53	3·00	10·7	2·6	0·64	8·0
1	50	69	41·1	41·4	29·8	19·4	4·75	2·94	11·7	3·1	0·81	9·0
29	54	67	61·2	55·2	39·7	18·9	4·57	2·46	12·9	3·8	0·97	22·0
15	56	66	38·4	35·0	25·2	14·3	3·64	1·85	14·0	3·7	1·03	5·5
9	64	66	39·5	36·6	26·3	14·6	3·02	1·64	13·3	3·5	1·24	11·5
11	66	64	52·2	43·9	31·6	17·7	—	2·67	11·6	3·1	0·87	11·5
47	67	71	57·3	43·2	31·1	20·0	—	—	11·2	2·8	0·91	14·5
31	70	62	41·1	37·5	27·0	15·1	4·01	2·93	13·1	3·1	0·89	12·0
37	72	66	49·3	45·5	32·7	17·1	4·16	2·58	10·9	2·8	0·62	15·0
23	73	67	60·4	48·5	34·9	19·9	4·50	2·95	12·4	2·9	0·76	13·0
27	73	64	60·6	38·6	27·8	17·0	3·80	2·75	10·2	2·7	0·64	23·5
39	73	66	51·2	38·6	27·8	15·2	4·45	2·51	16·0	3·4	0·93	11·0
17	74	71	55·8	39·5	28·4	19·0	6·63	3·55	9·7	2·7	0·65	14·5
35	74	68	54·0	48·9	35·2	20·9	5·09	2·79	12·3	3·3	1·14	12·0
45	74	64	44·7	44·5	32·0	16·7	4·34	2·57	12·6	2·8	1·38	12·5
33	76	64	56·3	47·4	34·1	16·0	4·96	2·78	13·5	3·2	0·98	12·0
7	77	71	50·9	34·3	24·7	18·5	3·05	1·95	10·7	2·1	0·50	13·0
25	77	67	52·2	38·4	27·6	15·9	4·12	2·48	11·4	2·7	0·66	9·5
41	78	67	47·2	38·5	27·7	16·7	4·77	3·33	10·5	2·9	0·89	10·0
43	78	67	54·5	36·1	26·0	16·4	4·70	3·16	11·2	3·2	0·82	13·5
13	80	67	54·3	45·5	32·7	21·1	5·98	3·55	12·0	3·1	0·92	19·0
Mean	66	67	50·4	41·3	29·7	17·3	4·43	2·69	11·9	3·0	0·87	13·0

effect of the 'background' of sodium[24] counts. Appropriate dilution of the injection fluids were assayed for antipyrine, sodium[24] and iodine[131] along with the blood and plasma samples, and calculations of the fluid spaces carried out as described earlier (Greenway *et al.*, 1965).

In later experiments involving three quadriplegics (see Table I), '*Schedule HTO*' was used, employing the dilution of tritiated water instead of antipyrine for the measurement of total body water. In these cases, the initial injection consisted of 0·5 mc. tritiated water[1] and 35 μc. sodium[24] in 20 ml. saline. Blood sampling times and the procedure for RISA injection and assay of gamma-emitting, isotopes were the same as '*Schedule Antip*'. Urine was also collected during the period of equilibration of tritiated water and assayed for tritium along with the blood samples, so that corrections could be made for loss of injected tritium from the body during equilibration.

Samples for tritium measurement (2 to 3 ml.) were placed in 50-ml. round flasks with ground joints, shell-frozen in ethanol-solid CO_2, connected by a 90° tube and straight receiver adaptor to a receiving tube cooled in ethanol CO_2 and vacuum applied from an oil pump. Six such subliming units were arranged around a single Dewar of freezing mixture and fed by a manifold from one pump. One ml aliquots of the distillates were counted for tritium in a Packard Tri Carb liquid Scintillation spectrometer. The liquid scintillator was 14 per cent. (w/v) dioxane solution of napthalene containing 8 g./litre 2, 5-diphenyloxozole (PPO) 50 mg./litre, 1, 4-bis-2-(5-phenloxazolyl)-benzene (POPOP). A 1 : 1000 dilution of the injection fluid was assayed for tritium along with the blood and urine samples.

Total body water was calculated as the ratio of tritium counts injected (less counts excreted in urine up to sampling time) divided by the concentration of tritium counts in blood distillate. In most cases, the equilibration was complete in three hours and the resulting values for all four samples were averaged. In a few cases, the three-hour sample was not in agreement with later samples and was excluded.

Skinfold thickness was measured at two sites with Lange calipers, having a surface area of 30 mm.^{2} and a constant pressure of 10 g./mm.^{2}, (*a*) the posterior upper arm at a point midway between the acromial process and the olecranon and (*b*) just below the inferior angle of the scapula. The values quoted for the 'sum of skinfolds' are the sums of these two measurements in millimetres.

The mean values of the various measures of body composition in each of the four groups were the basis of statistical evaluation for significant differences among the groups. The null hypothesis examined was that each group of patients was a sample of patients from a single population of chronically ill persons hospitalised at Highland View Hospital and no differences among the means were expected except sampling differences. Therefore, differences among the four means were examined by analysis of variance (Crow *et al.*, 1960), and differences were considered significant when the observed differences among the means would occur less than 1 per cent. of the time by chance ($P < 0{\cdot}01$). When analysis of variance showed a significant difference among the means, all combinations of pairs of means were contrasted for significant differences by the method of Scheffé (1953). Correlation coefficients were determined between many of the body composition parameter and age within the paraplegic, well-nourished, and poorly-nourished groups.

The indexes used in the present work for determining the significance of the

[1] Abbot Laboratories, Oak Ridge, Tenn.

changes in body composition parameters in individuals have been published elsewhere (Greenway *et al.*, 1965). They were derived from a series of duplicated observations of the parameters in a group of chronically ill patients using 'Schedule Antip.' exclusively. Although the two methods of body water estimation yield very similar results, the experimental variability of the tritium method is inherently less (Prentice *et al.*, 1952), and the significance of changes in total body water in those cases when 'Schedule HTO' was used should be underestimated rather than overestimated by use of the criteria developed from 'Schedule Antip.'.

Derived Body Composition Parameters. The following parameters were calculated from the basic measurements made in 'Schedule Antip.' or 'HTO':

Body fat was calculated as

$$\text{Percentage body fat} = 100-(1{\cdot}39 \times \text{percentage total body water}).$$

This formula of Keys and Brozek (1953) is a first approximation for body fat and assumes that fat free tissue contains a constant 72 per cent. water.

Lean body mass was taken as body weight less body fat.

'Intracellular water' was calculated as total body water less sodium space, although it is realised that sodium space is generally larger than true extracellular water and that the values so obtained for 'intracellular water' are lower than the actual volume of water in body cells.

Total circulating haemoglobin and serum proteins were calculated by multiplying blood and plasma volumes by the corresponding blood or serum concentrations.

RESULTS AND DISCUSSION

I. *Comparison by Groups.* The basic measurements of body composition of the spinal cord injured patients, groups 1 and 2, are given in Table I. Those for the other chronically ill groups of patients, groups 3 and 4, are summarised in Tables IIA and IIB.

Since *the age distribution* of the paraplegic and quadriplegic groups were quite different from the well-nourished and poorly-nourished groups, correlation coefficients were calculated for each body parameter and age in the paraplegic, well-nourished, and poorly-nourished groups. The quadriplegic groups was not included because of the small number of subjects. The only significant ($P < 0{\cdot}05$) correlations with age were in the well-nourished group. Both lean body mass and litres of intracellular water had negative correlations with age and sodium space as percentage of lean body mass had a positive correlation with age. The possible significance of these correlations will be discussed below in relation to the comparison of the groups for each of the specific body composition parameters.

The distribution of body weight in the four experimental groups in absolute terms and as percentage of average body weight (as defined by the Metropolitan Life Insurance Tables, 1960, for their heights, age and sex) is shown in Figure 1. The spinal cord injured patients covered a wide range, from 61 to 118 per cent of average body weight, but exhibited no particular tendency to overweight or underweight. Their mean weights, both actual and percentage of average, were similar to the group of well-nourished chronically ill, while the poorly-nourished group has a significantly lower mean weight ($F = 17{\cdot}4$, $P < 0{\cdot}005$ for absolute weight; $F = 24{\cdot}2$, $P < 0{\cdot}005$ for percentage of average weight).

In Figure 2 are compared *the body fat* (calculated from body water) content of

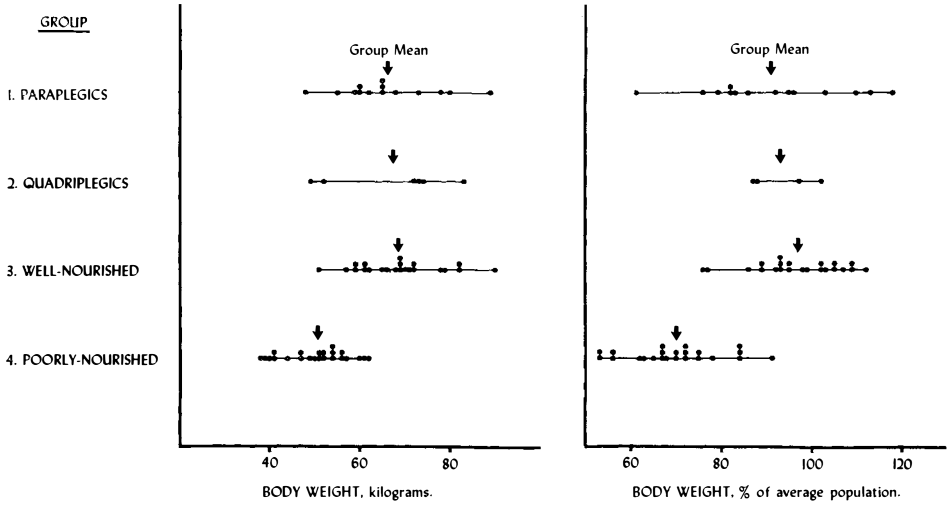

FIG. 1

Body weight distribution. Average body weight is taken as that listed in the Metropolitan Life Insurance Tables, 1960, for a given sex, age and height.

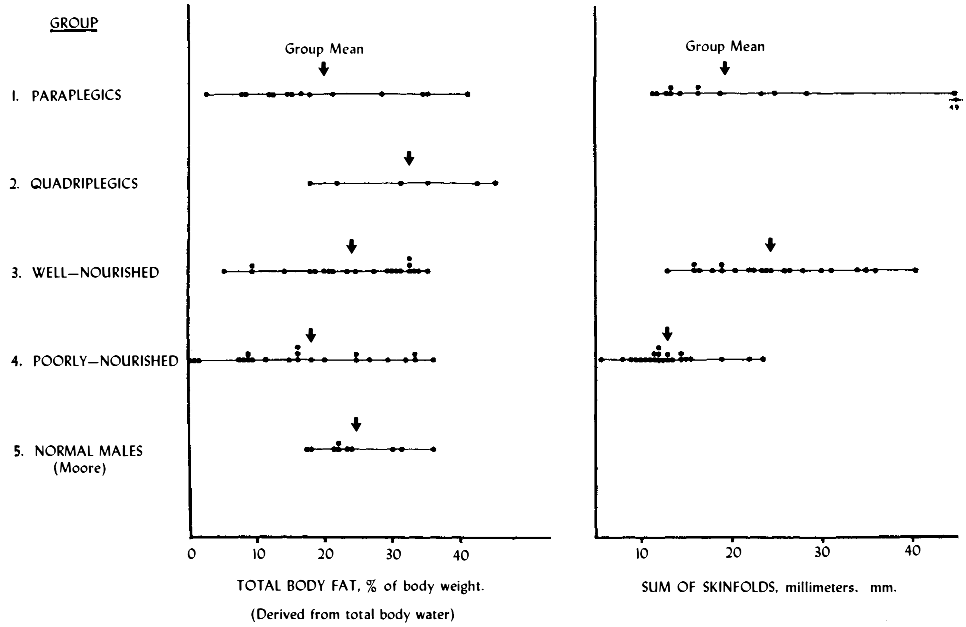

FIG. 2

Body fat distribution.

the groups of patients and also a group of normal males of age-range 23 to 54 years reported by Moore *et al.* (1963*a*). This group of normals is nearer the age of the spinal cord injured groups than the older groups of chronically ill patients. The differences among the means in the four study groups was significant ($F = 4\cdot7$, $P < 0\cdot01$). The pair of means with a significant difference were the quadriplegic and poorly-nourished group. The lower body hydration observed in several of the quadriplegics is a finding compatible with an accumulation of body fat. Estimation of body fatness by measurement of skinfold thickness also placed the paraplegics intermediate between the chronically ill control groups (fig. 2). However, the differences in means among the three groups was significant ($F = 15\cdot0$, $P < 0\cdot005$) with the well-nourished and poorly-nourished means different. Skinfold measurements were not made on the quadriplegic patients.

The distribution of absolute *lean body mass* of the paraplegics (and the quadriplegics, with the exception of the female) were similar to those of the well-nourished patients and the normal males, as shown in Figure 3. The means were significantly different ($F = 10\cdot9$, $P < 0\cdot005$); the poorly-nourished mean was significantly lower than both the paraplegic and well-nourished mean.

The parameter of '*intracellular water*' (fig. 3) showed a significant difference among the means of the four patient groups ($F = 12\cdot5$, $P < 0\cdot005$). Both the quadriplegic and poorly-nourished means were significantly different from the well nourished mean.

In an earlier comparison of groups of well-nourished and poorly-nourished chronically ill patients (Houser *et al.*, 1963) the parameters which showed the greatest differences (after those reflecting body weight and fatness) were those which represented *extracellular fluid*, especially sodium space and plasma volume expressed as percentage of lean body mass. The sodium spaces of the four groups of patients, relative to lean body mass are compared in Figure 4. Note that, by a simple change of scale, this could also be considered as a plot of sodium space as percentage of total body water. The difference in means of the four groups was significant ($F = 9\cdot7$, $P < 0\cdot005$), and the mean of the well-nourished group was significantly different from each of the other three means. In this case, the proportion of body water accounted for as sodium space was elevated in the paraplegics and quadriplegics giving distributions similar to the poorly-nourished control group and means greater than that of the well-nourished group.

Such an elevation of relative sodium space may be explained as either (*a*) a retention of extracellular water as subclinical oedema or (*b*) erosion of the lean body mass of the type described by Moore *et al.* (1963*b*), which leads to a higher ratio of extracellular to total body water due primarily to loss of skeletal muscle mass. From the significant positive correlation of age and relative sodium space described above in the well-nourished group, one would expect a lower mean value in the younger groups than that observed. Our interpretation is that factors associated with their physical state have transcended any effect that age might have.

In view of the normal body weights of the spinal cord injured patients, it is most likely that a combination of (*a*) and (*b*) has occurred in the spinal cord injured patients with some replacement of muscle tissue by water. It may be argued that in such cases, the assumption that lean body mass contains a fixed 72 per cent. of water is no longer true. However, if the lean tissue is overhydrated, the 'true' 'normally hydrated' lean body mass would be lower than that calculated on the above assumption. Therefore the values for sodium space as a percentage of true

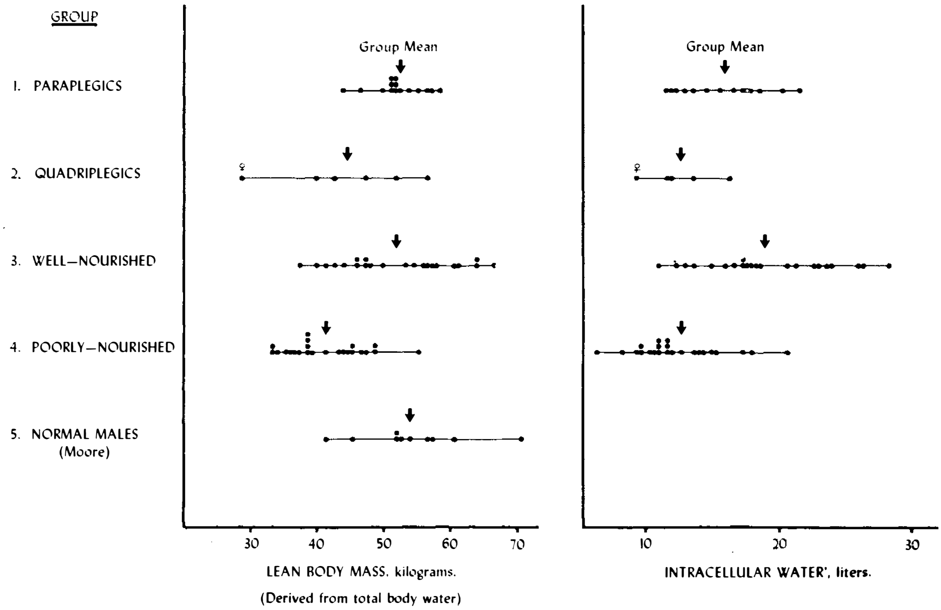

FIG. 3

'Lean tissue' distribution. Note that lean body mass is derived from total body water above, and 'intracellular water' from total body water and sodium space.

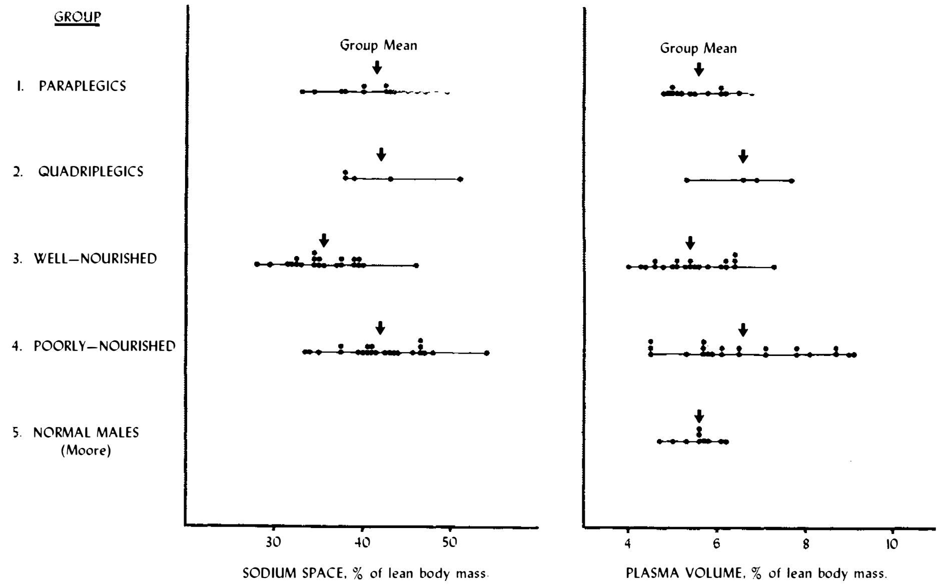

FIG. 4

'Extracellular water' distribution.

lean body mass for the spinal cord injured patients would be even higher than shown in Figure 4, and increase the separation from the well-nourished control group.

As also shown in Figure 4, the relative elevation of sodium space in the paraplegic patients did not extend to plasma volume. The mean value of plasma volume (relative to lean body mass) for the group of paraplegics was nearer to those of the well-nourished patients and normals, while the mean of the poorly-nourished patients was elevated enough to cause a significant difference among the means of the four patient groups ($F = 5.5$, $P < 0.005$). The mean values of both the paraplegic group and the well-nourished group are significantly different from the poorly-nourished group. The mean value of the quadriplegic group is based on only four observations and consequently is difficult to interpret in relation to the other three groups.

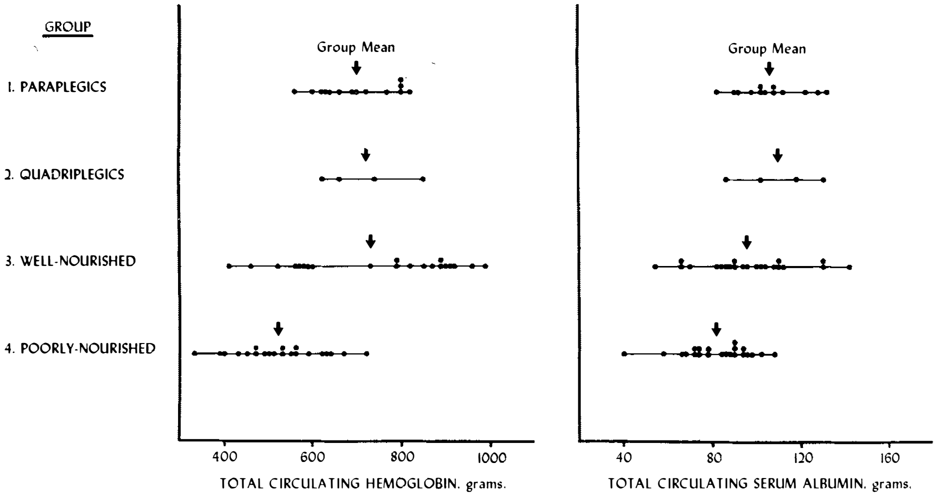

FIG. 5
Total circulating protein distribution.

The total circulating protein levels of the four patient groups, as represented by total haemoglobin and total serum albumin, are compared in Figure 5. The means of the spinal-cord injured groups were as high or higher than the well-nourished groups with the poorly-nourished group responsible for the significant differences in means ($F = 10.6$, $P < 0.005$ for haemoglobin; $F = 7.4$, $P < 0.005$ for serum albumin). The means for both paraplegic patients and well-nourished patients were significantly different from the poorly-nourished group for haemoglobin. The paraplegic and poorly-nourished groups differed significantly for albumin.

In summary, the mean value of one or more of the four groups of patients was significantly different ($P < 0.01$) from the over-all mean in the case of all 10 parameters illustrated in Figures 1 to 5.[1] The significant differences between pairs of means are summarised in Table III. Paraplegics and well-nourished both differed

[1] Analysis of variance was also carried out on the groups of paraplegics, well-nourished and poorly-nourished patients, with exclusion of the quadriplegics. The differences among means remained significant ($P < 0.01$) for nine parameters but became non-significant ($F = 2.6$, $P < 0.05$) in the case of total body water (as percentage of body weight).

Table III

Summary of the Significant Differences between Pairs of Means for all Combinations of the Four Study Groups—Paraplegia, Quadriplegia, Well-nourished and Poorly-nourished—for each of the Body Composition Parameters

Study groups compared	Body weight		Total body fat	Sum of skinfolds	Lean body mass	Intra-cellular water	Sodium space %	Plasma vol.	Total circulating	
	Actual	% of avg.							Hgb.	Alb.
1 and 2	—	—	—	—	—	—	—	—	—	—
1 and 3	—	**	—	—	—	—	**	—	—	—
2 and 3	—	—	—	—	—	**	*	—	—	—
1 and 4	**	**	—	—	**	—	—	*	**	**
2 and 4	**	**	*	—	—	—	—	—	—	—
3 and 4	**	*	—	**	**	**	**	**	**	—

Study Groups:

1. Paraplegics
2. Quadriplegics.
3. Well-nourished.
4. Poorly-nourished.

— Difference between means not significant.
* $P < 0.05$.
** $P < 0.01$.

from the poorly nourished significantly in five parameters: (i) body weight, (ii) percentage average weight, (iii) lean body mass, (iv) plasma volume, and (v) circulating haemoglobin. Although there were no significant differences between the means of the paraplegic and quadriplegic groups for any of the parameters, there also were no differences between the quadriplegic group means and the poorly-nourished group means except in weight parameters and percentage of body fat. The paraplegic group means, therefore, most closely resembled the well-nourished group means both in absolute values and in their relationship to the other group means. The one exception was the parameter, sodium space as percentage of lean body mass. For this parameter, the means for the paraplegic, quadriplegic, and poorly-nourished groups were similar and all were significantly higher than the well-nourished group.

The paraplegics studied showed, as a group, normal body weights and circulating proteins, but higher levels of tissue hydration than a group of well-nourished but older patients with other chronic illnesses. The elevated sodium space noted in the spinal cord injured patients is consistent with erosion of body cell mass, possibly associated with mild oedema due to impaired venous return. Among the small group of quadriplegics studied, several had evidence of increased body fat which, in association with normal weights, must represent a replacement of lean tissue by adipose tissue. The spinal-cord injured groups showed no evidence of depletion of circulating proteins. Examination of the data in Table I has revealed no obvious correlation between body composition parameters and (*a*) age or (*b*) time since injury.

II. *Longitudinal studies on spinal-cord injured patients.* During the period in which the body compositions of seven spinal cord injured patients were followed, unidirectional trends were observed in five cases. In the cases of quadriplegics Q2 and Q5 initial phases of weight gain (Phase 1) were succeeded by weight loss (Phase 2). The over-all changes in body composition are summarised in Tables IVA and IVB with separation of the changes in Q2 and Q5 into Phases 1 and 2.

Weight gains were evidenced by quadriplegics Q2 (Phase 1) Q5 (Phase 1) and by paraplegics P13 and P14. In the case of the quadriplegics, these gains were due to accumulation of fat, even at the expense of lean body mass in Q2. By contrast, P13 showed no increase in body fat, but a decrease in sodium space which reflects a relative increase in intracellular water and a probable increase in cellular tissue in general. (The lower reproducibility of total body water measurement by the antipyrine method rendered this change non-significant in body water and lean body mass estimates.) On this basis, the weight gain by P14 was partly fat and partly lean tissue.

Weight losses were demonstrated by Q2 (Phase 2), Q5 (Phase 2), Q4 and by P6. Again, the change in body composition of the quadriplegics was due to fat, but the relatively small weight loss by P6 is mainly from extracellular and intracellular water.

No changes in blood or blood proteins were significant except for an increase in the plasma volume of Q5 over a three-year period. Subject P2 showed no significant change in weight of any other parameter during the observations.

It might be concluded that the quadriplegics studied had relatively labile body weights, with a tendency to accumulate fat on the uncontrolled diets used in these studies where intake was mainly determined by appetites. This is consistent with the findings of the group comparison study (fig. 2) where high percentages of body

Table IVa

Longitudinal Changes in the Gross Body Composition of a Group of Quadriplegic Male Patients

Quadriplegic	Q2		Q4	Q5	
	Phase 1	Phase 2		Phase 1	Phase 2
Time of first observation (months after injury)	5	27	6	62	75
Period covered by study (mo.)	22	9	28	13	36
No. of observations	4	2	5	6	6
Body weight (kg.)					
Initial	60·8	74·2	83·3	73·4	87·9
Change	+13·4	−7·2	−12·5	+14·4	−6·1
Sig. (P)	< 0·001	< 0·001	< 0·001	< 0·001	< 0·001
Body water (l.)					
Initial	41·6	30·5	41·2	34·2	30·4
Change	−11·1	+3·9	−2·1	−3·8	+0·2
Sig. (P)	< 0·001	NS	NS	NS	NS
Body fat (kg.)					
Initial	3·0	31·8	26·1	25·9	45·6
Change	+28·8	−12·7	−9·7	19·7	−6·2
Sig. (P)	< 0·001	< 0·01	< 0·05	< 0·001	NS
Lean body mass (k.g.)					
Initial	57·8	42·4	57·2	47·5	42·4
Change	−15·4	+5·4	−2·8	−5·3	+0·3
Sig. (P)	< 0·001	NS	NS	NS	NS
Sodium space (l.)					
Initial	—	16·9	—	18·0	19·9
Change	—	+0·3	NS	+1·9	−1·7
Sig. (P)	—	NS	NS in 7 mo.	< 0·01	< 0·05
Plasma vol. (l.)					
Initial	—	1·92	3·01	3·27	—
Change	—	+0·41	+0·03	—	−0·75*
Sig. (P)	—	NS	NS	—	< 0·05
Total Hgb. (g.)					
Initial	—	489	622	847	—
Change	—	+11	+68	—	−70
Sig. (P)	—	NS	NS	—	NS
Total serum albumin (g.)					
Initial	—	69	86	102	—
Change	—	−13	−18	—	−33
Sig. (P)	—	NS	NS	—	< 0·01

* Represent overall changes in both phases of Subject Q5.

Changes with negative signs represent losses.

Significance of change is determined from the standard deviation of duplicate estimations on a group of 26 chronically ill patients in this laboratory (Greenway *et al.*, 1965).

TABLE IVB

Longitudinal Changes in the Gross Body Composition of a Group of Paraplegic Male Patients

PARAPLEGIC	P2	P6	P13	P14
First observation (months after injury	3	3	2	5
Period covered by study (mo.)	15	19	21	51
No. of observations	5	4	6	5
Body weight (kg.)				
Initial	59·8	65·1	80·4	62·4
Change	+1·7	−4·7	+6·2	+12·7
Sig. (P)	NS	<0·001	<0·001	<0·001
Body water (l.)				
Initial	36·8	36·9	37·9	37·0
Change	+1·6	−3·1	+5·7	+1·0
Sig. (P)	NS	NS	NS	NS
Body fat (kg.)				
Initial	8·6	13·9	27·6	11·0
Change	−0·5	−0·3	−1·6	+11·3
Sig. (P)	NS	NS	NS	<0·05
Lean body mass (kg.)				
Initial	51·2	51·2	52·7	51·4
Change	+2·2	−4·4	+7·9	+1·4
Sig. (P)	NS	NS	NS	NS
Sodium space (l.)				
Initial	19·5	19·3	26·2	23·2
Change	+1·6	−2·0	−7·1	−5·5
Sig. (P)	<0·05	<0·01	<0·001	<0·001
Plasma vol. (l.)				
Initial	2·62	3·17	3·43	2·84
Change	+0·05	+0·07	−0·31	−0·29
Sig. (P)	NS	NS	NS	NS
Total Hgb. (g.)				
Initial	704	642	719	664
Change	+8	+118	+46	−53
Sig. (P)	NS	NS	NS	NS
Total serum albumin (g.)				
Initial	82	108	128	102
Change	+11	−16	−17	−3
Sig. (P)	NS	NS	NS	NS

See legends on Table 4A.

fat were found in some quadriplegics. One quadriplegic (Q2) voluntarily restricted his caloric intake after gaining weight (Phase 1) and succeeded in reversing this process (Phase 2). Evidence for the erosion of lean body mass after injury was seen in one case (Phase 1 of Q2). The course of body composition changes in paraplegics was variable, probably depending on rehabilitation therapy as well as diet.

Ten of the paraplegics listed in Table I were maintained on the metabolic ward following the initial body composition studies for a period of 12 weeks on a controlled diet containing enough calories to adjust the body weight of each patient towards a value of 90 per cent. of his average weight (as given by the Metropolitan Life Insurance tables). The diet of three paraplegics contained 50 g. protein per day, and that of the other seven, 100 g. per day. Body composition by 'Schedule Antip.' was measured at four-week intervals for a total of four estimations per patient. During this relatively short period, most of the observed changes in body composition were too small to be statistically significant with the exception of body weight. One of the low-protein and four of the high-protein diet patients lost weight significantly ($P < 0{\cdot}05$). In all cases except one (who was on 100 g. protein diet) the sodium spaces of these patients showed a decrease, but this was great enough to be significant in only three cases (two on the 100 g. protein diet). This observation suggests that the elevated ratios of sodium space to lean body mass in spinal-cord injured subjects discussed earlier might be reversed by dietary control, at least in some cases. In the 12-week period, one paraplegic increased his lean body mass significantly on a 100 g. protein diet and one had a significant loss on a 50 g. protein diet. Further study would be required to test whether protein intake level has any influence on the apparent lean body mass of spinal-cord injured subjects.

Some of the major changes in body composition which might be expected to occur after spinal cord injury and during subsequent rehabilitation are those related to muscle mass, which is only measured indirectly from total body water in these studies. The measurement of total exchangeable potassium would be desirable for this purpose, as has been done recently in subjects with idiopathic periodic paralysis by Shizume *et al.* (1966).

The major clinical implication of the present observations in the case of the spinal-cord injured would be control of the relatively labile body weight by caloric restriction to compensate for the reduced muscular activity. The clinical significance of the high extracellular hydration found in such patients is not known, but an adequate high protein diet may help to control it by decreasing the tendency to oedema and/or erosion of lean body mass.

Summary

1. The body composition of groups of 14 paraplegic and six quadriplegic patients were compared with those of groups of other chronically ill patients, judged clinically to be either 'well-nourished' or "poorly-nourished'.

The spinal-cord injured patients had values of sodium space (expressed relative to body weight or lean body mass) similar to those of the poorly-nourished group, while in nine other parameters of body composition they resembled a well-nourished group of patients. The increased sodium space in the spinal-cord injured patients is consistent with erosion of their lean body mass.

2. The changes in body composition of three quadriplegic and four paraplegic patients were followed for varying lengths of time up to 51 months. Although many of the changes were significant in individual cases, there was no consistent trend in body composition. Both gains and losses of weight were observed, the largest factor in these being changes in body fat. Ten paraplegics showed a tendency to decrease their sodium space after 12 weeks of controlled dietary intake with significant changes in three cases.

RÉSUMÉ

1. La composition des paramètres corporels d'un groupe de 14 paraplégiques et de 6 quadriplégiques a été comparée avec un groupe d'autres maladies chroniques cliniquement jugées comme étant 'de bonne condition', ou 'de condition médiocre'.

Les malades atteints de traumatismes médullaires avaient des valeurs de l'espace sodique (exprimé en rapport avec le poids ou la masse minima du corps) semblables à celles du groupe de condition 'médiocre'. Tandis-que dans 9 autres paramètres de composition corporelle il ressemblaient au groupe dit 'en bonne condition'. L'espace sodique était en augmentation chez les traumatisés médullaires en rapport avec l'evaluation de leur masse corporelle debase.

2. Les changements de la composition corporelle de 3 tétraplégiques et de 4 paraplégiques ont été suivis jusqu'a 51 mois. Bien que beaucoup de changements ont été significatifs dans des cas individuels, il n'y avait aucune base directrice consistante de la composition corporelle. Des gains et des pertes de poids ont été observés, le principal facteur étant celui de la graisse corporelle. 10 paraplégiques ont montré une tendance a diminution de l'espace sodique après 12 semaines de diététique controlée avec un changement marqué dans 3 cas.

ZUSAMMENFASSUNG

Der Körperaufbau in 14 Paraplegikern und 6 Tetraplegikern wurde mit Gruppen anderer chronisch Krankeuverglichen, die klinisch entweder als 'gut ernährt' oder 'schlecht ernährt' beurteilt wurden.

Die Rückenmarksverletzten zeigten einen ähnlichen Sodiumgehalt wie die schlechternährte Gruppe, obgleich sie in 9 andern Parametern der Gruppe der gut—ernährten Patienten glichen. Der grössere Sodiumgehalt in Rückenmarksverletzten steht in Einklang mit dem Schwund der mageren Körpermasse.

Die Veränderungen im Körperaufbau von 3 Quadriplegikern und 4 Paraplegikern wurden in verschiedenen Zeitdauern bis zu 51 Monaten verfolgt. Obwohl viele der Veränderungen für individuelle Fälle bezeichnend waren, bestand keine konsistente Tendenz im Körperaufbau. Zunahme und Abnahme des Körpergewichts wurde beobachtet, und der Hauptfaktor bestand in Änderung des Körperfetts. 10 Paraplegiker zeigten eine Tendenz zur Abnahme ihres Sodiumgehaltes nach 12 Wochen kontrollierter Diät mit erheblicheren Veränderungen in 3 Fällen.

REFERENCES

ARIEFF, A. J., PYSIK, S. W., TIGAY, E. L. & BERNSOHN, J. (1960). *Illinois Medical Journal*, **117**, 219.

COOPER, I. S. & HOEN, T. I. (1952). *Neurology*, **2**, 332.

COOPER, I. S., RYNEARSON, E. H., MACCARTY, C. S. & POWER, M. H. (1950). *Journal of Clinical Endocrinology*, **10**, 858.

CROW, E. L. DAVIS, F. A. & MAXFIELD, M. W. (1960). *Statistics Manual*, p. 120. New York: Dover.

GREENWAY, R. M., LITTELL, A. S., HOUSER, H. B., LINDAN, O. & WEIR, D. R. (1965). *Proceedings of the Society of Experimental Biology and Medicine*, **120**, 487.

HOUSER, H. B. WEIR, D. R., LITTELL, A. S., GREENWAY, R. M. & LINDAN, O. (1963). *Annals of the New York Academy of Sciences*, **110**, 898.

KEYS, A. & BROZEK, J. (1953). *Physiological Reviews*, **33**, 245.

MOORE, F. D., OLESON, K. H., MCMURREY, J. D. PARKER, H. V., BALL, M. R. & BOYDEN, C. M. (1963*a*). *The Body Cell Mass and Its Supporting Environment*, Philadelphia: Saunders.

MOORE, F. D., OLESON, K. H., MCMURREY, J. D. PARKER, H. V., BALL, M. R. & BOYDEN, C. M. (1963*b*). *The Body Cell Mass and Its Supporting Environment*, Philadelphia: Saunders.

O'DONNELL, F. B. & GARDNER, W. J. (1953). *Journal of the American Medical Association*, **153**, 706.

POLLOCK, L. J., BERNSOHN, J., PYSIK, S. W., FINKLE, J. R. & BLUSTEIN, H. (1954). *Archives of Neurology and Psychiatry*, **71**, 116.

PRENTICE, T. C., SIRI, W., BERLIN, N. I., HYDE, G. M., PARSON, R. J., JOINER, E. E. & LAWRENCE, J. H. (1952). *Journal of Clinical Investigation.*, **31**, 412.

ROBINSON, R. (1954). *Proceedings of the Royal Society of Medicine*, **47**, 1109.

SCHEFFÉ, H. (1953). *Biometrika*, **40**, 87.

SHIZUME, K., SHISHIBA, Y., SAKUMA, M., YAMAUCHI, H., NAKAO, K. & OKINAKA, S. (1966). *Metabolism*, **15**, 145.