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The relation of total body potassium to height, weight, and age in normal adults

K. BODDY, PRISCILLA C. KING, R. HUME, AND ELSPETH WEYERS

From the Scottish Research Reactor Centre, East Kilbride, and the Department of Medicine, Southern General Hospital, Glasgow

SYNOPSIS Total body potassium was measured in 103 healthy adults using a shadow-shield whole-body monitor of high sensitivity. The range of height was 147 to 192 cm, of weight 43 to 92 kg, and of age 18 to 77 years.

The values obtained for total body potassium were correlated with height, with weight, and with height and weight. Age was then included as an additional variable.

The standard deviation from regression was smaller when total body potassium was correlated with height than with weight and was further reduced, to about 9%, in a multiple regression using height and age. The advantages of this relationship over indices involving weight are discussed.

The smallest standard deviation from regression, 7·5%, was obtained when total body potassium was correlated with height, weight, and age. The usefulness of this relationship is discussed with comment on its limitations.

A regression equation was derived between lean body mass (derived from height and weight) and total body potassium with a standard deviation from regression of 5·5% in males and 7·3% in females.

The importance of potassium as a body electrolyte is well established but the only method of directly measuring the total body content of this mineral is by use of highly sensitive whole-body radioactivity monitors. An advantage of this technique is that a single measurement only is required, so that results are obtained rapidly and with minimum inconvenience to the patient. When the monitor has been calibrated, the need to administer radioactive isotopes is obviated.

In studying changes in body potassium due to treatment or disease, control values may be obtained before treatment or after recovery. Expressing the difference as a percentage change is adequate in some investigations. However, in certain clinical disorders it may be highly desirable to know at a time when no control values are available whether the total body potassium differs from that in normal control subjects and if so to what extent. Total body potassium per unit body weight (m-equiv/kg BW) (mmol/kg) has been used previously as an index but the dependency on body weight only limits its usefulness because of the effect of obesity, oedema, and starvation. Expression of total body potassium in relation to lean body mass (m-equiv/kg LBM) (mmol/kg) largely avoids this problem but in practice is not clinically convenient because the estimation of lean body mass by density or by dilution techniques involves delay, expense in terms of money and man power, and further disturbance of the patient. It has been shown, however, that lean body mass can be estimated with acceptable accuracy in adults from the height and weight of the subject (Hume, 1966; Hume and Weyers, 1971). Since the subject's height is not usually affected by the same factors as those influencing body weight, the possibility that total body potassium was significantly related to height as well as weight merited investigation. The relationships between total body potassium and lean body mass also deserved further study.

Correspondence: Dr Keith Boddy, Scottish Research Reactor Centre, East Kilbride, Glasgow.

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Materials and Methods

The study included 103 healthy control subjects (49 males and 54 females). All were on a normal diet and fluid intake. The subjects ranged in weight from 43·1 to 93·3 kg, in height from 147·3 to 191·8 cm, and in age from 18 to 77 years (Table I).

Although it would have been advantageous if

Subject	*Age*	*Weight (kg)*	*Height (cm)*	*Lean Body Mass (LBM) (kg)*	*Potassium (m-equiv)*	*Potassium (m-equiv/kg LBM)*
Males						
1	54	70·0	156·2	51·0	2928	57·4
2	20	57·0	171·5	49·7	3064	61·6
3	24	72·8	177·8	57·9	4281	73·9
4	30	53·0	166·4	46·8	2793	59·7
5	30	75·0	174·0	57·7	3808	66·0
6	44	54·0	170·2	48·2	2974	61·7
7	30	62·0	177·8	53·5	3893	72·8
8	34	74·0	167·6	55·6	3826	68·8
9	26	64·0	181·6	55·3	4228	76·5
10	26	56·7	161·9	47·1	2757	58·5
11	58	55·3	171·5	49·1	2852	58·1
12	25	68·0	172·7	54·5	3703	68·0
13	25	80·7	175·3	60·4	4345	71·9
14	24	58·6	179·1	52·4	3593	68·6
15	24	60·9	174·0	52·0	3703	71·2
16	24	68·0	179·1	56·2	3660	65·1
17	24	69·0	180·3	57·0	4177	73·3
18	25	83·5	184·2	63·2	4795	75·9
19	23	78·9	170·2	58·3	3903	66·9
20	43	59·0	157·5	46·8	2499	53·4
21	51	61·7	160·7	48·8	2680	54·9
22	46	67·6	170·2	53·7	3478	64·8
23	43	78·5	174·0	59·2	3747	63·3
24	22	52·0	170·8	47·5	3315	69·8
25	77	47·2	157·5	42·0	2320	55·2
26	31	80·7	175·5	60·5	4274	70·6
27	35	74·5	177·8	58·5	3440	58·8
28	35	70·5	176·5	56·6	3366	59·5
29	27	69·4	171·5	54·8	3072	56·1
30	64	73·9	170·2	56·3	3174	56·4
31	58	54·4	151·1	43·2	2253	52·2
32	65	62·1	171·5	51·8	2757	53·2
33	43	81·7	177·8	61·5	4049	65·8
34	47	71·7	177·8	57·4	3460	60·3
35	43	75·3	184·2	60·6	4107	67·8
36	43	80·7	172·7	59·7	3373	56·5
37	42	60·5	170·2	50·8	3171	62·4
38	25	69·5	177·8	56·7	3312	58·4
39	28	72·7	182·9	59·3	3921	66·1
40	26	65·9	177·8	55·1	4013	72·8
41	38	61·8	167·6	50·9	3233	63·5
42	24	60·0	172·7	51·3	3368	65·7
43	23	85·4	191·8	66·5	4417	66·4
44	46	92·3	171·5	63·6	3668	57·7
45	26	65·4	174·0	53·7	3333	62·1
46	21	63·5	177·8	54·1	3880	71·7
47	20	69·9	175·3	56·0	4143	74·0
48	21	78·0	181·6	61·0	4422	72·5
49	22	65·3	167·6	51·3	3345	65·2
Mean	35	68·0	173·2	54·6	3532	64·7
Females						
50	23	62·4	169·0	47·2	2742	58·1
51	29	57·0	161·3	42·2	2563	60·7
52	23	54·0	163·8	42·6	2849	66·9
53	23	45·4	156·2	36·9	2223	60·2

Table I *Total body potassium together with relevant physiological data*

children had been included in the present study, this would have necessitated administering radioactive isotopes to healthy children which was considered ethically undesirable.

Total body potassium was measured using the Merlin mobile whole-body monitor (Boddy, 1967) with a NaI detector 29·2 cm diameter by 10·2 cm deep. A shadow-shield of 10 cm thick lead bricks, a total weight of less than 8 000 kg, surrounded the detector housed in a central turret. The patient, lying supine on a motorized couch, passed beneath the detector and was scanned from head to feet. The output was taken to a TMC 400-channel pulse height analyser. After printout of the accumulated data, the patient adopted the prone position, the direction of travel of the couch was reversed and the patient was scanned from feet to head. The data were again recorded and mean values were obtained for the

Subject	*Age*	*Weight (kg)*	*Height (cm)*	*Lean Body Mass (LBM) (kg)*	*Potassium (m-equiv)*	*Potassium (m-equiv/kg LBM)*
54	24	60·8	160·0	42·5	2563	60·3
55	22	69·8	166·4	47·8	2711	56·7
56	23	60·0	161·3	42·9	2593	60·5
57	25	50·8	165·1	42·4	2673	63·0
58	70	54·4	154·9	38·5	1995	51·8
59	38	63·0	160·0	43·1	2445	56·7
60	23	44·1	152·4	34·7	2064	59·5
61	25	49·4	158·8	39·1	2146	54·9
62	23	60·3	168·9	46·6	2685	57·6
63	23	69·9	172·7	50·8	3202	63·0
64	23	51·0	157·5	38·9	2350	60·4
65	23	52·2	162·6	41·6	2310	55·5
66	53	48·1	157·5	38·1	2123	55·7
67	24	48·5	165·1	41·8	2473	59·2
68	23	53·1	154·9	38·2	2483	65·0
69	24	53·5	161·3	41·3	2187	53·0
70	24	64·9	167·6	47·1	2624	55·7
71	20	64·0	162·6	44·6	3084	69·2
72	37	60·8	165·1	44·9	2489	55·4
73	29	62·8	165·1	45·4	2361	52·0
74	24	88·0	168·9	53·6	2778	51·8
75	42	62·1	165·1	45·3	2276	50·2
76	24	52·6	163·8	42·3	2018	47·7
77	25	76·7	182·9	57·3	3443	60·1
78	59	57·0	157·5	40·4	2084	51·6
79	38	61·2	161·3	43·2	2463	57·0
80	21	55·4	160·0	41·2	2555	62·0
81	58	56·3	151·1	37·2	1972	53·0
82	42	65·3	147·3	37·7	2302	61·1
83	62	65·3	157·5	42·5	2202	51·8
84	48	49·9	162·6	41·0	2056	50·1
85	41	50·3	157·5	38·7	2082	53·8
86	60	54·0	153·7	37·8	2087	55·2
87	49	68·5	156·2	42·7	2381	55·8
88	57	66·2	172·7	49·9	2476	49·6
89	60	64·0	161·3	43·9	2079	47·4
90	60	62·6	172·7	49·0	2315	47·2
91	65	64·0	166·4	46·4	2458	53·0
92	68	62·1	156·2	41·1	2033	49·5
93	72	47·2	160·0	39·1	2018	51·6
94	49	43·1	148·6	32·7	2005	61·3
95	21	62·8	168·9	47·2	2742	58·1
96	34	55·0	167·6	44·8	2601	58·1
97	18	49·5	163·8	41·7	2652	63·6
98	24	61·7	171·5	48·2	2982	61·9
99	19	48·5	156·2	37·6	2425	64·5
100	18	57·2	160·0	42·0	2289	54·5
101	28	69·9	171·5	50·2	3358	66·9
102	41	73·5	171·5	51·1	3166	62·0
103	30	61·7	167·6	45·6	2552	56·0
Mean	36	58·7	162·4	43·2	2460	56·9

Table 1 *continued*

two positions. The sensitivity obtained was at least comparable with that of the conventional steel or lead room monitors. The subject counting rate in the potassium-40 photopeak (1·36-1·56 Mev) was expressed as m-equiv (mmol of potassium without the administration of a radioactive isotope, using the procedure described in detail elsewhere (Boddy, King, Tothill, and Strong, 1971). The estimated coefficient of variation of this procedure was shown to be ± 3·9% for a subject having 3 600 m-equiv (mmol) K.

Total body water (TBW) and lean body mass (LBM) were calculated from the weight (W) and height (H) of each subject according to the formulae of Hume and Weyers (1971). The relationships were as follows:

$$\text{Males: TBW (litres)} = 0{\cdot}2968\ \text{W (kg)} + 0{\cdot}1948\ \text{H (cm)} - 14{\cdot}0129$$

$$\text{Females: TBW (litres)} = 0{\cdot}1838\ \text{W (kg)} + 0{\cdot}3446\ \text{H (cm)} - 35{\cdot}2701$$

where

$$\text{LBM (kg)} = \text{TBW} \times \frac{100}{73}\ \text{(Pace and Rathbun, 1945).}$$

Results

Relevant physiological data for each subject are

Independent Variables	*Correlation Coefficient*		*Standard Deviation from Regression (%)*	
	Males	*Females*	*Males*	*Females*
Height	0·818	0·732	9·7	10·1
Weight	0·688	0·594	12·3	11·9
Height and weight	0·875	0·765	8·3	9·6
Height and age	0·841	0·806	9·3	8·8
Height, weight, and age	0·907	0·875	7·3	7·8

Table II *Correlation of total body potassium with height, weight, and age*

summarized in Table I. The values obtained for total body potassium are given in the same table together with the calculated lean body mass.

The linear regressions of total body potassium on height and on weight were computed by the method of least squares. A multiple regression on height and weight was then calculated and finally age was included as an additional variable. These results are summarized in Table II, which shows correlation coefficients and standard deviations from regression. The correlation was highly significant in each case. The relationships of particular interest and potential importance are

(*a*) Total body potassium on height and age:

Males: m-equiv K (mmol K) = 53·02 H − 9·74 Age − 5305

Females: m-equiv K (mmol K) = 33·63 H − 7·73 Age − 2727

(*b*) Total body potassium on height, weight, and age:

Males: m-equiv K (mmol K) = 23·96 W + 35·15 H − 12·09 Age − 3762

Females: m-equiv K (mmol K) = 14·76 W + 22·07 H − 9·05 Age − 1669

The linear regression of calculated lean body mass on total body potassium was also computed. The relationships obtained were:

Males: LBM (kg) = $7{\cdot}550 \times 10^{-3}$ m-equiv K + 27·98

Females: LBM (kg) = $1{\cdot}014 \times 10^{-2}$ m-equiv K + 18·23

which were highly significant (r = 0·83 and 0·76 respectively) with a standard deviation from regression of 5·5 and 7·3% of the mean respectively.

Discussion

Total body potassium can be measured conveniently by a whole-body monitor without the administration of a radioactive isotope. In some clinical circumstances, however, it is not sufficient to know the total body potassium of a patient without reference to the 'normal' value or range of body potassium for that individual. The most sensitive index of 'normality' will have the smallest range and therefore give better resolution between 'normal' and 'abnormal' values for total body potassium. However, if the index involves a reference to some physical characteristic such as body weight, for example in m-equiv K/kg BW (mmol K/kg BW), then the index must not be invalidated as a result of variation in the reference characteristic.

In normal males and females total body potassium varies so widely with body habitus and with age (Table I) that reference to some physical characteristic is essential to provide a more definitive index. Previously, total body potassium has been related to body weight (m-equiv K/kg BW) (mmol K/kg BW) and age (Anderson and Langham, 1959; McNeill and Green, 1959; Baarli, Madshus, Liden, and McCall, 1961; Blahd, Cassen, and Lederer, 1962; Delwaide, Verly, Colard, and Boulenger, 1962; Remenchik and Miller, 1962; Von Dobeln, 1962; Meenely, Ball, Ferguson, Payne, Lorimer, Weiland, Rolf, and Heyssel, 1962; Woodward, Trujillo, Schuch, and Anderson, 1965; Oberhausen and Onstead, 1965; Hughes, Williams, and Smith, 1967; Allen, Anderson, and Langham, 1969).The ranges (± 2 × coefficient of variation) were about ± 20 to 40%. However, the usefulness of m-equiv K/kg BW (mmol K/kg BW) as an index is limited also by the aberrations in body weight in conditions such as obesity, oedema, and starvation. It is, therefore, in circumstances of particular clinical interest that this index is least reliable. Total body potassium has been related to lean body mass, fat-free weight, or total body water and a corresponding relationship such as m-equiv K/kg LBM (mmolK/kg LBM) has been used as an index of 'normal' potassium (Woodward *et al*, 1965; Allen *et al*, 1969; Remenchik and Miller, 1962; Von Dobeln, 1962; Oberhausen and Onstead, 1965; Hughes *et al*, 1967). The coefficients of variation were about 6 to 9% of the mean. To permit comparison, however, lean body mass must be estimated and this can only be done indirectly from complicated body density studies (Steinkamp, Cohen, Gaffey, McKey, Bron, Siri, Sargent, and Isaacs, 1965; Durnin and Rahman, 1967) or from the measurement of total body water which is related to lean body mass (Pace and Rathbun, 1945). These additional measurements involve delay and cause further inconvenience to the patient. In conditions of electrolyte disturbance, when the potassium concentration in lean body mass may be abnormal, there are frequently abnormalities also of total body water. In these cases, the use of m-equiv K/kg LBM (mmol K/kg LBM) as an index will be unsatisfactory.

The relationship between total body potassium and height or height and age has, evidently, not been reported previously but the present study shows that height provides a better index than weight in respect of the standard deviations from regression, ie, about 9%. Although the inclusion of age as an additional variable significantly improved the correlation in statistical terms, in practice age makes little contribution to the estimated m-equiv K using these relationships. Height also provides a better index than weight because in adults height will not be affected by obesity, oedema, or starvation. A corresponding reservation applies to the inclusion of lean body mass (ie height + weight) in an index in conditions such as electrolyte disorders. The novelty of this relationship to height and age and its potential usefulness because of its relative independence of clinical disorder raises the question of its physical basis. Von Dobeln (1962) indicated that lean body mass, to which total body potassium is related, could be estimated from height and skeletal parameters with a coefficient of variation of ± 4%. Other evidence suggesting that skeletal size, and height in particular, is a significant factor in indices of 'normality' is provided by Nicholson and Zilva (1964) who found that H^3/W was the most satisfactory index to describe normal values of body constituents.

When weight was included as a variable in addition to height and age, the correlation was significantly improved and the standard deviation from regression was reduced to about 7·6%. The 'normal' range was then ± 15% (± 2 × coefficient of variation). The regression equations are more strongly dependent on height than on weight as shown by the greater correlation coefficient. The coefficient of height is greater than that of weight, and, in all but one male and one female subject, the height was more than twice the weight. For example, for a 70 kg male of only 160 cm height, the contribution of the height term is more than three times that of the weight term. If the subject became oedematous to an extent of 10 litres potassium-free fluid, a situation which is scarcely compatible with life (Black, 1967), the regression would overestimate the normal body potassium by only about 240 m-equiv K (mmol K) which is within a single standard deviation of the non-oedematous value. However, when major aberrations in weight are suspected as a result of gross oedema, obesity, or starvation, height and age are likely to provide the more reliable index.

The two pairs of equations involving height and age, with and without weight, would appear therefore to be satisfactory, when used appropriately, in a wide range of clinical disorders and particularly those in which potassium status might be involved. The relationships are already proving of significant clinical usefulness and interest in our own experience (Boddy, King, Lindsay, Briggs, Winchester, and Kennedy, 1972).

The estimation of lean body mass from the measured total body potassium is potentially valuable, especially in conditions where the use of total body water is unreliable. The good correlation in control subjects between lean body mass, estimated from the height and weight relationships of Hume and Weyers (1971), and total body potassium is noteworthy. It was suggested from the chemical analysis of four cadavers (Forbes, Gallup, and Hursh, 1961) that lean body mass was consistently related to total body potassium in the ratio of 68.1 m-equiv/kg (mmol/kg) but the validity of using a single constant for both sexes was subsequently questioned (Barter and Forbes, 1963). In our own series the mean values for males and females were significantly different and were equivalent to a potassium content of lean body mass of 64·5 and 57·0 m-equiv/kg (mmol/kg) respectively. These values are lower than that of Forbes *et al* (1961) quoted above, and that of 76·2 m-equiv/kg (mmol/kg) reported in males by Hughes *et al* (1967) but are comparable with the following: 65·4 in males and 58·3 in females (Allen *et al*, 1960), 59·3 in a population of unspecified sexes (Remenchik and Miller, 1962), and 69·9 in males and 59·3 in females (Von Dobeln, 1962). The available evidence appears to confirm that the potassium content per kg lean body mass is different in males and females and the mean values obtained by various workers are in fair agreement. However, the coefficient of variation found by other workers is rather greater than the values of 5·5 and 7·3% obtained for males and females respectively in our series.

Conclusions

Relationships have been obtained between total body potassium and height or height and age which enable the total body potassium to be predicted in normal adults while avoiding the errors which may be associated with indices involving body weight. The relationships should, therefore, be of particular value in oedema, obesity, starvation, and other conditions where potassium metabolism is of interest but aberrations in body weight might cause artefacts. When anomalous body weights are not anticipated, the standard deviation from regression can be reduced to 7·5% from about 9% by use of the regression equation relating total body potassium to weight, height, and age.

Correlation of lean body mass with total body potassium showed that the potassium content per kg lean body mass was significantly different between males and females. The derived regression equations had standard deviations from regression of 5·5 and 7·3% respectively, permitting an estimation of lean body mass from a measurement of total body potassium.

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