TOTAL-BODY POTASSIUM DURING THE FIRST YEAR OF LIFE DETERMINED BY WHOLE-BODY COUNTING OF ^{40}K

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Total-body potassium was determined by whole-body counting of ^{40}K in 31 white, normal infant boys and in 33 infant girls at 1, 4, 9, and 12 months of age. Anthropometric measurements of skeletal growth, subcutaneous fat, and lean tissues supplemented measurements of total-body potassium. Infant boys had significantly higher amounts of total-body potassium at each age. Amounts of total-body potassium per kilogram of body weight were nearly the same in both sexes at all ages, except a decrease in relative amounts was observed at age 4 months in both sexes. The correlation coefficient between total-body potassium and chronologic age in infant boys and girls was 0.94 and 0.89, respectively; the correlation coefficient of total-body potassium with weight was 0.93 and 0.92, respectively. In relation to height, two intersecting regression lines showed the breaking point of total-body potassium at about 59.9 cm for infant boys and at about 64.3 cm for infant girls.

The role of potassium as the major intracellular cation necessary for muscle contraction (*1*), synthesis of tissue protein (*2*), activation of various ATPs (*3,4*), and for oxidative phosphorylation in mitochondria (*5*)—and the relationship of potastium to sodium ions—(*6*) has been well established.

The total-body content of potassium has been determined by chemical analysis of adult cadavers (*7*) and stillborns (*8*). The indirect analysis of exchangeable potassium has been facilitated in adults (*9–11*) and in hospitalized "normal" infants and children (*12*) by radioactive potassium (^{42}K) using the dilution principle (*13*). More recently, total-body potassium was determined by whole-body counting of naturally radioactive potassium (^{40}K) in a large sample of adults (*14,15*), in children (*16*), and in infants (*17*).

The content of potassium varies in different tissues, and therefore its relation to age and sex is important for elucidating tissue changes in the field of body composition and human growth. From the knowledge of total-body or exchangeable potassium, fat-free mass (*18*) or cellular mass (*19*) can be calculated if certain assumptions are made. Of paramount importance to medicine is the knowledge of total-body or exchangeable potassium combined with data on total-body fluids (total-body water and bromine space) that allows for calculations of intracellular potassium concentration expressed in milliequivalents per liter of intracellular water. Depletion of intracellular potassium in the myocardium, for example, has been associated with lesions in mitochondria, sarcoplasmic reticulum, and myofibrils (*20*). Multiple tracer methodology provides a precise description of chemical anatomy of body fluids, which has been documented in various diseases (*21–23*) including malnutrition (*24*) and muscle disease (*25*).

To appraise the magnitude of abnormalities of either total-body or intracellular potassium in infancy and because adequate information on the total-body potassium of infants beyond 1 month of age is lacking, we obtained measurements on a number of healthy subjects. The purposes of our study were to determine (A) total-body potassium on the same subjects serially from early infancy to 1 year of age; (B) any sex differences in total-body potassium during this vigorous period of growth; and (C) any significant relationships of total-body potassium to chronologic age, weight, or height.

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SUBJECTS AND METHODS

The subjects for this study were white, healthy normal infants: 31 boys and 33 girls. All were full-term at birth, and all were examined at the Well-Baby Clinic of the Mayo Clinic at ages 1, 4, 9, and 12 months. Pediatricians explained the nature of the study to mothers of newborns, and those who agreed to have their infants included in this investigation brought their children to the Laboratory of Body Composition.

Total-body potassium was determined by whole-body counting of naturally radioactive potassium (^{40}K), which emits gamma rays of 1.46 MeV. The whole-body counter and the counting procedure for infants 1 month old have been described by Novak, et al (*17*). A similar procedure was used for counting infants 4 and 9 months old. However, for infants 12 months old, a larger phantom was used to calibrate the whole-body counter. The phantom consisted of plastic bottles filled with distilled water containing 120 gm of potassium. The length of the phantom was 75.0 cm and the weight was 10.1 kg. The four upper detectors of the whole-body counter (arranged in a roof configuration) and the two lower detectors were used for counting. The dimensions of each plastic detector were 18 × 18 × 6 in. The center of the upper detectors was 38 cm (15 in.) above the cart on which the subject was lying, and the lower detectors were 5 cm (2 in.) below the cart. The average counting efficiency for this geometry and phantom was 0.423 cps/gm of potassium.

The counting cycle of 1,000 sec background, 1,000 sec phantom, 600 sec subject, 1,000 sec phantom, and 1,000 sec background was used to minimize variations in counter sensitivity. With an average background of 38 cps and an average of 8.5 net counts of the subject, the standard error of counting 12-month-old infants was 3.7%, calculated according to the following formula:

$$\text{s.e.}(\%) = \frac{100}{S}\left(\frac{B}{t_B} + \frac{B+S}{t_S}\right)^{1/2},$$

in which S = cps of the subject,
B = background cps,
t_B = background counting time, and
t_S = counting time of the subject.

All infants passed the counting time in the whole-body counter in a peaceful sleep with a background of soft music. A television camera and adequate lighting in the steel counting room allowed visual observation of the resting infants.

After the counting was completed, anthropometric measurements of height and weight of the infant and of the bi-iliac diameters and widths of elbow, wrist, knee, and ankle were measured by the use of a sliding caliper. Subcutaneous fat measurements included those of the upper arm skinfold, forearm skinfold, thigh, calf, and subscapular skinfolds. These were measured by using Lange skinfold calipers with a constant pressure between the jaws of 10 gm/mm². Lean tissues of upper and lower extremities were appraised by using corrected diameters that were calculated according to the following formula:

$$d^1 = \frac{c}{\pi} - \text{skinfold},$$

in which, d^1 is the corrected diameter, π is 3.14159, and c is the circumference of the extremity.

RESULTS

Heights and weights. Table 1 gives means and standard deviations of heights, weights, and total-

TABLE 1. HEIGHT, WEIGHT, AND TOTAL-BODY POTASSIUM (TBK) BY SEX

Factor	Examination 1 Male	Examination 1 Female	Examination 2 Male	Examination 2 Female	Examination 3 Male	Examination 3 Female	Examination 4 Male	Examination 4 Female
	Means and standard deviations							
Height (cm)	54.9†	53.1†	65.2‡	63.2‡	73.2‡	70.9‡	76.3†	74.6†
	±2.5	±2.6	±1.9	±2.2	±1.7	±2.6	±1.9	±2.7
Weight (kg)	4.30*	3.94*	7.16‡	6.53‡	9.49†	8.76†	10.18*	9.64*
	±0.58	±0.60	±0.63	±0.61	±0.93	±0.88	±1.01	±1.03
TBK (mEq)	202*	185*	307*	278*	449*	398*	484*	447*
	±32	±31	±49	±41	±54	±81	±59	±71
TBK (mEq/kg)	47.2	47.2	43.0	42.6	47.6	45.5	47.7	46.4
	±7.3	±5.5	±6.1	±5.4	±6.3	±8.5	±5.3	±6.5
TBK (gm)	7.83*	7.28*	12.16*	10.82*	17.68†	15.58†	19.09*	17.91*
	±1.3	±1.3	±1.8	±1.6	±2.1	±2.6	±2.3	±2.5
TBK (gm/kg)	1.83	1.85	1.70	1.65	1.87	1.78	1.87	1.85
	±0.28	±0.22	±0.23	±0.21	±0.25	±0.29	±0.22	±0.22

Significant difference between sexes: *$p < 0.05$; †$p < 0.01$; ‡$p < 0.001$.

body potassium and total-body potassium per kilogram of body weight for each sex at each examination. Infant boys and girls were examined at about the same average age, plus or minus 2 weeks from the mean age. These examinations corresponded approximately to ages of 1, 4, 9, and 12 months.

The rate of growth in height of infant boys was 3.4 cm/month between 1 and 4 months, 1.6 cm/month between 4 and 9 months, and 1.0 cm/month between 9 and 12 months. The rate of growth in height of infant girls was 3.4 cm/month between 1 and 4 months, 1.5 cm/month between 4 and 9 months, and 1.2 cm/month between 9 and 12 months. The mean height of infant boys was significantly greater than that of infant girls at each age measured, namely by 1.8 cm, 2.0 cm, 2.3 cm, and 1.7 cm, respectively. The rate of increase in weight of infant boys was 0.95 kg/month, 0.47 kg/month, and 0.23 kg/month between successive examinations. The rate of increase in weight of infant girls was 0.86 kg/month, 0.45 kg/month, and 0.29 kg/month, respectively. The mean weight of infant boys was significantly higher than that of infant girls at each age measured, namely by 0.36 kg, 0.63 kg, 0.73 kg, and 0.54 kg, at the successive ages.

Total-body potassium. The mean values of total-body potassium of infant boys increased from the value of 202 mEq found at approximately 1 month of age to 307 mEq, 449 mEq, and 484 mEq at 4, 9, and 12 months, respectively. The calculated rate for change of total-body potassium was 35.0 mEq/month between ages 1 and 4 months, 28.4 mEq/month between ages 4 and 9 months, and 11.7 mEq/month between 9 and 12 months of age.

The mean values of total-body potassium of infant girls increased similarly from the value of 185 mEq observed at 1 month to 278 mEq, 398 mEq, and 447 mEq, respectively, found at subsequent examinations at 4, 9, and 12 months. The calculated rate for change of total-body potassium in infant girls showed monthly increases of 31.0 mEq/month between ages 1 and 4 months, then 24.0 mEq/month and 16.3 mEq/month between ages 4 and 9 months and between 9 and 12 months, respectively.

When the means of total-body potassium were analyzed statistically for sex differences, the infant boys always had significantly higher amounts of total-body potassium at each age. At 1 month, this difference was 17 mEq, at 4 months 29 mEq, at 9 months 51 mEq, and at 12 months 37 mEq.

When the mean values of total-body potassium were expressed in relative terms, i.e., per kilogram of body weight, infant boys maintained their body composition during the first year of life (the same mean relative values of total-body potassium of ap-

TABLE 2. CORRECTED DIAMETERS OF LEAN TISSUES AND SUBCUTANEOUS FAT SKINFOLDS BY SEX

	Means and standard deviations							
	Examination 1		Examination 2		Examination 3		Examination 4	
Factor	Male	Female	Male	Female	Male	Female	Male	Female
Lean tissue								
Upper arm (cm)	3.05*	2.93*	3.71*	3.57*	4.04	4.00	4.09	4.05
	±0.23	±0.25	±0.23	0.20	±0.27	±0.20	±0.25	±0.21
Forearm (cm)	3.00*	2.87*	3.55*	3.42*	3.91*	3.76*	3.98†	3.82†
	±0.29	±0.19	±0.18	±0.24	±0.29	±0.24	±0.27	±0.16
Thigh (cm)	4.50	4.34	5.86	5.87	6.64	6.67	6.72	6.76
	±0.43	±0.42	±0.47	±0.46	±0.46	±0.61	±0.65	±0.55
Calf (cm)	3.19†	3.03†	3.90	3.83	4.41*	4.23*	4.58	4.55
	±0.24	±0.21	±0.26	±0.32	±0.34	±0.26	±0.42	±0.35
Skinfold								
Subscapular (mm)	5.4	5.4	6.8	7.4	6.9	7.6	6.6	7.3
	±1.4	±1.5	±1.1	±2.7	±1.7	±1.8	±1.5	±1.7
Upper arm	6.0	5.5	8.8	8.7	10.4	9.6	10.5	10.4
(dorsal) (mm)	±1.4	±1.2	±1.6	±2.1	±2.3	±2.0	±2.1	±2.6
Upper arm	3.9	3.8	5.3	6.2	6.2	6.0	5.5	6.1
(ventral) (mm)	±0.8	±1.0	±1.2	±2.2	±1.5	±1.5	±1.3	±1.9
Forearm (mm)	5.9	5.6	8.8	9.0	9.7	9.2	9.2	9.1
	±1.5	±1.1	±1.7	±1.9	±2.4	±1.8	±2.0	±1.9
Thigh (mm)	8.1	8.4	13.7	14.9	13.4	13.1	13.3	14.4
	±2.0	±2.1	±3.0	±3.6	±4.9	±3.0	±4.4	±3.7
Calf (mm)	7.8	7.2	13.6	12.5	15.8	15.5	15.0	13.9
	±1.8	±1.7	±2.1	±2.6	±2.6	±2.4	±2.8	±1.7

Significant difference between sexes: *$p < 0.05$; †$p < 0.01$.

TABLE 3. SKELETAL DIAMETERS BY SEX

Factor	Examination 1 Male	Examination 1 Female	Examination 2 Male	Examination 2 Female	Examination 3 Male	Examination 3 Female	Examination 4 Male	Examination 4 Female
Diameter								
Bi-iliac (cm)	9.3*	9.0*	11.1‡	10.6‡	12.1†	11.7†	12.5*	12.2*
	±0.5	±0.4	±0.6	±0.4	±0.6	±0.4	±0.6	±0.5
Elbow (cm)	3.1*	2.9*	3.5‡	3.2‡	3.9*	3.7*	4.0†	3.8†
	±0.3	±0.3	±0.2	±0.2	±0.3	±0.2	±0.2	±0.2
Wrist (cm)	2.6†	2.4†	3.0*	2.9*	3.3*	3.2*	3.4*	3.3*
	±0.2	±0.2	±0.1	±0.2	±0.3	±0.2	±0.2	±0.2
Knee (cm)	4.0*	3.8*	4.8†	4.6†	5.4‡	5.1‡	5.5*	5.3*
	±0.4	±0.3	±0.3	±0.2	±0.3	±0.3	±0.3	±0.3
Ankle (cm)	2.9	2.8	3.3‡	3.1‡	3.8‡	3.5‡	4.0*	3.8*
	±0.2	±0.2	±0.2	±0.2	±0.2	±0.2	±0.2	±0.3

Means and standard deviations.

Significant difference between sexes: $^*p < 0.05$; $^\dagger p < 0.01$; $^\ddagger p < 0.001$.

proximately 47 mEq/kg of body weight). The only exception appeared at the age of 4 months when a decrease to 43.0 mEq/kg was observed.

Infant girls had the same relative amount of total-body potassium at 1 month of age as did infant boys, i.e., 47.2 mEq/kg of body weight. A similar decrease to that of infant boys was also observed in infant girls at 4 months of age when a relative value of 42.6 mEq/kg was found. Subsequently, at ages 9–12 months, an increase to 45.5 mEq/kg and 46.4 mEq/kg for girls was observed.

The differences in the means of relative amounts of total-body potassium between the sexes were not statistically significant at any of the ages examined.

Anthropometric appraisal. Means and standard deviations of corrected diameters of extremities and subcutaneous fat skinfolds are shown in Table 2.

Infant boys had significantly larger amounts of lean tissues than did girls, particularly in the upper arm, forearm, and calf. However, the corrected diameters of the thigh were practically the same in infants of both sexes.

The relative fatness as measured by subcutaneous fat skinfolds did not show significant differences between the sexes at any particular age interval and at any site measured. However, the greatest increase in subcutaneous fat skinfolds was detected at the age of 4 months in both sexes.

Table 3 gives the appraisal of the skeletal framework as measured by various skeletal diameters. The infant boys showed significantly larger measurements at nearly all age intervals in all five bone widths.

Correlations and regression equations. The relationship between total-body potassium and chronologic age, weight, and height in both infant boys and girls was examined by using the straight-line, parabolic, or two intersecting lines approach as described by Mellits (*26*). The correlation coefficient between total-body potassium and chronologic age in infant boys was 0.94, and the straight-line regression equation was TBK (mEq) = 173 + 0.90 (age in days). For infant girls, the relationship of total-body potassium to chronologic age was adequately described by the straight-line TBK (mEq) = 164 + 0.78 (age in days). The correlation coefficient between total-body potassium and chronologic age for infant girls was 0.89. The straight-line regression equations of total-body potassium to weight of infant boys was TBK (mEq) = −7.47 + 47.33 (weight in kilograms), and for infant girls it was TBK (mEq) = 1.67 + 44.84 (weight in kilograms) (Figs. 1–2). The correlation coefficient between total-body potassium and weight for infant boys was 0.93, and for infant girls it was 0.92.

The relationship of total-body potassium to height for infant boys is shown in Fig. 3. The coefficient of correlation was 0.94. A parabola seemed to be the best fit, although two intersecting lines fit equally well (F value for the parabola is 10.7 and for the two intersecting lines, 9.0), as compared with a single straight-line fit. Moreover, by using two intersecting lines, a breaking point of total-body potassium between the two lines was located approximately at 59.9 cm.

The relationship of total-body potassium to height for infant girls is presented in Fig. 4. The parabola and the two intersecting lines fitted the trend significantly better in comparison with the straight-line fit (F value for the parabola was 14.8; for the two intersecting lines it was 7.4). The intersecting point of total-body potassium between the two lines for infant girls was located approximately at 64.3 cm. The linear correlation coefficient was 0.92.

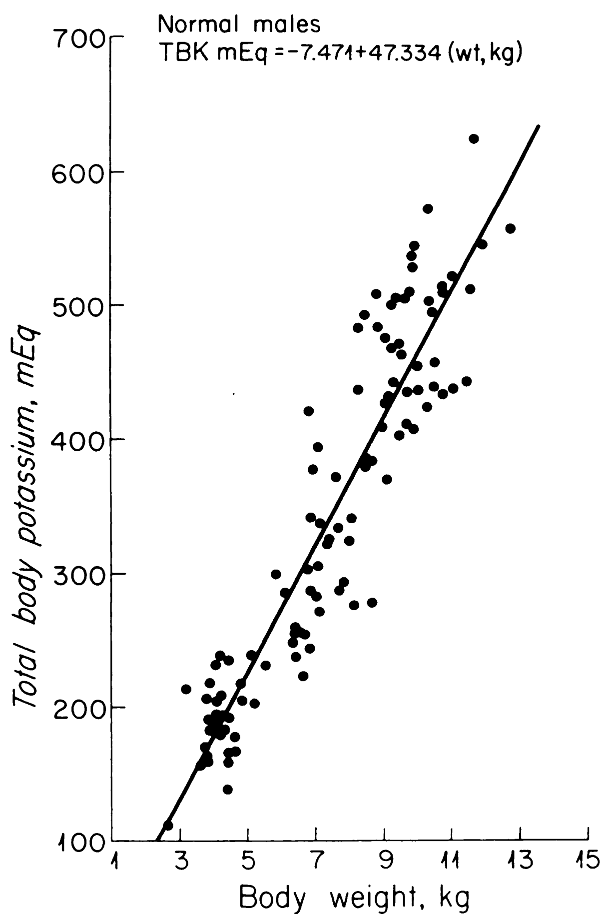

FIG. 1. Relationship of total-body potassium to body weight in infant boys.

COMMENT

The results of these serial observations of total-body potassium of infants of both sexes during the first year of life indicated that male infants had higher values of total-body potassium. Moreover, they also had greater heights and weights at all ages, from which observations were made. Potassium differences between sexes practically disappeared when relative values of total-body potassium were considered. Even though infant boys had significantly higher corrected diameters of extremities with high potassium content, this effect was balanced by significantly higher skeletal diameters with low potassium content. Thus, the net results of relative values of total-body potassium were the same as in infant girls. The concentration of approximately 47 mEq/kg of body weight was maintained throughout the first year. The only exception to this was observed at 4 months in both sexes. At that time, a decrease to 43.0 mEq/kg and 42.6 mEq/kg was found in infant boys and girls, respectively. This decrease indicated that tissues low in potassium were added faster to the body weight than were cellular tissues. Because body fat has a very low concentration of potassium as compared to lean tissues, it appears that accumulation of fat occurred in infants of both sexes between 1 month and 4 months of age. The six skinfolds that were measured at the same sites with standardized calipers indicated that the largest changes in skinfolds occurred between the first and the fourth months to both sexes as compared with the successive skinfold measurements at 9 and 12 months, when practically no changes in skinfolds were noted. Similar findings were reported by Maresh (*27*) who observed increases in fat of both sexes, evidenced by tissue widths measured on roentgenograms during the first 6 months of life.

Lack of data on total-body potassium in infants from other studies limits the scope of objective comparative evaluation of findings from our study. However, Maresh and Groome (*28*) reported the results of serial observations at monthly intervals on total-body potassium of one infant girl and of three infant boys. In general, their data on two infant boys showed decreasing amounts of total-body potassium per kilogram of body weight. One infant boy had (mEq/kg) 49.4 at 1 month, 34.1 at 4 months, 39.7 at 9 months, and 39.8 at 12 months of age. The second infant had 46.8 at 1 month and 34.2, 33.3, and 37.0 at 4, 9, and 12 months, respectively. When

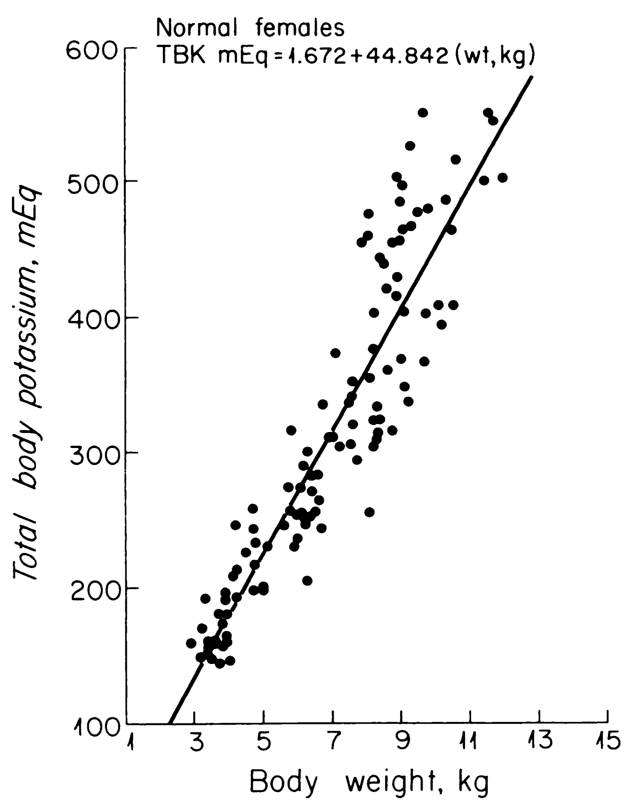

FIG. 2. Relationship of total-body potassium to body weight in infant girls.

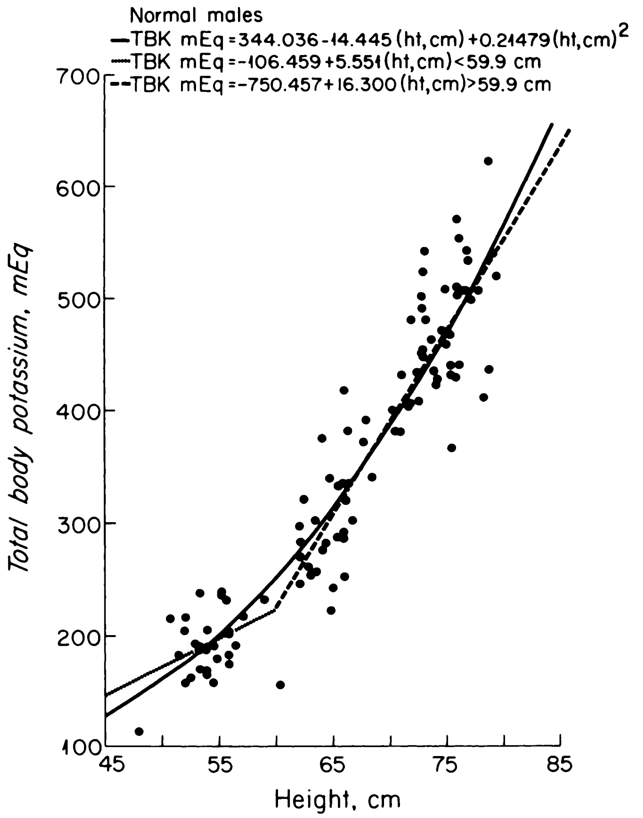

FIG. 3. Relationship of total-body potassium to height in infant boys.

these values were compared with the averages in our study, only the two values of total-body potassium obtained at 1 month of age corresponded to averages in our study. But all the other values of the two infants determined at 4, 9, and 12 months were lower by about 7.0–10.0 mEq/kg when compared with the results of our study.

In the study of Allen, et al (*29*), only three infant boys and five infant girls between birth and 12 months had averages of 366 mEq (40.9 mEq/kg) and 384 mEq (44.4 mEq/kg). Their average weight was 8.94 kg and 8.64 kg, respectively. The final average weight of five girls and their total-body potassium correspond well to the weight of 8.76 kg found in the 9-month-old infant girls of our study who had 398 mEq (45.5 mEq/kg). Garrow (*24*) reported a total-body potassium of 46.0 mEq/kg for a 1-year-old child who was counted in a special whole-body infant counter with a 4π geometry. Thus, with a whole-body counter of a similar geometric design and efficiency, comparative evaluation of total-body potassium even in small subjects is possible.

When exchangeable potassium was determined by Christian and Talso (*30*) in infants who were 1–27 hr old, 118 mEq (35.5 mEq/kg) was found, without consideration being given to separate sexes. Previous to that study, Gribetz, et al (*22*) reported 15 values of exchangeable potassium for hospitalized infants and children who were 1 month to 15 years old, and 40.0 mEq/kg were reported for two infant boys who were 1 and 2 months old, respectively (weights 2.41 kg and 5.10 kg), 41.0 mEq/kg for 4- and 5-month-old boys (weights 3.80 kg and 4.65 kg), and 37.0 mEq for another two boys who were 5 and 6 months old (weights 6.35 kg and 7.00 kg). However, the authors remarked that these two values were low because the two infants had not fully recovered from an acute infection. Because exchangeable potassium, even at adequate equilibration, accounts for about 90% of total-body potassium, the results correspond well to average total-body potassium values.

Ultimately, the values of total-body or exchangeable potassium obtained by whole-body counting or by dilution principle using radioisotopic potassium (^{42}K) have to be validated against the results obtained by chemical analysis, which are available only for full-term stillborn infants. Camerer (*31,32*), early at the beginning of this century, reported average values of 40 mmole/kg for six full-term newborns. Iob and Swanson (*33*) found 43.2 mEq/kg for one full-term infant whereas Widdowson and Dickerson (*8*) noted 42.9 mEq/kg of total-body potassium in a full-term infant whose weight was 3.5 kg.

In various diseases, total or exchangeable po-

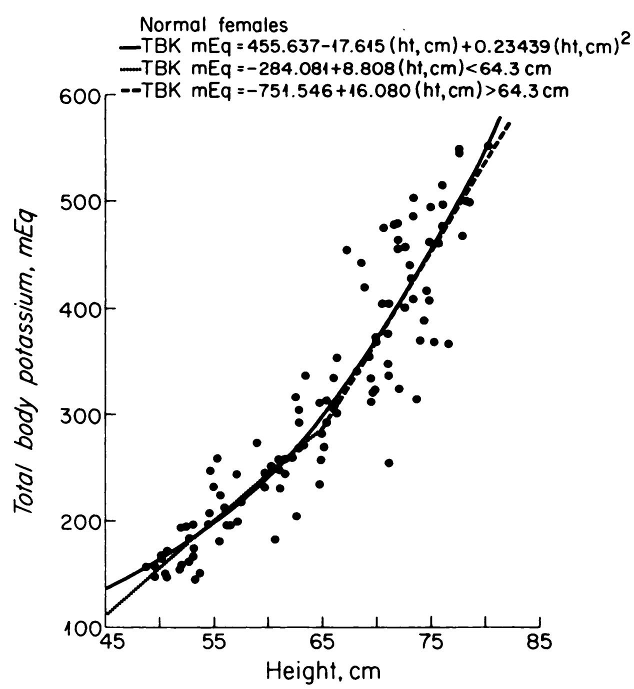

FIG. 4. Relationship of total-body potassium to height in infant girls.

tassium seemed to be diminished. Gribetz, et al (*22*) found an average value of 29 mEq/kg in exchangeable potassium for nine edematous nephrotic children who were 1–14 years old. When the exchangeable potassium was corrected for excess water, i.e., per kilogram of nonedematous weight, the average value increased to 36 mEq/kg. Malnourished infants seemed to be severely potassium-depleted according to the report of Smith and Waterlow (*34*). Garrow (*24*) reported values as low as 20 mEq/kg in severely malnourished edematous children whereas nonedematous malnourished children seemed to attain nearly normal potassium per kilogram of body weight (40 mEq/kg). Moderate-to-severe depressions of exchangeable and total-body potassium were reported by Blahd, et al (*35,36*) in patients with primary muscle disease; the decreases were related to severity of muscle involvement. Reba, et al (*37*) found the same amount of potassium in cardiac patients with growth retardation as in normal children of the same sex and weight but not of the same chronologic age. Similar results were observed by Novak and Feldt (*23*) in infants and children with congenital heart disease.

Total-body potassium that was obtained from normal healthy infants in this study and the prediction equations based on simple anthropometric measurements can serve as normal guidelines for the distribution of total-body potassium and for comparisons of total-body potassium obtained in infants with various pathophysiologic states.

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