Potassium per kilogram fat-free mass and total body potassium: predictions from sex, age, and anthropometry

INGRID LARSSON, ANNA KARIN LINDROOS, MARKKU PELTONEN, AND LARS SJÖSTRÖM

Department of Body Composition and Metabolism, The Sahlgrenska Academy at Göteborg University, SE-41345 Göteborg, Sweden

Submitted 9 May 2001; accepted in final form 6 October 2002

Larsson, Ingrid, Anna Karin Lindroos, Markku Peltonen, and Lars Sjöström. Potassium per kilogram fat-free mass and total body potassium: predictions from sex, age, and anthropometry. Am J Physiol Endocrinol Metab 284: E416–E423, 2003. First published October 15, 2002; 10.1152/ajpendo.00199.2001.—Total body potassium (TBK) is located mainly intracellularly and constitutes an index of fat-free mass (FFM). The aim was to examine whether TBK and the TBK-to-FFM ratio (TBK/FFM) can be estimated from sex, age, weight, and height. A primary study group (164 males, 205 females) and a validation group (161 and 206), aged 37–61 yr, were randomly selected from the general population. TBK was determined by whole body counting, and FFM was estimated as dual-energy X-ray absorptiometry (DEXA; FFMDEXA). The primary study group was used to construct sex-specific equations predicting TBK and TBK/FFM from age, weight, and height. The equations were used to estimate TBK and TBK/FFM in the validation group. The estimates were compared with measured values. TBK in different age ranges was predicted, with errors ranging from 5.0 to 6.8%; errors for TBK/FFM ranged from 2.7 to 4.8%, respectively. By adding FFMDEXA as a fourth predictor, the error of the TBK prediction decreased by approximately two percentage units. In conclusion, TBK and TBK/FFM can be meaningfully estimated from sex, age, weight, and height.

body composition; dual-energy X-ray absorptiometry; potassium-40; total body potassium-to-fat-free mass ratio; randomly selected study groups

BECAUSE 98% OF THE TOTAL BODY POTASSIUM (TBK) is located intracellularly (27), TBK is an excellent indicator of the respiratory cell mass of the body. TBK has therefore been the subject of intensive research during the last 50 years.

In a classic paper from 1956 (9), Forbes and Lewis reported the potassium (K) content of two male corpses, (9, 11), one female corpse previously examined by Widdowson et al. (26) in 1951, and one adult carcass of unknown sex examined by Shol (20) already in 1939. The potassium content of these cadavers was 66.5 (male), 66.6 (male), 72.6 (female), and 66.8 (adult) mmol/kg fat-free mass (FFM), or an average of 68.1 mmol K per kg FFM.

In a follow-up paper from 1961, Forbes et al. (7) reported TBK in 42 males and 8 females measured by means of a whole body counter. FFM was estimated as TBK/68.1, and body fat (BF) was calculated as body weight minus FFM. In males, percent BF was correlated with skinfold (r = 0.80) and with the weight-to-height ratio (r = 0.56). Although Forbes et al. did not specifically conclude that the potassium content of FFM is constant, the subsequent literature often interpreted these data as evidence that it was.

More recently, several reports have indicated that the potassium content of the body is dependent not only on FFM but also on sex (8, 12), age (6, 13) and body build (asthenic vs. athletic) (5, 15, 18). Also, some studies based on underwater weighing (28) or computed tomography (CT)-based body composition (14, 21) have indicated that the potassium content per kilogram FFM may be lower than 68.1 mmol/kg. Taken together, these studies suggest that the relation between TBK and FFM is not as straightforward as previously assumed and that more sophisticated conversion procedures are required. FFMI estimates based on TBK are dependent on a valid assumption of the potassium content per kilogram FFM. Therefore, our primary aim was to examine whether potassium-based FFM determinations could be improved by using individual rather than fixed TBK-to-FFM ratio (TBK/FFM) estimates. The individual TBK/FFM ratios were predicted from age, weight, and height by using the measured ratio as the dependent variable. TBK was determined using whole body counting and FFM by means of dual-energy X-ray absorptiometry (DEXA).

Our secondary aim was to examine whether TBK could be predicted from age, weight, and height alone or with the addition of FFM determined by DEXA (FFMDEXA). Such estimates are potentially important, because relatively few whole body counters are available worldwide.

METHODS

The Swedish Obese Subjects reference study. The Swedish Obese Subjects (SOS) reference study is an ongoing study including randomly selected middle-aged inhabitants of the...
city of Molndal, Sweden. The main purpose of the study is to obtain a reference sample for the SOS project (22). Other purposes of the study are to examine body composition, risk factors of cardiovascular disease, habitual dietary intake, and various aspects of quality of life in relation to age.

The subjects were randomly selected from a population registry by use of a computer-based procedure. Each subject received a written invitation to a health examination along with an explanation of the purpose of the investigation. Between August 1994 and December 1998, 360 men and 452 women were examined (response rate: 52% in men and 57% in women). Of these individuals, 349 men and 423 women were examined with both DEXA and TBK techniques.

Individuals showing large differences between measured body weight and the sum of DEXA compartments (see results and Fig. 1) were excluded. Thus 325 males and 411 females remained available. After allocation to age groups, these individuals were randomized to a primary study group (164 men and 205 women) and a validation group (161 men and 206 women).

Anthropometry. All anthropometric measurements in this study were performed with the subjects dressed in underewear after an overnight fast. Body height was measured to the nearest 0.01 m with the subject standing back to a wall-mounted stadiometer in bare feet. Weight was measured to the nearest 0.1 kg with calibrated scales. Body mass index (BMI) was calculated as weight in kilograms divided by height in meters squared (kg/m²). The following anthropometric measurements were also performed: waist and hip circumferences, sagittal trunk diameter, and thigh, neck, and upper-arm circumferences (22, 23).

DEXA. Body composition by means of DEXA results in a three-compartment model consisting of bone mineral content (BMC), BF, and lean tissue mass (LTM) (25). BMC plus LTM corresponds to FFM with the TBK technique and several other two-compartment methods. The DEXA scanner used was a LUNAR DPX-L scanner (system no. 7156; Scanexport Medical, Helsingborg, Sweden) with software version 1.31 and with the extended analysis program for total body analysis (LUNAR Radiation, Madison WI). This scanner uses a constant potential X-ray source and a K-edge filter to achieve a congruent beam of stable dual-energy radiation. A quality assurance test was conducted on a daily basis, as recommended by the manufacturer (16). DEXA determines BMC, BF, and LTM without using body weight. Therefore, one way to validate the method is to compare the sum of the three body compartments with body weight. The manufacturer does not recommend examinations of individuals heavier than 120 kg, because the sum of BMC, BF, and LTM gradually lags behind weight at higher body weights.

Precision errors of the scanner were determined by comparing results from two separate examinations of 10 healthy subjects. They were 1.7% for BF, 0.7% for LTM, 1.9% for BMC, and 1.5% for bone mineral density (BMD). One total body scan exposes the subject to a radiation dose equivalent to 0.5 μSv, which is in the lower range of radiation exposure measurements (17). For comparison, the radiation from one chest radiography is 80 times higher than a total body DEXA.
scan, and the daily background radiation in Göteborg is 3 μSv (source: Department of Radiation Physics, Göteborg University).

**TBK counting.** With the TBK method, body weight is compartmentalized into FFM and BF. The natural abundance of the potassium-40 isotope \(^{40}\text{K}\) is a constant fraction (=0.012%) of all natural potassium (6). The \(^{40}\text{K}\) isotope emits a 1.46-MeV \(γ\)-ray that can be counted using a detection system with appropriate shielding. The measurements took place in a high-sensitivity, 37 whole body counter containing four plastic scintillators with a total volume of 700 liters (24). The standard deviation of a single TBK determination (usually between 2,000 and 4,000 mmol) was ~80 mmol (3). The conversion of TBK into FFM is traditionally based on the assumption that 1 kg FFM contains 68.1 mmol K (FFM\(_{68.1}\)) (9).

We constructed TBK-to-FFM\(_{\text{DEXA}}\) ratios (TBK/FFM\(_{\text{DEXA}}\)) in the primary study group and regressed these by weight (W), height (H), and age (A) separately for men and women. In the validation group, we used the resulting equations to predict individual TBK/FFM\(_{\text{WHA}}\) ratios. FFM\(_{\text{WHA}}\) was calculated from TBK either by using Forbes’ ratio (68.1 mmol K/kg FFM) or by using the individually determined TBK/FFM\(_{\text{WHA}}\). In this study, FFM\(_{\text{K}}\) and BF\(_{\text{K}}\) designate FFM and BF determined with the TBK method without specifying which TBK/FFM ratio was used, whereas FFM\(_{68.1}\) indicates FFM determined from TBK and the assumption of 68.1 mmol K/kg FFM. FFM\(_{\text{WHA}}\) indicates FFM determined from TBK and the individually estimated [TBK/FFM]\(_{\text{WHA}}\). BF\(_{\text{WHA}}\) (BF\(_{68.1}\) or BF\(_{\text{WHA}}\)) was calculated as the difference between body weight and FFM\(_{68.1}\) or FFM\(_{\text{WHA}}\).

**Human subjects.** The protocol was approved by the ethics committee of the Medical Faculty of Göteborg University, and written informed consent was obtained from all subjects before the examinations.

**Statistical procedures.** Age, height, weight, and body composition measurements are presented as means ± SD for men and women separately. To describe age-related differences in body composition, the subjects were divided into one of five age groups: 37–41, 42–46, 47–51, 52–56, and 57–61 yr of age. Age-trend calculations were also performed using age, TBK, and TBK/FFM as continuous individual variables. Subjects were allocated to either a primary study group or a validation group by means of the Microsoft Excel (Microsoft, 1998) random function within each sex and age group.

In the primary study group, multiple linear regression analysis was performed to develop sex-specific predictive equations to estimate individual TBK/FFM from age, weight, and height. Measured TBK/FFM were used as dependent variables. Similarly, TBK was estimated from age, weight, and height with or without FFM\(_{\text{DEXA}}\), and measured TBK was used as a dependent variable.

Measurements of sagittal diameter and circumference of waist, hip, thigh, neck, upper arm, age squared, weight squared, and height squared were also considered and tested as predictors (independent variables) in the regression analyses. P values were considered significant when <0.05 in two-sided tests.

Equations obtained from the primary study groups were then applied on the validation groups, and errors between measured and estimated TBK or TBK/FFM were calculated as the within-subjects coefficient of variation (2)

\[
\frac{\sqrt{\sum d^2}}{n} \times 100
\]

where \(d\) is the difference between measured and estimated value, \(n\) the number of paired observations, and \(X\) the grand mean.

The statistical analyses were conducted with a JMP statistical software package, version 3.2.1 (SAS Institute, Cary, NC).

**RESULTS**

Because the main purpose of this study was to examine relationships between TBK and FFM\(_{\text{DEXA}}\), it was important to exclude individuals with erroneous values on these variables. It was not possible for us to check the potassium measurements independently. However, the sum of the DEXA-determined BMC, LTM, and BF (DEXASUM) could be compared with the simultaneously measured body weight. Figure 1, A and B, shows the difference between body weight and DEXASUM as a function of body weight in those 349 men and 423 women in whom both DEXA and TBK were measured. The slopes were positive and significant in both sexes, and most observations above 100 kg body wt were located above the regression line, indicating an increasing difficulty of the DEXA equipment to detect the total body mass with increasing body weight. Some outliers with <100 kg body wt were also observed.

To minimize the effects of systematic and random errors on the final TBK/FFM\(_{\text{DEXA}}\) ratios, all individuals with body weights >100 kg or with [body weight – DEXASUM] beyond ±2 SD shown in Fig. 1, A and B, were excluded in Fig. 1, C and D. The excluded individuals were 24 men [age: 51.9 ± 5.6 (40.9–61.1) yr; height: 181.6 ± 5.5 (174.0–194.0) cm; weight: 97.2 ± 13.0 (74.5–115.0) kg] and 12 women [age: 48.6 ± 7.4 (37.9–60.9) yr; height: 169.3 ± 4.7 (162.0–178.0) cm; weight: 77.6 ± 13.8 (60.0–107.0) kg]. The excluded subjects represented 6.8 and 2.8%, respectively, of the men and women who were examined with both DEXA and the TBK technique.

After the exclusions, the difference between body weight and DEXASUM was −0.1 ± 0.5 kg in men and 0.2 ± 0.4 kg in women, which was not significantly different from zero in either sex (Fig. 1, C and D). In women, the slope for [body weight – DEXASUM] vs. body weight was reduced from 0.0061 to 0.0017 and was no longer significant. In men, the corresponding slope dropped from 0.013 to 0.006 and the significance level from \(P = 0.0002\) to \(P = 0.03\).

The men and women of Fig. 1, C and D, were first divided into age groups, and within each age group individuals were randomized to a primary study group or a validation group, as described in Statistical procedures. Table 1 shows age, height, weight, BMI, TBK, FFM, and BF of all men and women within the primary study group and the validation group.

There were no significant differences between the primary study group and the validation group either in men or in women. All measurements in Table 1, except age and BF, were lower in women than in men. Although women had a lower BMI than men, they had...
higher BF as measured both with the DEXA and the TBK$_{68.1}$ methods.

Individually determined TBK and FFM$_{DEXA}$ observations were used to calculate TBK/FFM$_{DEXA}$ for all men and women in the primary study group. These ratios were multivariately regressed by age, weight, and height, the resulting sex-specific equations were (see Table 2)

**Males:**

\[
\text{TBK/FFM} = 98.30 - 0.1594 \times \text{age} + 0.1431 \times \text{weight} - 0.1849 \times \text{height}
\]

**Females:**

\[
\text{TBK/FFM} = 94.39 - 0.1735 \times \text{age} + 0.1169 \times \text{weight} - 0.1567 \times \text{height}
\]

where TBK/FFM is given in millimoles per kilogram, age in years, weight in kilograms, and height in centimeters.

All three predictors contributed significantly to the explained variances (Table 2).

In contrast, the sagittal trunk diameter and circumferences of waist, hip, thigh, neck, and upper arm did not contribute to the explained variances, nor did age squared, weight squared, or height squared when added separately as a fourth variable in these equations \((P = 0.10–0.97)\).

In addition, Table 2 provides TBK estimates based on age, weight, and height alone and also when FFM$_{DEXA}$ is added. In the former equations, age was negatively related to TBK, whereas weight and height were positively related to TBK. The explained variance was 52\% in women and 68\% in men. When FFM$_{DEXA}$ was added as a predictor, the explained variances increased to 73 and 88\%, respectively. Height became negatively related to TBK in men and tended to be so in women.

In the validation group, the correlation between the measured TBK/FFM and the same ratio estimated from age, weight, and height were significant both in men \((r = 0.48, P < 0.0001)\) and in women \((r = 0.39, P < 0.0001)\). When TBK was estimated from age, weight, and height, the estimate was closely related to measured TBK both in men \((r = 0.75, P < 0.0001)\) and in women \((r = 0.73, P < 0.0001)\). These associations were even stronger when FFM$_{DEXA}$ was added as a predictor (men: \(r = 0.93, P < 0.0001\); women: \(r = 0.90, P < 0.0001\); data not shown in figures).

In the validation group, the difference between FFM$_{DEXA}$ and FFM$_{68.1}$ was not significantly different from zero either in men (\(-0.3 \pm 3.3\) kg) or in women (\(0.3 \pm 2.5\) kg) (see Table 1). However, this difference was

### Table 1. Age, height, weight, BMI, TBK, FFM, and BF in the primary study group and the validation group

<table>
<thead>
<tr>
<th>Variables</th>
<th>Primary Study Group</th>
<th>Validation Group</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Men</td>
<td>Women</td>
</tr>
<tr>
<td>Numbers</td>
<td>164</td>
<td>205</td>
</tr>
<tr>
<td>Age, yr</td>
<td>49.3 ± 6.9</td>
<td>49.0 ± 6.8</td>
</tr>
<tr>
<td>Height, cm</td>
<td>172.9 ± 6.0</td>
<td>166.5 ± 5.6</td>
</tr>
<tr>
<td>Weight, kg</td>
<td>80.7 ± 9.4</td>
<td>66.6 ± 10.0</td>
</tr>
<tr>
<td>BMI, kg/m²</td>
<td>25.1 ± 2.7</td>
<td>24.0 ± 3.4</td>
</tr>
<tr>
<td>TBK, mmol</td>
<td>4,216 ± 473</td>
<td>2,927 ± 359</td>
</tr>
<tr>
<td>FFM$_{DEXA}$</td>
<td>61.2 ± 5.8</td>
<td>43.3 ± 4.3</td>
</tr>
<tr>
<td>FFM$_{68.1}$</td>
<td>61.9 ± 5.9</td>
<td>43.2 ± 5.3</td>
</tr>
<tr>
<td>BF$_{DEXA}$</td>
<td>19.6 ± 5.9</td>
<td>23.0 ± 8.0</td>
</tr>
<tr>
<td>BF$_{68.1}$</td>
<td>18.7 ± 5.9</td>
<td>23.6 ± 8.1</td>
</tr>
</tbody>
</table>

Values are means ± SD. BMI, body mass index; TBK, total body potassium; FFM$_{DEXA}$, fat-free mass determined by dual-energy X-ray absorptiometry (DEXA); FFM$_{68.1}$, FFM determined by the TBK method based on the assumption of 68.1 mmol K/kg FFM according to Forbes et al. (7); BF$_{DEXA}$, body fat determined by DEXA; BF$_{68.1}$, BF calculated as the difference between body weight and FFM$_{68.1}$.
negatively related to body weight in women ($P = 0.0053$) and tended to be so in men ($P = 0.08$) (Fig. 2, A and B); i.e., $\text{FFM}_{68.1}$ resulted in larger values than $\text{FFM}_{\text{DEXA}}$ at large body weights but in smaller values at low body weights. This weight bias disappeared completely if $\text{FFM}_K$ was calculated as $\text{TBK}/(\text{TBK}/\text{FFM}_{\text{DEXA}})$, since $[\text{FFM}_{\text{DEXA}} - \text{TBK}/(\text{TBK}/\text{FFM}_{\text{DEXA}})]$ is equal to zero (data not shown). However, the bias also disappeared when $\text{FFM}_K$ was calculated from measured $\text{TBK}$ and $\text{TBK}/\text{FFM}$ individually estimated from weight, height, and age according to the sex-specific equations of Table 2 (Fig. 2, C and D).

As indirectly suggested by Table 2, $[\text{FFM}_{\text{DEXA}} - \text{FFM}_{68.1}]$ might be biased not only by weight but also by age and height. Usually, this turned out to be the case, and these biases disappeared or decreased when individually estimated $\text{TBK}/\text{FFM}$ was used. (women: $[\text{FFM}_{\text{DEXA}} - \text{FFM}_{68.1}]$ vs. age, regression coefficient ($\beta$) = 0.070, $P < 0.01$; $[\text{FFM}_{\text{DEXA}} - \text{FFM}_{\text{WHA}}]$ vs. age, $\beta = -0.018$, $P = 0.42$; $[\text{FFM}_{\text{DEXA}} - \text{FFM}_{68.1}]$ vs. height, $\beta = 0.066$, $P < 0.02$; $[\text{FFM}_{\text{DEXA}} - \text{FFM}_{\text{WHA}}]$ vs. height, $\beta = 0.026$, $P = 0.31$; men: $[\text{FFM}_{\text{DEXA}} - \text{FFM}_{68.1}]$ vs. age: $\beta = -0.22$, $P < 0.0001$; $[\text{FFM}_{\text{DEXA}} - \text{FFM}_{\text{WHA}}]$ vs. age, $\beta = -0.11$, $P < 0.001$; $[\text{FFM}_{\text{DEXA}} - \text{FFM}_{68.1}]$ vs. height, $\beta = 0.016$, $P = 0.69$; $[\text{FFM}_{\text{DEXA}} - \text{FFM}_{\text{WHA}}]$ vs. height, $\beta = -0.038$, $P = 0.27$).

The difference between $\text{BF}_{\text{DEXA}}$ and $\text{BF}_{68.1}$ was not significantly different from zero in men in the validation group (0.4 ± 3.4 kg) but was so in women (−0.5 ± 2.5 kg; $P = 0.0075$) (Table 1). Although $[\text{FFM}_{\text{DEXA}} - \text{FFM}_{68.1}]$ was negatively related to body weight (see above), $[\text{BF}_{\text{DEXA}} - \text{BF}_{68.1}]$ was positively related to body weight in women ($P = 0.0053$). In men, the slope was also positive but nonsignificant ($P = 0.14$; Fig. 3, A and B). Compared with $\text{BF}_{\text{DEXA}}$, $\text{BF}_{68.1}$ thus resulted in smaller BF values at large body weights and in larger values at low body weights, particularly in women. This weight bias disappeared when $\text{BF}_K$ was calculated as the difference between body weight and $\text{FFM}_{\text{WHA}}$ (Fig. 3). Similarly, the biases of $[\text{BF}_{\text{DEXA}} - \text{BF}_{68.1}]$ by age and height disappeared or decreased when the prediction equations of Table 2 were used (data not shown).

In Tables 3 (men) and 4 (women), measured values for weight, height, BMI, $\text{TBK}$, and $\text{TBK}/\text{FFM}_{\text{DEXA}}$ are given by age groups in the pooled study group (primary + validation groups). In this cross-sectional study, the increase in BMI by age was more dependent on decreasing height than on increasing weight in both sexes. TBK as well as $\text{TBK}/\text{FFM}_{\text{DEXA}}$ decreased with age in both men and women.

In addition, Tables 3 and 4 are comparing the anthropometrically estimated TBK and $\text{TBK}/\text{FFM}_{\text{WHA}}$ with the measured TBK and $\text{TBK}/\text{FFM}_{\text{DEXA}}$ in the validation group.
The [TBK/FFM]_WHA estimated from weight, height, and age in the validation group were similar to actually measured TBK/FFMDEXA in all age groups of men and women. The errors based on the squared differences between measured and estimated ratios ranged between 2.7 and 3.8% in men and 3.2 and 4.8% in women. The prediction of TBK from weight, height, and age resulted in errors ranging between 5.3 and 6.6% in men and women.

Table 3. Body weight, height, BMI, TBK, and measured as well as predicted TBK and TBK/FFM by age in indicated study groups in men

<table>
<thead>
<tr>
<th>Age groups, yr</th>
<th>Group</th>
<th>Men</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>P + V</td>
<td></td>
</tr>
<tr>
<td>Age, yr</td>
<td>37–41</td>
<td>39.4 ± 1.4</td>
</tr>
<tr>
<td>Numbers</td>
<td>61</td>
<td>60</td>
</tr>
<tr>
<td>Body weight, kg</td>
<td>P + V</td>
<td>80.0 ± 9.8</td>
</tr>
<tr>
<td>Height, cm</td>
<td>P + V</td>
<td>180.6 ± 6.5</td>
</tr>
<tr>
<td>BMI, kg/m²</td>
<td>P + V</td>
<td>24.5 ± 2.8</td>
</tr>
<tr>
<td>TBK, mmol</td>
<td>P + V</td>
<td>4,365 ± 555</td>
</tr>
<tr>
<td>TBK/FFMDEXA, mmol/kg</td>
<td>P + V</td>
<td>70.4 ± 3.4</td>
</tr>
<tr>
<td>Numbers</td>
<td>V</td>
<td>30</td>
</tr>
<tr>
<td>TBK/FFMDEXA, mmol/kg</td>
<td>V</td>
<td>70.6 ± 4.0</td>
</tr>
<tr>
<td>[TBK/FFM]WHA, mmol/kg</td>
<td>V</td>
<td>69.9 ± 1.4</td>
</tr>
<tr>
<td>Error, %</td>
<td>V</td>
<td>3.4</td>
</tr>
<tr>
<td>TBK, mmol</td>
<td>V</td>
<td>4,382 ± 619</td>
</tr>
<tr>
<td>TBK_WHA, mmol</td>
<td>V</td>
<td>4,317 ± 346</td>
</tr>
<tr>
<td>Error, %</td>
<td>V</td>
<td>6.2</td>
</tr>
<tr>
<td>TBK_WHAAD, mmol</td>
<td>V</td>
<td>4,328 ± 506</td>
</tr>
<tr>
<td>Error, %</td>
<td>V</td>
<td>3.7</td>
</tr>
</tbody>
</table>

Values are means ± SD. P, primary study group; V, validation group; TBK/FFMDEXA, ratio of measured TBK by whole body counter and measured FFMDEXA; [TBK/FFM]WHA, predicted TBK/FFM based on weight, height, and age according to equation in Table 2; Error, within-subjects coefficient of variation (2) between measured and predicted TBK/FFM or measured and predicted TBK; [TBK/FFM]WHA, predicted TBK from weight, height, and age according to equation in Table 2; TBK_WHAAD, predicted TBK from weight, height, age and FFMDEXA according to equation in Table 2.
men and between 5.0 and 6.8% in women. Adding FFMDEXA to the prediction of TBK reduced errors to 2.7–3.9% in men and 3.3–4.8% in women.

**DISCUSSION**

There has been a lack of appropriate information on potassium content per kilogram FFM in the literature. This prediction study on body composition, based on a randomly selected sample from the general population, illustrates that TBK/FFM can be predicted from sex, weight, height, and age, with errors being <5% in the age interval 37–61 yr. Thus our equations can improve the estimation of FFM from TBK when whole body counters are available.

Our independent measurements of TBK with a whole body counter and of FFM with DEXA made it possible to predict TBK from sex, weight, height, age, and FFMDEXA with errors <5%. Predictions of TBK from sex, weight, height, and age alone resulted in errors ranging between 5.0 and 6.8%. Thus research sites with or without access to DEXA are able to make meaningful estimates of TBK. Such estimates are of importance, since TBK is a valuable indicator of respiratory cell mass.

In this cross-sectional study, we found that, although randomly selected women had a lower BMI, they had more BF than randomly selected men, irrespective of the method (DEXA or TBK) used. Also, BMI increased with age in both sexes, primarily due to decreasing height. Similar results have previously been obtained in cross-sectional (3, 19) and longitudinal (6) studies.

The TBK content was ~30% lower in women than in men across the five age groups. This sex difference, as well as the decline in TBK with age, is consistent with earlier longitudinal (6, 10) and cross-sectional (1, 13, 19) studies. The agreement with longitudinal studies implies that the decline in TBK with age in this study is related more to the biology of aging than to generation differences.

The manufacturer of LUNAR's DEXA machines points out that, at body weights >120 kg, DEXASUM gradually lags behind body weight. Figure 1 indicates that, when observations >100 kg body wt are excluded, the difference between body weight and DEXASUM is negligible, particularly in women.

Our results show that the now-40-yr-old assumption of Forbes et al. (7) on potassium content per kilogram FFM (68.1 mmol/kg) is approximately true in 50-yr-old men and 45-yr-old women. However, between the ages of 39 and 59 yr, TBK/FFM decreases 3.3 mmol/kg in men and 1.9–2.7 mmol/kg in women, suggesting that the potassium content per kilogram FFM is not constant.

Because weight, height, and age were related to TBK/FFM (Table 2), it was anticipated that the difference between FFMDEXA, here considered the "gold standard," and FFM68.1 might be biased by these variables. In fact, this was the case. For instance, FFM68.1 overestimated FFM at large body weights but underestimated FFM at low body weights in both men and women (Fig. 2). When the potassium-determined FFM was calculated from TBK by use of the anthropometrically estimated [TBK/FFM]WHA on an individual basis, the weight, height, and age biases disappeared.

The standard deviations for predicted TBK and predicted TBK/FFM were smaller than for actually measured values. Thus our equations are not able to detect the total biological variation in these respects. However, resulting errors were acceptable in all age and sex groups, and the weight, height, and age bias of [FFMDEXA − FFM68.1] disappeared when our equations were used. Thus, despite imperfections, our equations appear to be useful.

TBK was related negatively to age but positively to weight and height (Table 2). When FFMDEXA was also used to predict TBK, height became negatively related to TBK. Thus, by keeping FFM constant, TBK decreases with increasing height. This is consistent with

---

**Table 4. Body weight, height, BMI, TBK, and measured as well as predicted TBK and TBK/FFM by age in indicated study groups in women**

<table>
<thead>
<tr>
<th>Group</th>
<th>Women</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age groups, yr</td>
<td></td>
</tr>
<tr>
<td>Age, yr</td>
<td></td>
</tr>
<tr>
<td>Numbers</td>
<td></td>
</tr>
<tr>
<td>Body weight, kg</td>
<td></td>
</tr>
<tr>
<td>Height, cm</td>
<td></td>
</tr>
<tr>
<td>BMI, kg/m²</td>
<td></td>
</tr>
<tr>
<td>TBK, mmol</td>
<td></td>
</tr>
<tr>
<td>TBK/FFMDEXA, mmol/kg</td>
<td></td>
</tr>
<tr>
<td>Error, %</td>
<td></td>
</tr>
<tr>
<td>TBK/FFMDEXA, mmol/kg</td>
<td></td>
</tr>
<tr>
<td>[TBK/FFM]WHA, mmol/kg</td>
<td></td>
</tr>
<tr>
<td>Error, %</td>
<td></td>
</tr>
<tr>
<td>TBK/WHAD, mmol</td>
<td></td>
</tr>
<tr>
<td>Error, %</td>
<td></td>
</tr>
</tbody>
</table>

See Table 3 legend for definitions.

---

*E422 POTASSIUM CONTENT IN HUMANS*

*AJP-Endocrinol Metab • VOL 284 • FEBRUARY 2003 • www.ajpendo.org*
the fact that bone and skin contain less potassium per kilogram than the rest of FFM (4, 8).

There are a number of factors that limit the generalizability of our results. Our equations have been shown to be valid for the age interval 37–61 yr, the body weight range 45–100 kg, and the height ranges 160–195 cm in men and 150–179 cm in women. Outside these intervals, the errors are unknown. Furthermore, the equations may not be valid for individuals suffering from diseases that influence body composition or for athletic persons. Finally, our calculations of TBK/FFM are dependent on the validity of the DEXA technique.

Using underwater weighing, Womersley et al. (28) reported individual FFM density and TBK values for 36 men and 43 women. From this information, we calculated the TBK-to-FFM density ratio and found it to range from 56.5 to 77.8 (mean ± SD: 66.0 ± 3.9) mmol/kg in men and from 52.9 to 72.1 (61.6 ± 4.9) mmol/kg in women.

Similarly, comparisons between TBK and CT examinations in 17 males (14) and 12 women (21) suggest a TBK/FFM of 64.7 mmol/kg in men and 62.0 mmol/kg in women. Thus both underwater weighing and CT result in lower TBK/FFM than the DEXA technique. Although the sum of FFM (BMC + LTM) and BF was close to body weight, this fact does not exclude the possibility that the DEXA technique allocates a too-small fraction of body weight to FFM and a too-large fraction to BF, thus resulting in apparently large TBK/FFM of 64.7 mmol/kg in men and 62.0 mmol/kg in women. Thus both underwater weighing and CT result or for athletic persons. Finally, our calculations of TBK/FFM are dependent on the validity of the DEXA technique.

In conclusion, we have demonstrated that TBK and TBK/FFM can be predicted from age, weight, and height with errors small enough to make the equations useful within a wide range of biological applications.

This study was supported by the Swedish Medical Research Council Grant no. 05239.

REFERENCES