Measurement of total body electrical conductivity: a new method for estimation of body composition

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ABSTRACT A new method for the estimation of body composition in human subjects is described which entails the measurement of total body electrical conductivity. The method is based on the principle that the electrical conductivity of lean tissue is far greater than that of fat. Comparative studies in 19 adults of widely varying fatness have demonstrated excellent correlations between the total electrical conductivity of the subjects and both their total body water (r = 0.87) and total body potassium (r = 0.86). This noninvasive method, which is safe, simple, rapid, and convenient, should prove useful in the nutritional assessment of individuals and populations. *Am J Clin Nutr* 1983;37:735-739.

KEY WORDS Human body composition, total body electrical conductivity, total body water, total body potassium

Introduction

There is an urgent need for a method for measuring lean body mass (LBM) and total body fat (TBF) that is simple, rapid, reliable, and suitable for use in population surveys and in the assessment of body composition and its changes in individuals with limited ability to tolerate prolonged or physically stressful procedures (1). We report here preliminary studies of a new method for the estimation of human body composition that has the potential for meeting this need. It involves measurement of total body electrical conductivity (TOBEC).

The TOBEC method is based on the principle that the electrical conductivity of lean tissue is far greater than that of fat, owing to the much higher electrolyte content of lean tissue (2). A similar method has been used in the meat industry, and has been validated in pigs by subsequent gross dissection and weighing of the lean and fat components, and by comparison with 40K counting (3). The background, potential limitations, and safety of the TOBEC method with respect to human use have been reviewed recently (4).

Methods

The instrument employed in the present study is a prototype designed specifically for use with adult human subjects. As shown diagrammatically in Figure 1, it is built around a large solenoidal coil designed to accommodate the human body within its interior. The coil is driven by a 5 mHz oscillating radiofrequency current (5). The change in the coil impedance between the condition

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4 Postdoctoral Research Fellow. 5 University of Arizona, Tucson, AZ. 6 University of Göteborg, Göteborg, Sweden. 7 The EMME Company, Phoenix, AZ. Accepted for publication December 14, 1982.
FIG 1. Diagrammatic representation of instrument for measurement of TOBEC. Cutaway shows portions of solenoidal coil (The EMME Co, Phoenix, AZ 85009. Subsidiary of the DICKEY-John Corp, Auburn, IL 62615).

when the subject is inside the coil and when the coil is empty, is measured. This change is proportional to the total electrical conductivity of the body which, in turn, is proportional to LBM. TBF is estimated to be the difference (in kg) between LBM and total body weight.

To provide a consistent base-line for measurements, a "standard" was designed to generate a signal of constant magnitude. This device consists of a small rectangular wooden frame wound by several loops of cooper wire in series with a precision resistor. Each day it is placed in the center of the magnetic field within the instrument, with the wire loops coaxial to the coil. If the signal displayed by the instrument varies from the predicted value, the gain of the instrument is adjusted to correct for the deviation.

To assess the reproducibility of individual measurements performed on humans, TOBEC readings were obtained four times over a 10-min period in every subject studied (Table 1). Each measurement involved insertion of the subject, in the supine position, into the instrument by means of a stretcher on rollers connected to the device (Fig 1). Any single reading displayed by the instrument, while in operation, represents the mean of 10 determinations of TOBEC processed by the instrument's computer over a 10-s period. The amount of electromagnetic radiation received by a subject during a single measurement period is 2 to 3 orders of magnitude below any established regulatory limits for continuous exposure to radiofrequency waves (4).

Four men and 15 women participated in the study. One subject (subject I) had a past history of anorexia nervosa; four were normal volunteers; and the rest were overweight but otherwise healthy individuals recruited from the St Luke's Hospital Weight Control Unit. After the nature of the study and all procedures were explained, the subjects' written informed consent was obtained. The research was reviewed and approved by the Institutional Review Board, and the safety of the machine for use in humans was evaluated by C Andrew Bassett, MD, Professor of Orthopedic Surgery at Columbia University College of Physicians & Surgeons.

The potential ability of the TOBEC method to estimate LBM in humans was assessed by comparison of the data derived from electrical conductivity measurements (mean of four consecutive observations) obtained in each subject with those derived from: 1) anthropometric measurements entailing use of the formulas of Steinkamp et al (6); 2) total body water (TBW) by tritium dilution (7); and 3) total body potassium (TBK), determined by 40K counting in a 4 π liquid scintillation counter (8) (Table 1).

Results

There was a strong linear relationship (Fig 2a) between TOBEC values (means of four
TABLE 1
Comparison of data pertaining to body composition in 19 adults

<table>
<thead>
<tr>
<th>Age (yr)</th>
<th>Sex</th>
<th>BMI (kg/m²)</th>
<th>Fat (%)</th>
<th>Lean body mass (kg)</th>
<th>TBK (mEq)</th>
<th>TBW (l)</th>
<th>TOBEC* (mEq)</th>
<th>CV (Coefficient of variation)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A 63</td>
<td>M</td>
<td>36.7</td>
<td>52.6</td>
<td>55.7</td>
<td>3572</td>
<td>55.3</td>
<td>39.9 ±0.49</td>
<td>0.02</td>
</tr>
<tr>
<td>B 34</td>
<td>M</td>
<td>51.0</td>
<td>85.4</td>
<td>85.6</td>
<td>3508</td>
<td>66.5</td>
<td>28.6 ±0.85</td>
<td>0.06</td>
</tr>
<tr>
<td>C 35</td>
<td>M</td>
<td>38.3</td>
<td>44.7</td>
<td>87.2</td>
<td>3829</td>
<td>61.3</td>
<td>28.6 ±0.66</td>
<td>0.05</td>
</tr>
<tr>
<td>D 53</td>
<td>F</td>
<td>41.2</td>
<td>62.5</td>
<td>64.4</td>
<td>2959</td>
<td>53.1</td>
<td>17.7 ±0.49</td>
<td>0.05</td>
</tr>
<tr>
<td>E 39</td>
<td>F</td>
<td>45.7</td>
<td>62.7</td>
<td>61.1</td>
<td>3108</td>
<td>49.9</td>
<td>17.2 ±0.40</td>
<td>0.05</td>
</tr>
<tr>
<td>F 43</td>
<td>F</td>
<td>47.3</td>
<td>73.5</td>
<td>63.5</td>
<td>3002</td>
<td>53.3</td>
<td>16.6 ±0.22</td>
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<tr>
<td>G 38</td>
<td>F</td>
<td>37.3</td>
<td>54.3</td>
<td>45.5</td>
<td>2340</td>
<td>43.4</td>
<td>14.6 ±0.42</td>
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<tr>
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<td>F</td>
<td>35.9</td>
<td>45.9</td>
<td>61.3</td>
<td>2142</td>
<td>46.0</td>
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<tr>
<td>I† 40</td>
<td>F</td>
<td>14.4</td>
<td>7.00</td>
<td>37.6</td>
<td>2250</td>
<td>34.6</td>
<td>11.2 ±0.20</td>
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<tr>
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<td>F</td>
<td>32.5</td>
<td>39.0</td>
<td>45.2</td>
<td>2288</td>
<td>44.1</td>
<td>10.8 ±0.5</td>
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<tr>
<td>K 29</td>
<td>F</td>
<td>36.9</td>
<td>42.2</td>
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<td>2972</td>
<td>37.2</td>
<td>10.4 ±0.45</td>
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<tr>
<td>L 25</td>
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<td>32.6</td>
<td>39.0</td>
<td>53.6</td>
<td>2326</td>
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<td>9.2 ±0.30</td>
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<tr>
<td>M 27</td>
<td>F</td>
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<td>33.7</td>
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<td>8.8 ±0.03</td>
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<tr>
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<td>25.5</td>
<td>18.2</td>
<td>38.0</td>
<td>2506</td>
<td>33.4</td>
<td>8.5 ±0.26</td>
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<tr>
<td>O 34</td>
<td>F</td>
<td>24.6</td>
<td>25.9</td>
<td>39.1</td>
<td>2530</td>
<td>33.1</td>
<td>6.7 ±0.76</td>
<td>0.23</td>
</tr>
<tr>
<td>P 42</td>
<td>F</td>
<td>29.5</td>
<td>34.9</td>
<td>43.3</td>
<td>2396</td>
<td>35.3</td>
<td>6.7 ±0.16</td>
<td>0.05</td>
</tr>
<tr>
<td>Q 33</td>
<td>F</td>
<td>22.7</td>
<td>24.7</td>
<td>41.1</td>
<td>2297</td>
<td>36.8</td>
<td>4.0 ±0.27</td>
<td>0.13</td>
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<tr>
<td>R 31</td>
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<td>38.7</td>
<td>44.8</td>
<td>52.7</td>
<td>1952</td>
<td>33.1</td>
<td>3.1 ±0.30</td>
<td>0.19</td>
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<tr>
<td>S 52</td>
<td>F</td>
<td>24.7</td>
<td>32.0</td>
<td>31.3</td>
<td>1874</td>
<td>30.1</td>
<td>2.7 ±0.005</td>
<td>0.003</td>
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</tbody>
</table>

* Mean ± SEM.
† Coefficient of variation of TOBEC measurements.
‡ Patient with a history of anorexia nervosa but weight stable for 2 yr.

readings) and TBW values (in liters) \( r = 0.870, p < 0.0001 \). The relationship between TOBEC and TBK (mEq) (Fig 2b) was equally good \( r = 0.860, p < 0.0001 \).

Lower correlation coefficients were found when TOBEC was compared with: 1) LBM calculated by subtracting TBF, derived by the method of Steinkamp et al (6) from total body weight (Fig 2c) \( r = 0.693 \) and 2) the body mass index \( (kg/m^2) \) \( r = 0.541 \).

The intercorrelations among TOBEC, TBK, and TBW were similar (TOBEC versus TBK, \( r = 0.86 \); TOBEC versus TBW, \( r = 0.87 \); TBK versus TBW, \( r = 0.83 \)). Smaller SEs of estimate were obtained when TOBEC was used to predict TBW (SEE = 5.351 l) and TBK (SEE = 291 mEq) than when TBK and TBW were used to predict each other (SEE = 6.07 l and 318 mEq, respectively).

Bartlett's (9) test for homogeneity of variance revealed significant differences among variances for individual subjects \( (\chi^2 = 70.867 \)
found to be 0.984 for a single measurement and 0.996 for the mean of four consecutive measurements conducted over a 10-min period (9). [Subsequent electronic improvements in the instrument practically eliminated the variance previously observed when the same subject was measured repeatedly (10)].

Discussion

In interpreting comparative measurements of this type, it should be recalled that estimates of LBM and TBF are subject to both errors of measurement and errors resulting from biological variability (11, 12). Despite fragile assumptions concerning the water and potassium content of lean tissue, it is encouraging that these different methods have yielded similar results.

It is also reassuring that subjects B and C who exhibited similar TBK and TBW values gave the same electrical conductivity readings, even though their TBF content, as estimated by the method of Steinkamp et al (6), differed strikingly. This observation is consistent with evidence (2, 13) indicating that the fat stored in adipose tissue should not produce a significant signal in the TOBEC instrument. In instances where the data obtained by measurement of TBK, TBW, and TOBEC are not as concordant, as in the case of subjects B and C, it is likely that factors such as variations in counting efficiency (14) and state of hydration (15) of lean tissue are at least partly responsible.

Although more complete evaluation of TOBEC as a source of information about LBM and TBF must await further research with suitable anthropomorphic phantoms and comparative studies of subjects measured by a variety of methods, it is clear that the use of TOBEC should provide a valuable new approach to the nutritional assessment of individuals and populations.

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References


FIG 2. Linear regressions on TOBEC of: a. TBW, slope = 0.954 ± 0.131 SE, intercept = 30.214 ± 2.168; b. TBK, slope = 49.467 ± 7.080 SE, intercept = 1980.789 ± 117.597 SE; c. LBM calculated from anthropometric measurements, slope = 1.081 ± 0.273 SE, intercept = 38.479 ± 4.530 SE; males (△) and females (○); 1) when TBW and TBK were regressed on TOBEC, the plot of the residual values exhibited randomness; 2) when the median value for TOBEC shown in Table 1 (10.8 U) is taken as an example, 1 TOBEC U equals 3.41 kg (based on TBK) or 5.12 kg (based on TBW).

with 18 df). The differences in variances among subjects were unrelated to body weight and other known physical characteristics of the subjects. Also, the reliability was
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Wiley and Sons, 1979.


