Assessment of the Heath-Carter somatotype in adults using bioelectrical impedance analysis

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Abstract. Using cross-sectional anthropometric data of 897 ethnically Russian individuals aged 16-61 years from the European part of Russia (Arkhangelsk, Moscow, and Samara), we checked the accuracy of our previously proposed bioimpedance-based formulae for the assessment of the endomorphy and mesomorphy ratings of the Heath-Carter somatotype, and suggested the revised formulae:

\[ \text{ENDOBIA} = -3.399/R + 0.992 \times \text{BMI} - 0.0102 \times \text{BMI}^2 - 0.85 \times \text{Sex} - 5.93 \quad (r^2=0.80; \text{SEE}=0.91) \]

\[ \text{MESOBIA} = 1.578/R + 0.479 \times \text{BMI} - 0.077 \times \text{BM} - 0.015 \times \text{Age} + 0.81 \times \text{Sex} - 4.14 \quad (r^2=0.87; \text{SEE}=0.54) \]

where \( R \) is the whole-body resistance at 50 kHz (Ohm), \( \text{BMI} \) – body mass index (kg/m²), \( \text{Sex} = 1 \) (male), 0 (female), \( \text{BM} \) – body mass (kg), \( \text{Age} \) (years).

These and previously proposed formulae for adults provided close and unbiased estimates of the endomorphy and mesomorphy ratings and can be used for the assessment of the somatotype in ethnically Russian adults.

1. Introduction

The Heath-Carter anthropometric method of somatotyping [1,2] is commonly used for the assessment of body physique in various areas of biomedical research such as anthropology and sports science [3,4]. It is based on calculation of the endomorphy, mesomorphy and ectomorphy ratings which characterize relative fatness, muscular-skeletal robustness, and relative linearity of a physique, respectively [2]. Its advantages are the use of a continuous rating scales and applicability to any ethnic group of both genders from childhood to old age, while the shortcomings are the need to accurately measure 10 specific anthropometric dimensions by a qualified anthropometrist and the dependence on the measurement instruments, including the type of skinfold caliper [2]. Despite the widespread use of anthropometry and skinfolds in population research [5,6], these drawbacks limit the availability of the Heath-Carter method for large-scale studies.

Closely associated with the assessment of body physique are body composition studies [7]. Along with anthropometry and skinfolds, bioelectrical impedance analysis is commonly used in field studies and larger surveys due to portability, reasonable accuracy, non-invasiveness, ease of use, and relatively low cost [8-10]. Recently, we have shown the possibility of using bioimpedance for the
evaluation of the Heath-Carter somatotype in children and adolescents, and suggested simple regression formulae for the endomorphy and mesomorphy ratings using only 3 measured parameters, namely, whole-body electrical resistance, height and weight [11]. For this, the data on apparently healthy ethnically Russian individuals aged 7-17 years living in the European part of Russia were used ($n = 2364$). These formulae were found reasonably accurate for the assessment of the somatotype in other ethnic groups of Russia – Adygeans, Kalmyks and Tatars [12], and even in disease conditions such as remission of childhood cancer [13], but less accurate in older age groups or in athletes [12].

The above mentioned formulae were then refined using an extended sample of ethnically Russian children and adolescents ($n = 3399$) by adding subject’s sex as a new independent variable [14], see table 1 below. In doing so, all related anthropometric data were measured directly, and skinfolds were assessed using recommended type of skinfold caliper – GPM/Holtain (see [2]). The refined formulae were built into the software of the ABC-01 ‘Medas’ (SRC Medas, Russia) bioimpedance instrument, and appropriate protocol of the somatotyping was implemented [14].

Similar formulae were suggested for adults [15] taking into account nonlinear dependence of the endomorphy rating on the BMI in this age group and using age as an additional independent variable for both ratings. For this, the data on apparently healthy ethnically Russian volunteers aged 16-86 years living in Eastern Siberia were used ($n = 3954$) while the skinfold data were obtained using the caliper Veresk (Veresk Ltd, Russia) [15] with then unclear calibration properties. Based on application of our previously suggested formulae for children and adolescents [11] to the age-matched subgroup of 16 and 17 years old individuals, it was assumed that the caliper Veresk might overestimate skinfold thickness [15]. Later, this assumption was supported in an experimental study utilizing different types of skinfold caliper: compared to the caliper GPM, the average skinfold, as measured by the caliper Veresk, was greater by about 25% [16]. Thus, the accuracy of the proposed formulae for adults was questioned.

Our aim was to test the accuracy of the bioimpedance-based formulae for the assessment of the endomorphy and mesomorphy ratings of the Heath-Carter somatotype in adults.

2. Subjects and methods

Our study group was comprised of 897 apparently healthy volunteers of the Russian ethnicity aged 16-61 years. Individuals under the age of 30 prevailed among our study subjects (figure 1). The data were collected in the European part of Russia: Arkhangelsk ($n = 519$), Moscow ($n = 230$), and Samara ($n = 148$) in 2010-2016 [17,18]. Belonging to the Russian ethnos was determined if, according to the surveyed, both his/her parents, as well as grandparents, related to this ethnic group. Bioimpedance was assessed using ABC-01 ‘Medas’ instrument (SRC Medas, Russia) according to a conventional whole-body tetrapolar scheme with measurements in a supine position and placement of disposable bioadhesive electrodes on ankle and wrist [19]. Anthropometry was performed following a conventional protocol [20] using the GPM anthropometric measurement kit (DKSH, Switzerland). Participants were excluded if they had a cardiac pacemaker or metal implants, or were pregnant.

![Figure 1. Age distribution of our study group ($n = 897$).](image-url)
To assess the somatotype, the following anthropometric dimensions were utilized: height (Ht), body mass (BM), upper arm girth with elbow flexed and relaxed (UAG), calf girth, elbow and knee breadths, as well as triceps, subscapular, abdominal and calf skinfold thickness. Arm muscles excursion (AME) and suprailliac skinfold thickness (SST) were estimated using the following formulae [15]: \( AME, \text{cm} = 1.705 - 0.01817 \times \text{Age}, \text{years} + 1.907 \times \text{Sex}; \)

\[ \text{SST, mm} = 0.8224 \times \text{AST} - 0.694, \text{where} \]

\[ \text{Sex} = 1 \text{ (male)}, 0 \text{ (female)}, \text{AST is the abdominal skinfold thickness, mm. Upper arm girth with elbow flexed and tensed was determined as the sum of UAG and AME. The Heath-Carter somatotype was then determined as described in [2].} \]

The bioimpedance body composition was assessed using Kushner-Schoeller equations for total body water in adults [21] and assuming constant hydration of fat-free tissue, and Houtkooper et al. equation for fat-free mass (FFM) in adolescents [22]. The fat mass (FM) was assessed as the difference between BM and FFM. The body mass index (BMI), fat-free mass index (FFMi) and fat mass index (FMI) were calculated as the ratio of BM, FFM and FM, respectively, to Ht squared.

### Table 1. Bioimpedance-based formulae [11,14,15] for the evaluation of the endomorphy (ENDO_{BIA}) and mesomorphy (MESA_{BIA}) ratings of the Heath-Carter somatotype.$^a$

| Formula | \( r^2 \) | SEE |
|---------|---------|-----|
| For children and adolescents (age 7-17 years, \( n = 2346 \)) [11] | | |
| \( \text{ENDO}_{BIA} = -3.225/R + 0.639 \times \text{BMI} - 0.416 \times \text{BM} - 2.20 \) | 0.81 | 0.65 |
| \( \text{MESA}_{BIA} = 2.195/R + 0.530 \times \text{BMI} - 0.097 \times \text{BM} - 4.55 \) | 0.81 | 0.54 |
| For children and adolescents, revised (age 7-18 years, \( n = 3339 \)) [14] | | |
| \( \text{ENDO}_{BIA} = -2.875/R + 0.625 \times \text{BMI} - 0.042 \times \text{BM} - 0.23 \times \text{Sex} - 2.33 \) | 0.83 | 0.65 |
| \( \text{MESA}_{BIA} = 1.467/R + 0.552 \times \text{BMI} - 0.096 \times \text{BM} + 0.59 \times \text{Sex} - 4.22 \) | 0.86 | 0.47 |
| For adults (age 16-86 years, \( n = 3954 \)) [15] | | |
| \( \text{ENDO}_{BIA} = -2.837/R + 0.916 \times \text{BMI} - 0.0109 \times \text{BM}^2 + 0.013 \times \text{BM} - 1.40 \times \text{Sex} + 0.017 \times \text{Age} - 5.95 \) | 0.90 | 0.69 |
| \( \text{MESA}_{BIA} = 891/R + 0.502 \times \text{BMI} - 0.073 \times \text{BM} + 1.17 \times \text{Sex} - 0.017 \times \text{Age} - 3.83 \) | 0.78 | 0.88 |

### Abbreviations: \( r^2 \) – coefficient of determination, SEE – standard error of estimate, \( n \) – sample size, \( R \) – whole-body resistance at 50 kHz (Ohm), \( \text{BMI} \) – body mass index (kg/m$^2$), \( \text{BM} \) – body mass (kg), \( \text{Sex} = 1 \) (male), 0 (female), \( \text{Age} \) (years).

$^a$ – The formulae are presented with rounded coefficients which didn’t affect the reported accuracy.

Accuracy of the bioimpedance-based formulae [11,14,15] (see table 1) for the endomorphy and mesomorphy ratings was tested, and revised formulae for adults were constructed. To characterize a proportion of the explained variance, the coefficient of determination \( r^2 \) was assessed. As a measure of accuracy, standard error of estimate (SEE) was calculated: \( \text{SEE} = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \bar{x})^2}{(n - k - 1)}} \), where \( n \) is the sample size, \( k \) is the number of independent variables, \( x_i \) is \( i \)th observation, and \( \bar{x} \) is the regression estimate. The results of somatotyping were presented on a somatchart [2].

All examinations were conducted in compliance with the rules of bioethics (expert decision of the MSU Commission on Bioethics, Application no. 22-ch, protocol no. 55 of 26.03.2015), by signing informed consent for each subject and confidential (depersonalized) use of the obtained data. Minitab 18.1 and MS Excel 2010 software programs were used for data analysis. Intergroup differences were assessed using Mann-Whitney test.

### 3. Results

General characteristics of the study group, including height, body mass, BMI and the Heath-Carter anthropometric somatotype [2], are presented in table 2. Our males were, in general, younger, taller and heavier, had significantly higher BMI and were more mesomorphic and ectomorphic than the females, while the females were more endomorphic. The BMI varied widely – from 14.5 to
45.4 kg/m². About a half of the study subjects were within the normal BMI range, while the rest were equally distributed between the underweight and overweight/obesity categories (Table 2).

Table 2. General characteristics of our study group: medians (interquartile range).

|     | Sex                   | Age (years) | Ht (cm) | BM (kg) | BMI (kg/m²) | ENDO | MESO | ECTO |
|-----|-----------------------|-------------|---------|---------|-------------|------|------|------|
| Males (n = 312) | 20.8a (18.5;24.0) | 176a (172;181) | 72.0a (64.0;80.0) | 22.8a (21.0;25.3) | 3.7a (2.5;5.3) | 4.9a (4.1;5.9) | 2.6a (1.5;3.7) |
| Females (n = 585) | 22.9 (20.1:34.7) | 163 (160;168) | 59.0 (53.2;66.4) | 22.0 (19.9;24.8) | 5.7 (4.6;7.1) | 4.0 (3.1;5.1) | 2.2 (1.1;3.3) |
| All (n = 897) | 22.0 (19.3;30.1) | 167 (162;174) | 63.4 (55.6;73.2) | 22.2 (20.2;25.0) | 5.1 (4.6;7.1) | 4.4 (3.3;5.4) | 2.4 (1.2;3.5) |

Abbreviations: Ht – height; BM – body mass; BMI – body mass index; ENDO, MESO, ECTO – the endomorphy, mesomorphy, and ectomorphy ratings of the somatotype, respectively [2].
a – statistically significant sex-related differences (p<0.05).

We observed pronounced age-related differences in the somatotype of our study subjects ranging from balanced mesomorph to endomorphic mesomorph in males, and from balanced endomorph to mesomorphic endomorph in females (Figure 2).

Figure 2. Somatochart: age-related differences in the Heath-Carter somatotype in males (●, n = 312) and females (○, n = 585). Median values for age subgroups.

Table 3. Accuracy of the bioimpedance-based formulae [11,14,15] for the endomorphy and mesomorphy ratings (ENDO_BIA, MESO_BIA) of the somatotype in our study group (n = 897).

| Study group                  | ENDO_BIA       | M (Q1;Q3) | r²  | SEE  | M (Q1;Q3) | r²  | SEE  |
|------------------------------|----------------|-----------|-----|------|-----------|-----|------|
| For children and adolescents |                |           |     |      |           |     |      |
| Males (n = 312)              | 3.0a (2.2;4.1) | 0.74      | 1.17| 4.9 (4.0;5.9) | 0.81 | 0.59 |
| Females (n = 585)            | 4.3a (3.5;5.7) | 0.72      | 1.49| 4.8a (3.9;5.8) | 0.86 | 1.07 |
| All (n = 897)                | 4.0a (3.0;5.2) | 0.74      | 1.39| 4.8a (3.9;5.8) | 0.79 | 0.93 |
| For children and adolescents, revised [14] | | | | | | |
| Males (n = 312)              | 3.0a (2.2;4.1) | 0.73      | 1.20| 5.0 (4.1;5.9) | 0.80 | 0.62 |
| Females (n = 585)            | 4.4a (3.5;5.8) | 0.72      | 1.43| 4.5a (3.7;5.6) | 0.87 | 0.89 |
| All (n = 897)                | 4.0a (3.0;5.3) | 0.75      | 1.35| 4.7a (3.8;5.7) | 0.83 | 0.81 |
| For adults [15]              |                |           |     |      |           |     |      |
| Males (n = 312)              | 3.5 (2.9;4.6)  | 0.76      | 1.05| 5.0 (4.2;5.8) | 0.80 | 0.60 |
| Females (n = 585)            | 5.7 (4.9;6.8)  | 0.74      | 0.89| 3.8 (3.1;4.8) | 0.88 | 0.54 |
| All (n = 897)                | 5.0 (3.9;6.2)  | 0.78      | 0.95| 4.2 (3.4;5.3) | 0.86 | 0.56 |

Abbreviations: M (Q1;Q3) – median and interquartile range; r² – coefficient of determination, SEE – standard error of estimate. a – statistically significant differences as compared to the conventionally derived values [2] presented in table 2 (p<0.05).
The bioimpedance-based formulae for children and adolescents [11,14] have underestimated the endomorphy rating in adults of both sexes and overestimated the mesomorphy rating in females while the estimate of the mesomorphy rating in males was unbiased (table 3). The formulae for adults [15] provided unbiased estimates of the endomorphy and mesomorphy ratings in our study group.

Using the same initial set of regression terms as in the derivation of the formulae [15], we obtained the revised bioimpedance-based formulae for the endomorphy and mesomorphy ratings in adults:

\[
\text{ENDO}_{\text{BLA}} = -3.399/R + 0.992 \times \text{BMI} - 0.0102 \times \text{BMI}^2 - 0.85 \times \text{Sex} - 5.93; \tag{1}
\]

\[
\text{MESO}_{\text{BLA}} = 1.578/R + 0.479 \times \text{BMI} - 0.077 \times \text{BM} - 0.015 \times \text{Age} + 0.81 \times \text{Sex} - 4.14, \tag{2}
\]

where \( R \) is the whole-body resistance at 50 kHz (Ohm), \( \text{BMI} \) is the body mass index (kg/m\(^2\)), \( \text{Sex} = 1 \) (male), 0 (female), \( \text{BM} \) is the body mass (kg), \( \text{Age} \) (years).

![Figure 3](image.png)

**Figure 3.** Scatterplots and regression lines of the bioimpedance-based vs the anthropometric endomorphy and mesomorphy ratings of the somatotype in our study group \((n = 897)\).

The data presented on figure 3 show that the accuracy of the formulae (1) and (2) was similar to (only slightly exceeded) those provided by the previously suggested ones for adults [15], see table 3. Both sets of formulae have yielded close estimates of the endomorphy and mesomorphy ratings in our study group despite the differences in the types of skinfold caliper used for data collection. Based on this, our previously suggested [15] and the newly obtained formulae (1) and (2) can be recommended for the assessment of the Heath-Carter somatotype in ethnically Russian adults.

4. Discussion

Early studies of the associations between body composition and the Heath-Carter somatotype showed moderate to high linear correlation of the endomorphy rating with the fat mass and/or percentage of fat mass in the body, but either no or weak correlation of the mesomorphy rating with the fat-free mass [23-25]. Probably, these findings served as an obstacle in the stimulating research by T. Nawarycz and L. Ostrowska-Nawarycz [26,27] who were the first to directly question applicability of BIA for the assessment of the somatotype but could not find a suitable body composition correlate for the mesomorphy rating.

Our results support the possibility of automatic evaluation of the endomorphy and mesomorphy ratings of the Heath-Carter somatotype in adults within the bioelectrical impedance analysis procedure with reasonable accuracy. Our principal finding was moderate to high correlation of the mesomorphy rating with the fat-free mass (FFM) index (i.e., height-normalized FFM [28]) both in children [11] and in adults (see table 4). In view of the strong linear correlation of the total body water volume (and,
hence, FFM) with the resistance index [29], this means that the mesomorphy rating should be highly proportional to the inverse value of the resistance thus making simple bioimpedance-based regression formula for the mesomorphy rating possible.

Table 4. Pearson correlations between the Heath-Carter anthropometric somatotype components and BIA body composition parameters in our study group (n = 897).

|        | MESO | ECTO | BM  | BMI | FM  | FMi | %FM | FFM | FFMi |
|--------|------|------|-----|-----|-----|-----|-----|-----|------|
| ENDO   | 0.53 | -0.74| 0.71| 0.80| 0.84| 0.86| 0.84| 0.34| 0.47 |
| Meso   | 1.00 | -0.88| 0.58| 0.80| 0.52| 0.57| 0.46| 0.48| 0.85 |
| ECTO   | 1.00 | -0.70| -0.91| 0.70| 0.76| 0.69| 0.48| 0.82 |
| ENDO   | 0.72 | -0.80| 0.74| 0.82| 0.80| 0.83| 0.82| 0.47| 0.62 |
| ECTO   | 0.70 | -0.88| 0.76| 0.91| 0.76| 0.73| 0.70| 0.60| 0.87 |

Abbreviations: ENDO, Meso, ECTO – the endomorphy, mesomorphy, and ectomorphy ratings of the somatotype, respectively [2]; BM – body mass; BMI – body mass index; FM – fat mass; FMI – fat mass index; %FM – percentage of fat mass in the body; FFM – fat-free mass; FFMi – fat-free mass index.

The similar accuracy of the previously suggested [15] and the newly obtained formulae (1)–(2) for adults which were developed using different types of skinfold caliper could mean that the dynamic calibration properties of the caliper Veresek would change with time, but met basic requirements during mass measurements. One can note, however, that these sets of formulae show a reversed accuracy for the endomorphy and mesomorphy ratings, see tables 1 and 3. Possible reason for this, in addition to inter-population differences, could be inter-observer differences and potential bias due to prediction, but not measurement, of the 2 out of 10 anthropometric parameters needed for the assessment of the somatotype. To address these issues, a prospective study in adults is necessary with special focus on measurement standardization and technical errors.

Availability of mass population bioimpedance data in many countries, including Russia, makes it possible to extract more complete knowledge on global variations of the somatotype. One can note, however, that the bioimpedance data are influenced by a number of factors, such as the instrument used, measurement scheme/standardization, and electrodes [30,31]. Thus, the development of inter-conversion formulae between the resistances or, alternatively, instrument-specific formulae for the somatotype will be needed for proper data comparison and interpretation.

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