Evaluation of the Heath-Carter Somatotype Revisited: New Bioimpedance Equations for Children and Adolescents

A.V. Anisimova[1], E.Z. Godina[1], D.V. Nikolaev[2,4], and S.G. Rudnev[3,4]

[1] Institute and Museum of Anthropology, Moscow State University, Moscow, Russia
[2] Scientific Research Centre 'Medas', Moscow, Russia
[3] Institute of Numerical Mathematics, Russian Academy of Sciences, Moscow, Russia
[4] Central Research Institute for Health Organization and Informatics, Moscow, Russia

Abstract— **Based on the results of the cross-sectional anthropological study of 2364 Russian children and adolescents aged 7-17 years, we suggest simple prediction formulae for automated bioimpedance-based evaluation of endomorphy and mesomorphy components of the Heath-Carter somatotype: $ENDO_{BIA}$ = 0.5282×FMi + 0.2580×BMI – 0.04822×BM – 1.881 (r^2=0.81, SEE=0.65); $MESO_{BIA}$ = 0.3651×FFMi + 0.42765×BMI – 0.09323×BM – 4.803 (r^2=0.81, SEE=0.54), where BMI, FMi and FFMi are, respectively, the body mass, fat mass and fat-free mass indices (kg/m^2), and BM is the body mass (kg). In addition, in order to avoid using indirect bioimpedance body composition estimates, alternative formulae are constructed based only on directly measured rather than estimated bioimpedance data: $ENDO_{BIA}$ = –3224.7/R + 0.63867×BMI – 0.04162×BM – 2.195 (r^2=0.81, SEE=0.65); $MESO_{BIA}$ = 2195.4/R + 0.52966×BMI – 0.09740×BM – 4.5522 (r^2=0.81, SEE=0.54), where R is the whole-body electrical resistance (Ohm) at a frequency of 50 kHz. These formulae can be used for the specified age range regardless of sex and, due to relatively high proportion of the explained variance, are suitable for individual typology.**

Keywords— **Somatotype, Heath-Carter typology, bioelectrical impedance analysis, the whole-body electrical resistance, fat mass index, fat-free mass index, prediction formulae.**

I. Introduction

The terms somatotyping and constitution study are generally used for the designation of one of the methods for the analysis and classification of body physique [1-5]. The Heath-Carter anthropometric somatotype [6] that was suggested as the development of the classical Sheldon's photoscopic scheme of the assessment of body physique [1], is one of the commonly used methods and still of important significance for anthropology and sports science [7-9].

The Heath-Carter somatotype represent an ordered set of three numbers: endomorphy (which is regarded as a relative body fatness), mesomorphy (a measure of musculoskeletal development), and ectomorphy (relative linearity of physique). Software for the Heath-Carter anthropometric somatotype calculation and management is available [6,10,11]. With this, the assessment of the Heath-Carter somatotype is not always possible because a significant number of anthropometric measurements is needed which require considerable expertise.

Classical studies revealed significant relationships of the Heath-Carter endomorphy component with percent body fat both in adults and children [12,13], and of the mesomorphy component with lean body mass in adults [12], whereas in children the mesomorphy showed little association with lean body mass alone or in combination with height and weight [13]. In their study of 260 adolescent boys aged 16 to 18 years, T. Nawarycz and L. Ostrowska-Nawarycz suggested an approach for the computerized analysis of the first and the second components of the Heath-Carter somatotype using bioimpedance analysis [14], now the most promising simple and easy to use method of body composition assessment [15]. Their regression equation for the endomorphy component was based on the bioimpedance percentage body fat (%BF), whereas the mesomorphy component was determined using body height, widths of humerus and femur epiphyses, circumferences of the upper arm and the calf, and the BIA %BF instead of skinfold data [14]. So, the formula for the second component of the somatotype included a number of parameters not routinely measured within the standard procedure of bioimpedance measurements.

Our aim was to re-analyse the relationships between the Heath-Carter somatotype and body composition and to develop prediction formulae for automated bioimpedance-based evaluation of the somatotype in children and adolescents suitable for use in a wide range of age in both sexes.

II. Subjects and methods

Anthropometry was performed in 2364 apparently healthy children and adolescents of the Russian ethnicity (1450 boys and 914 girls) aged 7-17 years using standard measurement protocol adopted at the Institute and Museum of Anthropology of the Lomonosov Moscow State University as described in [16]. The data were collected cross-sectionally in 2005-2013 at schools of Moscow (n=1456), Arkhangelsk (n=357), and Arkhangelsk region (n=551).

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Standing height (Ht) was accessed by the GPM (Martin type) anthropometer. Body mass (BM) was measured on a digital scale to the nearest 100 g. Body mass index (BMI) was calculated as the BM relative to Ht squared (kg/m^2). Calf, triceps, subscapular and supraspinale skinfold thicknesses were measured on the right side of the body using the GPM (Harpenden type) skinfold caliper to the nearest 0.1 mm. Femur and humerus biepicondylar breadths, as well as arm and calf girths were measured using appropriate instrumentation to the nearest 0.5 mm. Endomorphy (Endo), mesomorphy (Meso) and ectomorphy (Ecto) components of the Heath-Carter anthropometric somatotype were determined based on the above mentioned quantities using conventional formulae as described in [6].

The whole-body impedance was measured in a supine position on the right side of the body according to a conventional tetrapolar measurement scheme by the bioimpedance analyzer ABC-01 'Medas' (SRC Medas, Moscow, Russia) at a frequency of 50 kHz using disposable Ag/AgCl Schiller bioadhesive electrodes.

Fat-free mass (FFM) was accessed using Houtkooper equation [17]: FFM = $0.61 \times (Ht^2/R) + 0.25 \times BM + 1.31$, where Ht is the standing height (cm), R is the whole-body electrical resistance (Ohm), and BM is the body mass (kg). Fat mass (FM) was obtained as the difference between BM and FFM. Similarly to BMI, fat-free mass index (FFMi) and fat mass index (FMi) were calculated as the ratio of FFM (kg) and FM (kg), respectively, to height squared (m^2).

All statistical analyses were performed using Minitab 17 and MS Excel 2007 software packages.

III. RESULTS

Basic anthropometric characteristics of the study group are shown in Table 1, with (*) showing a statistically significant differences ($p<0.05$) between boys and girls for a given age.

Table 1 Height, weight and BMI of the study group according to age and sex, mean (SD)

Age	Body height, cm		Body mass, kg		BMI, kg/m^2	
	Boys	Girls	Boys	Girls	Boys	Girls
7	124.3 (6.7)	124.9 (6.8)	25.8 (4.9)	25.4 (5.2)	16.6 (2.0)	16.2 (2.3)
8	129.0 (6.3)	127.9 (5.8)	28.2 (5.3)	27.1 (5.0)	16.8 (2.0)	16.5 (2.2)
9	134.9 (6.0)	133.9 (5.8)	31.9 (6.3)	30.9 (6.1)	17.4 (2.7)	17.1 (2.6)
10	139.6 (5.6)	138.4 (7.1)	34.9 (6.4)	33.0 (7.1)	17.8 (2.6)	17.0 (2.3)
11	145.5 (8.0)	146.2 (7.9)	40.3 (10.0)	39.7 (10.1)	18.8 (3.4)	18.3 (3.2)
12	151.6 (7.1)	153.4 (8.2)	44.5 (8.8)	44.2 (11.1)	19.2 (3.0)	18.6 (3.4)
13	158.3 (8.8)	157.4 (7.6)	50.4 (11.4)	49.5 (11.5)	19.9 (3.1)	19.8 (3.6)
14	165.2 (9.5)*	161.6 (6.8)	56.4 (11.3)*	53.2 (10.3)	20.6 (3.0)	20.3 (3.2)
15	171.0 (8.4)*	162.3 (6.2)	61.8 (13.3)*	54.9 (8.5)	21.0 (3.6)	20.8 (2.9)
16	173.7 (7.2)*	164.6 (6.1)	65.3 (12.6)*	56.2 (7.5)	21.6 (3.3)	20.8 (2.7)
17	175.2 (6.5)*	162.4 (6.8)	66.4 (9.8)*	55.7 (8.0)	21.6 (2.7)	21.1 (2.5)

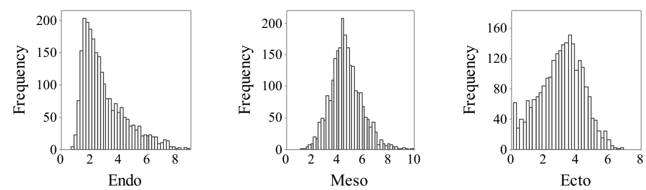

Fig. 1 The histograms of endo-, meso-, and ectomorphy components distributions of the Heath-Carter somatotype in the study group (n=2364)

Our data showed unimodal distributions of the Endo and Meso components of the somatotype in the study group having a pronounced positive skewness and kurtosis, respectively (see Fig. 1). The distribution of the Ecto component was also, largely, unimodal with a small additional peak at the value of 0.1 reflecting cumulative number of children on the left tail of the distribution, i.e. with zero or negative calculated values of the ectomorphy. The median somatotype of our study group was 2.5-4.5-3.2 that can be described as ectomorphic mesomorph according to Carter and Heath typology [6].

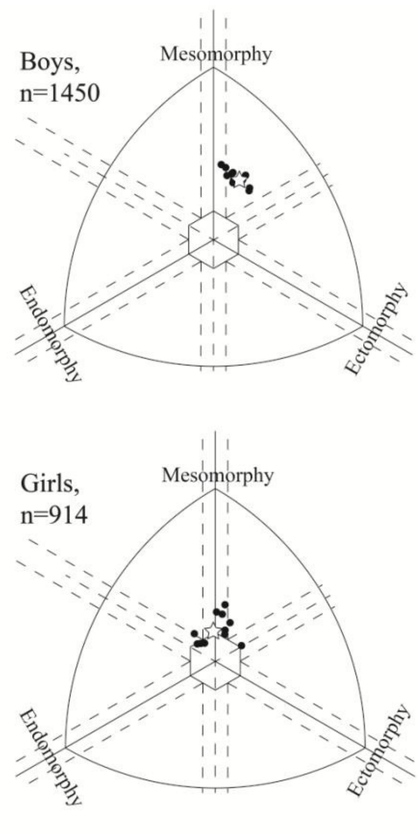

Fig. 2 The Heath-Carter somatocharts of the study group according to age and sex. Black circles show the median somatotypes for certain age (years); white star indicates the overall median somatotype

Table 2 The Heath-Carter somatotype of the study group according to age and sex

Age,	Boys				Girls			
years	n	Endo	Meso	Ecto	n	Endo	Meso	Ecto
7	50	2.2	5.0	2.5	47	2.3	4.5	2.7
8	86	2.2	5.0	2.7	94	2.6	4.4	2.9
9	79	2.2	4.9	2.9	82	2.9	4.6	2.9
10	90	2.3	4.7	3.1	43	2.8	4.4	3.4
11	103	2.3	5.1	3.1	66	2.9	4.2	3.3
12	118	2.5	5.0	3.0	97	2.7	3.8	3.7
13	152	2.4	4.9	3.2	100	2.9	4.0	3.3
14	191	2.1	4.8	3.3	98	3.4	3.9	3.0
15	221	2.1	4.5	3.5	110	3.6	3.9	3.0
16	217	2.0	4.9	3.3	103	3.6	3.9	2.9
17	143	2.0	4.5	3.4	74	3.6	4.1	2.7

In boys, our cross-sectional data showed the age trend from balanced mesomorph to ectomorphic mesomorph category (see Fig. 2 and Table 2), with the overall median ectomorphic mesomorph somatotype 2.2-4.8-3.2. The studied group of girls showed a more complex pattern of change, from balanced mesomorph to ectomorphic mesomorph and, then, through central phenotype, to endomorphic mesomorph category at the age of 17 thus reflecting adiposity traits in the somatic growth and sexual maturation. The overall somatotype of our girls was 3.1-4.2-3.1, or balanced mesomorph.

Table 3 Pearson's correlations between the Heath-Carter somatotype components and the bioimpedance body composition parameters in boys and girls (upper right and lower left parts of the table, respectively)

	Endo	Meso	Ecto	BM	BMI	FM	FMi	%FM	FFM	FFMi
Endo	•	0.69	-0.78	0.34	0.70	0.74	0.87	0.80	0.14	0.35
Meso	0.65	•	-0.89	0.31	0.72	0.53	0.64	0.49	0.19	0.57
Ecto	-0.80	-0.87	•	-0.24	-0.70	-0.57	-0.73	-0.64	-0.09	-0.47
BM	0.57	0.24	-0.41	•	0.85	0.77	0.53	0.30	0.96	0.86
BMI	0.80	0.63	-0.78	0.88	•	0.88	0.81	0.58	0.72	0.86
FM	0.73	0.38	-0.55	0.92	0.91	•	0.93	0.81	0.56	0.56
FMi	0.85	0.56	-0.72	0.79	0.92	0.95	•	0.94	0.28	0.39
%FM	0.79	0.40	-0.61	0.66	0.77	0.88	0.94	•	0.04	0.09
FFM	0.42	0.12	-0.26	0.97	0.78	0.79	0.62	0.48	•	0.87
FFMi	0.62	0.60	-0.69	0.81	0.90	0.70	0.67	0.43	0.81	•

The correlations of the Heath-Carter somatotype components Endo, Meso and Ecto in boys and girls with the indices of fat- and fat-free mass (FMi, FFMi) were higher as compared to absolute FM and FFM values or the %FM (Table 3). In this regard, we proposed the following simple prediction formulae for the bioimpedance evaluation of the Endo and Meso components of the somatotype:

$$ENDO_{BIA} = 0.5282\times FMi + 0.2580\times BMI - 0.04822\times BM - 1.881 \quad (r^2=0.81,\ SEE=0.65) \tag{1}$$

$$MESO_{BIA} = 0.3651\times FFMi + 0.42765\times BMI - 0.09323\times BM - 4.803 \quad (r^2=0.81,\ SEE=0.54) \tag{2}$$

All the components of the regression formulae (1) and (2) were essential (see Tables 4 and 5) with the regression lines for the residuals not significantly different from zero (Fig. 3).

Table 4 Contribution and order of entry of predictor variables to the regression model (1) for the endomorphy component of the Heath-Carter somatotype

Predictor variables	r^2	SEE	p
FMi	0.76	0.75	<0.001
BM	0.78	0.72	<0.001
BMI	0.81	0.65	<0.001

r^2 is the proportion of explained variance; SEE is the standard error of the model; p is the significance of contribution of the respective parameter to the stepwise multiple regression model

Table 5 Contribution and order of entry of predictor variables to the regression model (2) for the mesomorphy component of the Heath-Carter somatotype

Predictor variables	r^2	SEE	p
BMI	0.47	0.89	<0.001
BM	0.71	0.66	<0.001
FFMi	0.81	0.54	<0.001

r^2 is the proportion of explained variance; SEE is the standard error of the model; p is the significance of contribution of the respective parameter to the stepwise multiple regression model

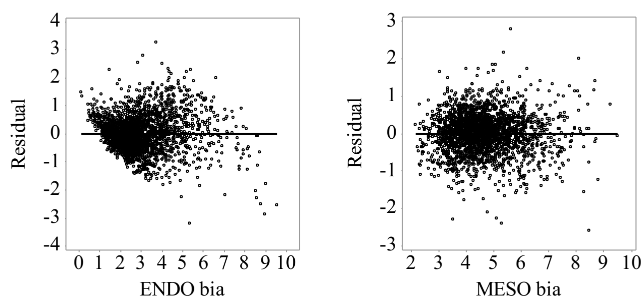

Fig. 3 The residuals and the respective regression lines for endomorphy and mesomorphy estimates of the Heath-Carter somatotype

One can note, due to mutual dependence of the FFM on the impedance index Ht^2/R, that the FFMi, as a ratio of FFM to Ht^2, should strongly correlate with the inverse value of the electrical resistance R. With this idea, in order to avoid using population-specific body composition equations, we constructed the alternative formulae for the evaluation of the Heath-Carter somatotype relying solely on measurements of height, weight, and the electric resistance:

$$ENDO_{BIA} = -3224.7/R + 0.63867\times BMI - 0.04162\times BM - 2.195 \quad (r^2=0.81,\ SEE=0.65) \tag{3}$$

$$MESO_{BIA} = 2195.4/R + 0.52966\times BMI - 0.09740\times BM - 4.5522 \quad (r^2=0.81,\ SEE=0.54) \tag{4}$$

These formulae are similar to Eqs. (1)-(2) in structure, have the same accuracy of the response variables approximation, and take an advantage of using only directly measured rather than estimated bioimpedance data. The relatively high values of the proportion of explained variance r^2 enable the use of these formulae for individual typology. Given that the ectomorphy, i.e., the third component of the somatotype, is calculated directly on patient's height and weight [6], we, thus, obtain an opportunity for automated bioimpedance-based evaluation of the overall Heath-Carter somatotype in children and adolescents. The respective algorithm was embedded in the current version of the ABC-01 'Medas' bioimpedance meter software.

IV. Conclusions

The assessment of body composition and somatotyping represent two different, but correlated, ways of describing human physique and structure. The Heath-Carter anthropometric somatotype [6] is one of commonly used methods of somatotyping and still of important significance for anthropology and sports science [7-9]. However, in practice, the assessment of the Heath-Carter somatotype is not always available because of the need for a significant number of anthropometric measurements that must be performed by a qualified specialist. In our work, based on the results of anthropological study of a large group of ethnically Russian children and adolescents, we suggested simple prediction formulae for automated bioimpedance-based evaluation of the Heath-Carter somatotype that are suitable for individual typology. We could recommend preferential use of the equations based on directly measured electrical resistance rather than estimated values of fat mass index or fat-free mass index. In contrast to the results obtained earlier by the other authors [14], the formulae are suitable for use both in boys and girls in a relatively wide age range, from 7 to 17 years, and rely solely on data collected within the traditional bioimpedance measurements procedure.

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Conflict of Interest

The authors declare that they have no conflict of interest.

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Address of the corresponding author:

Author: Sergey Rudnev
Institute: Institute of Numerical Mathematics
Street: Gubkin str., 8
City: Moscow
Country: Russia
Email: sergey.rudnev@gmail.com