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INTERRELATIONSHIP BETWEEN ANTHROPOMETRIC VARIABLES AND ESTIMATION OF HEIGHT IN ADOLESCENTS

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ABSTRACT

Anthropometric variables are important tools in the analysis of body proportions as well as in assessing nutritional status, health status, and body growth and development. The aim of the present study is to analyze the association between anthropometric variables and to establish which variable can best be used in height estimation. The study included a group of 95 adolescents of both sexes aged between 16 and 18 years. Height, weight, sitting height, chest circumference and arm span were measured. Descriptive statistical parameters were calculated for the variables analyzed and correlation and simple linear regression analyses were performed. Coefficients of correlation (r) as well as coefficients of determination (r^2) were calculated and the corresponding regression equations were obtained.We found strong correlation between arm span and height in girls, height and leg length in both sexes, chest circumference and weight in both sexes ($p < 0.0001$ in all of these cases). Moderate correlation was recorded between arm span and height in boys, arm span and leg length in girls, arm span and sitting height in both sexes, height and sitting height in both sexes, arm span and chest circumference in boys. Estimation of height from leg length was 71.44% in girls and 75.14% in boys and from arm span was 70.82% in girls.

KEY WORDS: *anthropometric variables, measurement, correlation, height estimation, adolescents*

INTRODUCTION

Anthropometric parameters and indicators are important tools in the comparative analysis of body proportions in different populations, as well as in assessing nutritional status, health status, and body growth and development (Botti *et al.*, 2009). The evaluation of anthropometric indicators is inexpensive and non-invasive (Pelegrini *et al.*, 2015).

Many studies in several different countries have focused on several anthropometric variables. Some studies aimed at the assessment of nutritional status with the help of various anthropometric variables (Klimek-Piotrowska *et al.*, 2015; Uddin *et al.*, 2015; Janjic *et al.*, 2016) while others have investigated the relationship

between anthropometric variables and health status (Petroff *et al.,* 2015).There is also research that focuses on the study of the relations between different anthropometric variables. Many of these studies have concentrated on the relation between height and arm span (Goon *et al.,* 2011; Bjelica *et al.,* 2001; Mohanty *et al.,* 2001). Other studies aimed at the estimation of height with the help of other anthropometric parameters. Thus, stature has been estimated based on footprint length, whose correlation proved to be positive and statistically significant, an important aspect in forensics (Moorthy *et al.,* 2014**).** Also, there has been research on assessing stature from middle finger length, the correlation being moderate and highly significant (Kuppast *et al.,* 2014). Other studies have analyzed the possibility of estimating stature based on different hand and foot measurements, as hand length, hand breadth, leg length and foot breadth. In all these situations correlations were positive and statistically significant, the highest correlation being found between height and foot length (Krishan & Sharma, 2007). Another research aimed to assess stature by using knee height (Özer *et al.,* 2007). Other studies have investigated determining stature by using various cephalo-facial measurements, all of which were significantly correlated with stature, especially measurements of the cephalic region (Krishan & Kumar, 2007). The results of other research show that waist circumference is correlated with body mass index, and a predictor of hypertension in children and adolescents (Burgos *et al.,* 2013).

Each part of the body is different in its own way both within an individual organism and as compared to other organisms. There is a relationship between the different parts of the body and the body as a whole (Moorthy *et al.,* 2014)**,** but variations occur between different ethnic and racial groups (Kasunka *et al.,* 2015). The most important differences in body size and shape are related to ethnicity, age and gender (Apeagyei, 2010). Given the existence of racial variations, it is important to conduct studies focusing on different races and regions (Mohanty *et al.,* 2001).

In this study, the anthropometric variables of height, sitting height, leg length, arm span, chest circumference and weight were analyzed in a group of Romanian adolescents. We analyzed these variables in comparison with similar age groups from different countries. We attempted to establish whether there is an association between these variables and also which variable can best be used in the estimation of another variable out of those analyzed, especially height, and to what extent. The fact that certain anthropometric variables can be estimated with the help of others may serve to reduce the number of anthropometric measurements, as these can be time consuming.

MATERIALS AND METHODS

The study included a group of 95 adolescents (35 boys and 60 girls) aged between 16 and 18 years from Timișoara (Romania). The average age of the group was 17.37 ± 0.95 years. The subjects included in the study were healthy and had no physical deformities. The following anthropometric variables were measured: height,

weight, sitting height, chest circumference and arm span. The measurements were taken by the same person, following the international standards for anthropometric assessment (International Society for the Advancement of Kinanthropometry, 2001).

A digital scale was used to measure weight. Height was measured with a stadiometer. For the height measurement, the barefoot subject was placed in a perfectly vertical position, with the head in the Frankfurt plane position, looking forward, with the trunk erect and knees straight. Arm span was measured with a flexible steel tape from the tip of one middle finger to another. The subject was standing against the wall with arms fully extended horizontally and palmar faces of the hands oriented forward. The chest circumference was measured with a metric tape. The measurements were taken at the end of a normal expiration, the subject having the arms in abduction. Sitting height is the height from the sitting platform to the vertex. To measure sitting height, the subject sat on a stool, with the trunk perfectly erect and the head in the Frankfurt plane position. Leg length was established by subtracting the measured values of the sitting height from the measured values of height.

Statistical analysis and graphic representation of data resulting from the measurements was performed using Microsoft Excel, GraphPadInStat and GraphPadPrism. Depending on whether the data distribution was Gaussian or not, parametric or nonparametric tests were performed. For statistical tests, the statistical significance coefficient (p) value ≤ 0.05 was considered to indicate a statistical significance (Marzillier, 1990). The following interpretation of the statistical significance coefficient was used, according to GraphPadInStat software: $p < 0.05$ = significant, $p < 0.01$ = very significant, $p < 0.001$ = extremely significant, $p > 0.05$ = not significant.

Descriptive statistical parameters were calculated for the variables analyzed and correlation and simple linear regression analyses were performed in order to establish whether there is an association between the anthropometric parameters measured. Coefficients of correlation (r) as well as coefficients of determination (r^2) were calculated and the corresponding regression equations were obtained. The correlation coefficient (r) was interpreted as follows: an r value of -1.0 or +1.0 means a perfect correlation relationship between the variables analyzed, values of $r > 0.7$ indicate a strong correlation between variables, values of r between 0.4 - 0.7 denote moderate correlation and values of $r < 0.4$ indicate weak correlation (Holmes & Opara, 2014).

The study was approved by the Ethical Committee of the Faculty of Chemistry, Biology and Geography of the West University of Timisoara and was carried out in accordance with the Declaration of Helsinki. The subjects gave an informed consent before the onset of the study.

RESULTS AND DISCUSSIONS

The descriptive statistical parameters of all measured variables for both female and male subjects are shown in Table 1. The differences between values measured in the two sexes are extremely significant ($p < 0.0001$). All average values are higher in males (Figure 1).

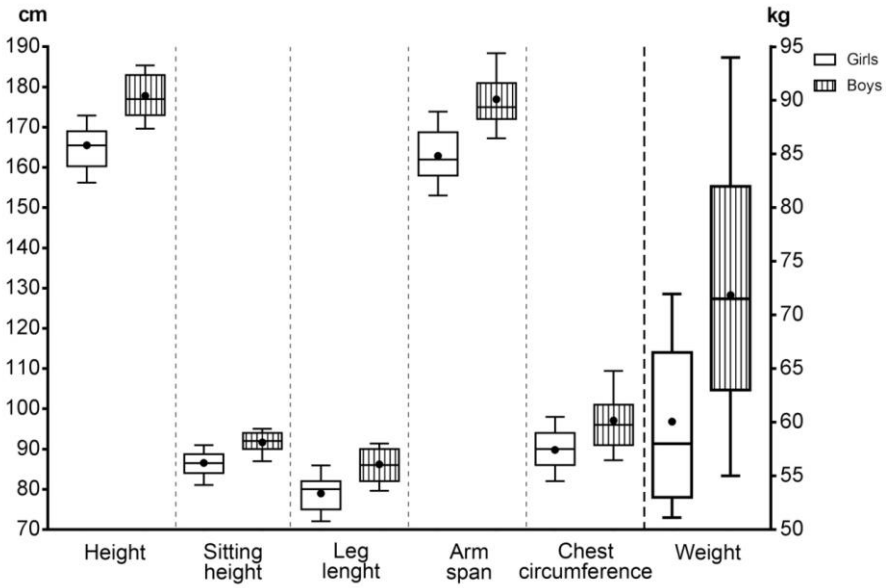

FIG. 1. Box plots showing comparative distribution of anthropometric variables in boys and girls. The box plots extend from the 25th to the 75th percentiles. The whiskers indicate the 10th and 90th percentiles, the central lines indicate the medians and the bullets show the mean values.

The results of correlation and simple linear regression analysis for all investigated variables are shown in Table 2. All correlations obtained are positive.

We found strong correlation ($r > 0.7$) between following variables: arm span and height in girls, height and leg length in both sexes, chest circumference and weight in both sexes, p being extremely significant in all of these cases ($p < 0.0001$).

Correlation coefficient between 0.4 - 0.7 was recorded for arm span and height in boys ($p=0.0039$), arm span and leg length in girls ($p < 0.0001$), arm span and sitting height in both sexes ($p < 0.0001$, $p=0.0064$), height and sitting height in both sexes ($p < 0.0001$, $p=0.0012$), arm span and chest circumference in boys ($p=0.0009$). In all of these cases p was very significant or extremely significant. The correlation analysis between the other variables showed a correlation coefficient under 0.4, most of the results being not significant in these situations.

TABLE 1: Statistical descriptive parameters of the analyzed anthropometric variables

Statistical parameters		Height (cm)	Sitting height (cm)	Leg length (cm)	Arm span (cm)	Chest circumference (cm)	Weight (kg)
Mean value	Girls	165.51 ±6.93	86.56 ±3.77	78.95 ±5.17	162.83 ±7.47	89.78 ±6.11	60.05 ±9.44
	Boys	177.8 ±5.84	91.57 ±2.91	86.22 ±4.97	176.91 ±7.88	97.02 ±8.24	72.78 ±15.56
Minimum value	Girls	150	77	66	145	73	44
	Boys	167	84	77	162	85	46
Maximum value	Girls	184	96	89	181	103	86
	Boys	186	98	97	198	121	94
Lower 95% CI	Girls	163.72	85.59	77.61	160.9	88.2	57.61
	Boys	175.79	90.57	84.52	174.2	94.19	67.43
Upper 95% CI	Girls	167.31	87.54	80.28	164.76	91.36	62.49
	Boys	179.81	92.57	87.93	179.62	99.86	78.13

CI = confidence interval

The highest correlation coefficient in the group of adolescents in this study was found between chest circumference and weight (r=0.88 in boys, r=0.71 in girls). Next are the correlation coefficients between height and leg length (r=0.86 in boys and r=0.84 in girls), arm span and height (r=0.84 in girls) and between arm span and leg length (r=0.68 in girls) (Table 2).

Estimation of height was best made by using arm span and leg length as independent variables. In the case of leg length the estimation of height is 71.44% in girls and 75.14% in boys. Using arm span the estimation of height is 70.82% in girls, but only 22.56% in boys. The weakest results of prediction of height were obtained in the case of using chest circumference of all variables.

Adolescence is a more difficult period to define in terms of chronological age. The WHO considers adolescence to be between the ages of 10 and 18 years, but this period can be extended from 8 to 19 years in girls and 10 to 22 years in boys, which are the boundaries of normal variation in the onset and end of adolescence (Malina *et al.* 2004). According to the WHO, the subjects of this study are towards the end of adolescence, the average age of girls being 17.51 ± 0.89 years and that of boys 17.14 ± 1.03 years. The growth spurt during adolescence, although a constant phenomenon, displays individual variations in duration and intensity. All parts of the skeletal and muscular systems are involved in this growth spurt, but to different extents (Tanner, 1981).

TABLE 2: Coefficients of determination and coefficients of correlation between anthropometric variables

Anthropometric variables		r	r^2	p
Arm span Height	girls	0.84	0.7082	< 0.0001 ***
	boys	0.47	0.2256	0.0039 **
Arm span Leg length	girls	0.68	0.4712	< 0.0001 ***
	boys	0.29	0.0860	0.0873 ns
Arm span Sitting height	girls	0.60	0.3670	< 0.0001 ***
	boys	0.45	0.2041	0.0064 **
Arm span Chest circumference	girls	0.001	3.210E-0.6	0.9892 ns
	boys	0.53	0.2860	0.0009 ***
Height Leg length	girls	0.84	0.7144	< 0.0001 ***
	boys	0.86	0.7514	< 0.0001 ***
Height Sitting height	girls	0.67	0.4616	< 0.0001 ***
	boys	0.52	0.2762	0.0012 **
Height Chest circumference	girls	0.18	0.0361	0.1461 ns
	boys	0.06	0.0041	0.7137 ns
Leg length Sitting height	girls	0.18	0.0332	0.1637 ns
	boys	0.03	0.0010	0.852 ns
Leg length Chest circumference	girls	0.33	0.1133	0.0085 ***
	boys	0.11	0.0127	0.5185 ns
Sitting height Chest circumference	girls	0.11	0.0127	0.3911 ns
	boys	0.32	0.1034	0.0597 ns
Arm span Weight	girls	0.31	0.0997	0.0140 *
	boys	0.54	0.2947	0.0008 ***
Height Weight	girls	0.18	0.0353	0.1504 ns
	boys	0.25	0.0649	0.1397 ns
Leg length Weight	girls	0.009	8.796E-05	0.9433 ns
	boys	0.10	0.0112	0.5453 ns
Sitting height Weight	girls	0.35	0.1287	0.0049 ***
	boys	0.33	0.1090	0.0527 ns
Chest circumference Weight	girls	0.71	0.5041	< 0.0001 ***
	boys	0.88	0.7900	< 0.0001 ***

***$P < 0.001$ = extremely significant, **$P < 0.01$ = very significant, *$P < 0.05$ = significant, ns = not significant

In girls the average height is 165.51 ± 6.93 cm and in boys 177.8 ± 5.84 cm. The stature of these adolescents in Romania is comparatively lower than that of other adolescents of similar age in some European countries, where the following average height values have been reported: in Poland 178.1 ± 6.5 cm in boys and 172.9 ± 8 5 cm in girls (Klimek-Piotrowska *et al.* 2015)**,** in Norway 180.1 ± 6.5 cm in boys and 166.7 ± 6.2 cm in girls (Bjørnelv *et al.* 2007), in Sweden 1.80 ± 0.62 m in boys and 1.67 ± 0.59 m in girls (Neovius *et al.* 2005), in Estonia 179.11 ± 6.29 cm in boys (Lintsi &Kaarma, 2006), in Croatia 1664 ± 58.5 mm in boys and 1800 ± 71.4 mm in girls

(Zivicnjak *et al.* 2003), but it is higher than that of adolescents in some Asian countries such as India and Japan, where smaller average height values have been reported, i.e. in India 155.2 ± 2.33 cm in boys and 143.3 ± 1.73 cm in girls (Tiwari *et al.* 2007), in Japan 157.9 ± 6.30 cm in girls (Ashizawa *et al.* 1994). Average heights obtained in the present study are also higher than those of similar aged teenagers in Bolivia, where average values of 165.5 ± 6.8 cm in boys and 154.9 ± 6.1 cm in girls were recorded (Botti *et al.* 2009).

Average weight values of the group investigated in this study are higher than those of a same age group in Bolivia (72.78 ± 15.56 kg in boys in this study, as compared to 58.6 ± 2.8 kg in boys in Bolivia, and 60.05 ± 9.44 kg in girls in this study, as compared to 54.5 ± 8.7 kg in girls in Bolivia), to which contribute the higher stature values. On the other hand, although in these adolescents from Romania average height values are lower than in the group of adolescents from Estonia (Lintsi & Kaarma, 2006), both average weight values and average chest circumference values in both sexes are larger in the Romanian adolescents as compared to those in Estonia, which indicates that in this case the larger weight in the group of Romanian adolescents is not due to larger stature. In comparison with the above-mentioned study conducted in Norway (Bjørnelv *et al.* 2007), where average height values in both sexes are also higher than in the case of this group of adolescents from Romania, girls' weight is lower in the present case as compared to that of girls in Norway (60.05 ± 9.44 kg to 62 ± 9.7 kg), while boys' weight is about equal (72.78 ± 15.56 kg in the present case, as compared to 72, 5 ± 12 kg in the Norwegian group).

Regarding the average value of the chest circumference obtained, of 89.78 ± 6.11 cm in girls and 97.02 ± 8.24 cm in boys, it has been found to be higher than that recorded in some adolescent groups in India (Tiwari *et al.* 2007) or Japan (Ashizawa *et al.* 1994).

A comparison of the average values obtained in the present study for arm span and height shows that in both sexes arm span are smaller than height. Thus, in males the average value of height is 177.8 ± 5.84 cm and of arm span is 176.91 ± 7.88 cm. In females the average value of height is 165.51 ± 6.93 cm and of arm span is 162.83 ± 7.47 m. However, if we compare the individual values of height with those of arm span, the results show that in the case of 75% of girls arm span is smaller than height, in 20% it is greater, and in 5% they have equal values. In 48.57% of boys arm span is smaller than height, in 40% arm span is larger than height, and in 11.42% the variables have equal values. Thus, in both sexes the most common situations are those where height values are higher than arm span values, but this is more evident in girls. Overall, the average values of height and arm span are very close in both boys and girls.

A comparison of the present study's results regarding the relationship between arm span and height with those of another study conducted in Romania showed similarities in women, where the average arm span value was also lower than the

average height value. In males however, the results were different, arm span being larger than height in that study (Radu *et al.* 2014). In a study on the relationship between height and arm span carried out in the Republic of Serbia in the adult population it was found that in males arm span is slightly larger than height and in females arm span is slightly smaller than height, but in both cases arm span allows realistic estimates of height (Popovic *et al.* 2013). The results of a study conducted in India showed that, in both sexes, average arm span values are greater than average height values (Shah *et al.* 2013).

Relations between anthropometric variables were investigated using simple linear regression and correlation analysis. All correlations obtained are positive, which show the evolution of all anthropometric variables in the same direction. With age this becomes different, as during the aging process certain anthropometric parameters decrease, generating a negative anthropometric profile (De Almeida *et al.* 2013).

Correlation analysis between height and arm span shows that between these two anthropometric variables there is a positive correlation in both sexes (Figure 2). In females there is strong correlation ($r = 0.84$), $p < 0.0001$, and height can be estimated from arm span in 70.82% of cases according to the regression equation below:

$$\text{Height} = 38.385 + 0.7807 \times \text{Arm span}$$

In males, the correlation coefficient between these variables is 0.47, p is very significant (0.0039), and stature is less predictable (22.56%) than in females, the regression equation being the following:

$$\text{Height} = 115.55 + 0.3519 \times \text{Arm span}$$

In comparison, the results of a study on the correlation between height and arm span carried out in India show a significantly higher correlation coefficient in females (0.783) than in males (0.689) (Alam *et al.* 2016). An analysis of the same correlation carried out in Nepal found moderate correlation between arm span and height, but the correlation coefficient was higher in males (0.68) than females (0.5) (Sah *et al.* 2013). A high correlation coefficient between arm span and height (0.76 in men, 0.72 in women) was also found in a study conducted in Nigeria (Goon *et al.* 2011). In Montenegro, the values of the correlation coefficient calculated were also high (0.861 in men, 0.809 in women) (Bjelica *et al.* 2012).

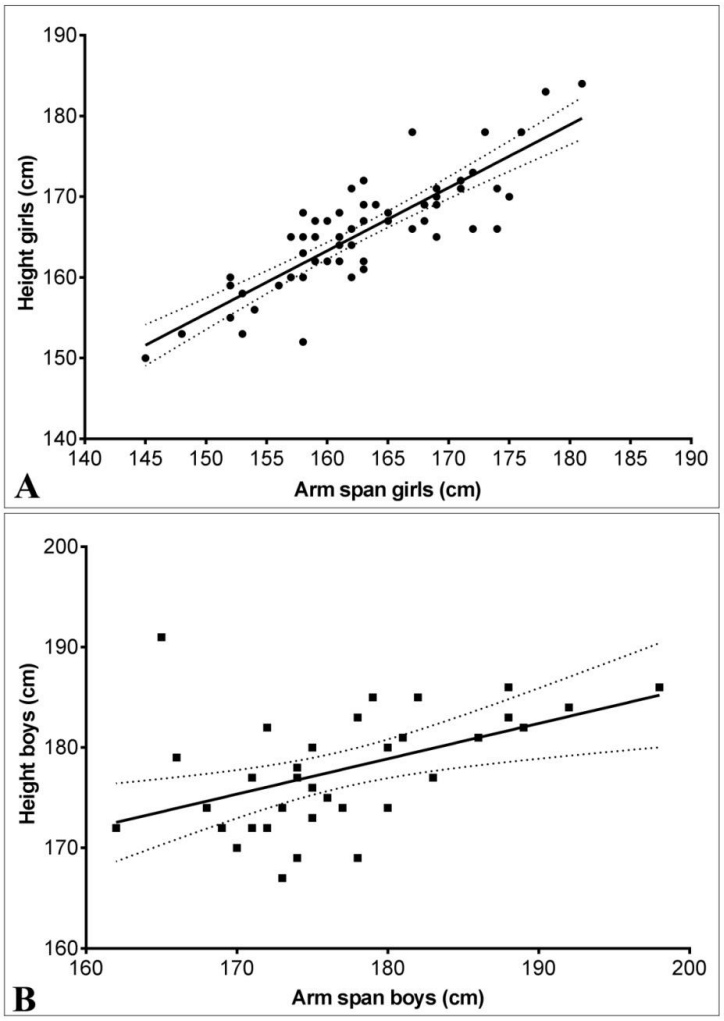

FIG. 2. Linear regression between height and arm span (A: in boys, B: in girls). The dotted lines represent the upper and lower 95% confidence interval.

To the different results regarding the relationship between height and arm span in girls and boys may contribute the different evolution of arm span as compared to height in the two sexes. Thus, arm span grows proportionally more than stature in females until the age of about 15 years and in males until about the age of 25. This is followed by a plateau in the ratio arm span / height up to about 45 years, when there is an almost linear increase in the ratio with age, initially more abrupt in women, which probably reflects decalcification and osteoporosis, more pronounced in postmenopausal women (Quanjer *et al.* 2014).

The results of the present study show that in 89.47% of subjects sitting height is larger than leg length, reflecting the fact that in most cases sitting height prevails over leg length in determining height. This is found both in girls (91.66%) and in boys (85.71%). This result is consistent with the results of a study conducted in Brazil, where at the age of 18 higher average values of trunk length to leg length were also recorded (Gigante et al. 2009), and in Taiwan, where sitting height proved to be higher than leg length at the same age (Lee *et al.* 2005). It is known that in the early stages of puberty there is an increase in the proportion of lower limbs within stature, then, as the overall growth rate decreases, the proportion of the sitting height increases progressively (Buckler, 1990). However, the growth of the lower limbs ends sooner than the growth of the sitting height, which continues into late adolescence. Thus, sitting height growth occurs over a longer period of time and contributes more to the growth gain during adolescence (Malina *et al.* 2004).The subjects of the present study are towards the end of adolescence, when probably the growth of sitting height has also taken place to a great extent. As Tanner shows, most of the growth spurt in height is due rather to an increase in sitting height than one in the length of the lower limbs (Tanner, 1981). In females, the percentage of subjects whose sitting height is larger than the leg length is higher than in males. This may be a consequence of the fact that in girls the onset of adolescence and the growth spurt occur earlier than in boys (Malina, 1999), which means that the increase in sitting height, which in both sexes begins later than the increase in leg length, is more advanced in girls than boys.

Next, the associations between height and its two components, sitting height and leg length, were analyzed separately. A stronger correlation was found between height and leg length ($r = 0.84$ in girls and $r = 0.86$ in boys), $p < 0.0001$ in both cases (Figure 3). Correlation between height and sitting height is moderate in both sexes ($r = 0.67$ in girls and $r = 0.52$ in boys), with p extremely significant in girls ($p < 0.0001$) and very significant in boys ($p=0.0012$). According to the coefficient of determination, in 75.14% of cases height in males can be expressed by leg length following the regression equation:

$$\text{Height} = 89.988 + 1.018 \times \text{Leg length}$$

In females, according to the coefficient of determination, in 71.44% of cases height can be calculated from leg length with the following formula:

$$\text{Height} = 76.094 + 1.133 \times \text{Leg length}$$

The estimation of height is lower when using sitting height than when using leg length. Thus, the coefficient of determination shows that for females in 46.16% of cases height can be expressed with the help of sitting height as follows:

Height = 57.307 + 1.250 x Sitting height

In males, the estimation of height from sitting height is of 27.62%, according to the regression equation:

Height = 81.333 + 1.053 x Sitting height

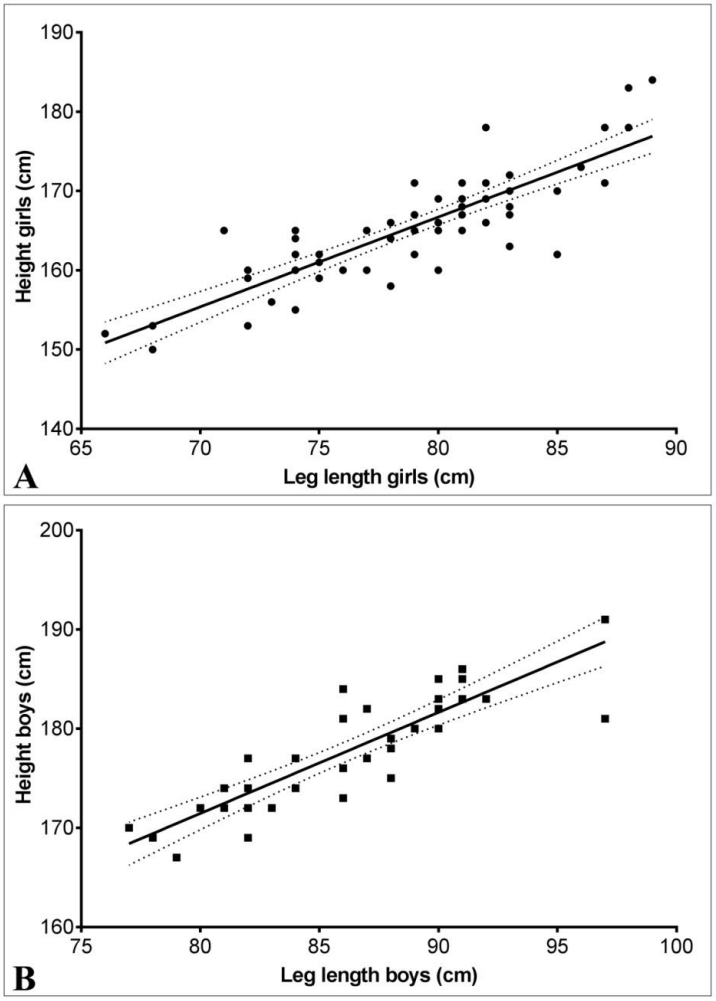

FIG. 3. Linear regression between height and leg length (A: in boys, B: in girls). The dotted lines represent the upper and lower 95% confidence interval.

To the better correlation between height and leg length than between height and sitting height in the sample analyzed may contribute the fact that during this period of late adolescence the growth of leg length is completed (Malina *et al.* 2004), and the leg length no longer undergoes large variations, while the growth of sitting height, which takes place later than that of leg length, is likely to still be incomplete, which may result in its greater variability.

Estimation of height from leg length ($r = 0.86$ in boys, $r = 0.84$ in girls) is better than the estimation of height from arm span in the group analyzed. However, it is not advisable to use leg length in estimating stature because the contribution of leg length to stature can be the cause of a high correlation coefficient (Mohanty *et al.* 2001).

As in the case of the relation between height and arm span, the relation between height and leg length and height and sitting height also requires the use of different equations in the case of girls and of boys, which reflects the different evolution of these variables in the two sexes.

The relationship between arm span and the two components of stature, i.e. sitting height and leg length, were also analyzed. In girls there was moderate correlation between arm span and leg length ($r = 0.68$), $p < 0.0001$. In boys, between the same anthropometric variables, $r = 0.29$, the result being statistically insignificant. Correlation coefficients between arm span and sitting height are 0.60 in girls and 0.45 in boys, p being extremely significant (<0.0001), and very significant respectively (p=0.0064).

Thus, in the group investigated, correlation coefficients were higher in the correlation analysis between arm span and height than between arm span and either of the two components of stature, sitting height and leg length.

A strong association was found between chest circumference and weight ($r=0.71$ in girls, $r=0.88$ in boys), $p< 0.0001$. With the exception of this situation, correlation analyses of chest circumference with other variables yielded low values of the correlation coefficient. In boys, the estimation of chest circumference from weight is of 79% through the following regression equation:

$$\text{Chest circumference} = 62.778 + 0.4706 \times \text{Weight}$$

In girls, in 50.41 % of cases chest circumference can be expressed through body weight according to the following regression equation:

$$\text{Chest circumference} = 62.541 + 0.4537 \times \text{Weight}$$

Chest circumference is the anthropometric variable best correlated with weight in the group analyzed.

CONCLUSIONS

All correlations between the anthropometric variables are positive. The strongest associations were found between chest circumference and weight in both sexes, height and arm span in girls, height and leg length in both sexes. Estimation of height was best undertaken in the group investigated by using arm span and leg length, the predictability being of 70.82% in girls in the case of arm span, and of 71.44% in girls and 75.14% in boys in the case of leg length.

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