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ANTHROPOMETRIC PREDICTION OF BODY COMPOSITION IN AMERICAN YOUTHS 12–17 YEARS OF AGE

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Abstract: Prediction equations for estimating fat weight from age, Quetelet's Index, and the triceps skinfold thickness were developed, for each sex, in 169 males and 66 females, 12 to 17 years of age, from Minneapolis and Philadelphia. Validation was carried out by a sequence of analyses done on 90% of the sample, the remaining 10% used for validation. This was conducted until all combinations of 90% had been used for prediction and of 10% for validation. The standard errors of estimate were too high to permit acceptable estimates to be made in individual subjects, the one SD error amounting to 27% of the mean fat weight. Even though good results were obtained for the sample as a whole, systematic errors were noted when the errors of estimate were calculated for Minneapolis and for Philadelphia youths separately. It is recommended that prediction equations for body composition not be used in adolescents of this age range.

Key words: anthropometric prediction, body composition, American youths.

Introduction

The most widely-used indicators of body composition in humans are anthropometric ones, derived from the careful measurement of the body using accepted techniques. The scientific and clinical literature abounds with reports which analyze various issues and problems related to body composition based upon anthropometry. The reasons for the widespread use of anthropometric techniques are obvious. They are relatively simple to apply, they are much less expensive than all of the presently available laboratory procedures and, most important of all, anthropometric methods are appropriate for large samples of all ages, male and female, located wherever they may be found in the world.

While anthropometry has many advantages as a technique used in the study of body composition, it also has its limitations. Anthropometric indicators are indirect ones and, rather than yielding estimates of variables such as the lean body mass, percent body fat, and the like, they provide measurements of whole body mass or of linear dimensions. As a result, considerable effort has been devoted by researchers to the validation of body measurements as indicators of body composition and numerous publications are available which report of the relationships between anthropometric dimensions and whole body composition (BROŽEK 1963a, 1963b, BEHNKE–WILMORE 1974, PAŘÍZKOVÁ 1977, MALINA 1980, LOHMAN 1981).

In general, the relationships between anthropometric variables and estimates of body composition derived from methods such as ^{40}K, densitometry, or the determination of body water are quite high. For example, in an early study, PASCALE et al. (1956) reported correlations between various skinfolds and body density in American adult males which ranged from -0.74 to -0.83. Similar results have been published by other investigators for additional samples, using such anthropometric indicators as weight, circumferences, skinfolds, and indices of weight-for-height (SATWANTI et al. 1977, HARSHA et al. 1978).

In view of the generally high relationship between anthropometry and estimates of whole body composition derived from laboratory procedures, many investigators have utilized combinations of body measurements, usually through multiple regression analysis, in an attempt to optimize the relationships, to account for a greater proportion of the variance, and to permit usable estimates of body composition to be made from combinations of anthropometric variables. A count of the number of papers which have presented such prediction equations is neither necessary nor fruitful; however, well over 100 equations may be found in the scientific literature without undue effort.

Unfortunately, the impact of this mass of equations upon researchers has been minimal. Only occasionally does one find a study in which an investigator has used someone else's equations in his or her study. Instead the majority of workers prefer to rely upon their own anthropometric data.

The reasons for the lack of utilization of the available prediction equations are based to a large extent upon methodological flaws present in the research designs of the studies from which the equations were generated. These flaws have been discussed (LOHMAN 1981, JOHNSTON 1982), and need not be repeated here. However, it is important to realize that the development of prediction equations which may be used on other groups is a complex task requiring a careful and rational selection of independent variables, as well as rigorous and appropriate means for validating the equations which result in order to determine their usefulness among other samples.

This paper examines the issue of predicting whole body composition in 12 to 17 year old youths from a linear combination of anthropometric dimensions. In particular, it addresses the question of the appropriateness of such equations for this age group, as opposed to the use of the body measurements themselves.

Subjects and Methods

The data presented in this paper have been drawn from a study of a sample of American youths, 12 to 17 years of age. The sample totalled 235, 169 males and 66 females and have been described in detail elsewhere (JOHNSTON et al. 1982). Of the total, 48 males and 41 females were from the Minneapolis, Minnesota, area, and 121 males and 25 females were from the Greater Philadelphia area. All techniques were applied similarly in both cities to minimize and effects due to different laboratories.

Estimates of body composition were made by means of body densitometry, determined by underwater weighing. The hydrostatic weighing technique involved four to six determinations of the weight in water taken to the nearest 25 gm, the mean of the last three recorded for analysis. Residual volume was estimated by the oxygen dilution technique of WILMORE (1969)

Table 1

Means and standard deviations of selected variables

Variable		Age (yr) 12	13	14	15	16	17
Males							
n		13	21	37	40	37	21
Height (cm)	x̄	151.2	160.7	165.7	169.6	173.5	175.0
	s	6.0	10.5	7.3	7.1	6.0	7.0
Weight (kg)	x̄	43.9	48.6	56.5	61.9	66.8	69.8
	s	8.4	12.3	12.3	9.0	9.9	16.2
Triceps (mm)	x̄	11.1	9.5	10.2	9.5	10.3	6.4
	s	6.7	4.6	6.1	4.1	5.5	3.0
Arm Muscle C (cm)	x̄	20.2	20.8	23.1	25.2	26.0	27.7
	s	1.8	2.3	2.3	2.2	2.0	3.2
% Body Fat	x̄	23.2	24.0	16.9	15.7	14.3	12.7
	s	8.4	6.2	7.1	7.5	7.3	6.3
Fat Weight (kg)	x̄	10.6	11.7	10.0	10.0	9.9	9.4
	s	6.2	4.5	6.3	5.6	6.1	6.4
Lean Body Mass (kg)	x̄	33.2	38.0	46.4	51.9	56.8	60.3
	s	4.2	9.5	8.7	7.2	7.1	12.0
Females							
n		6	10	12	16	12	10
Height (cm)	x̄	157.3	154.4	161.9	163.7	162.9	165.7
	s	3.4	5.9	7.3	6.0	4.4	5.8
Weight (kg)	x̄	43.4	44.8	53.8	58.3	57.2	55.3
	s	8.9	9.3	7.1	6.0	7.4	7.5
Triceps	x̄	10.1	10.9	13.9	16.2	15.2	13.2
	s	2.7	5.7	5.4	6.8	3.7	4.7
Arm Muscle C (cm)	x̄	19.1	19.8	20.8	21.6	21.8	20.7
	s	3.2	1.5	1.5	1.7	2.1	1.7
% Body Fat	x̄	24.9	25.1	26.6	27.4	28.1	27.9
	s	7.0	6.8	3.8	4.9	3.7	6.3
Fat Weight (kg)	x̄	10.8	11.6	14.4	16.1	16.2	15.7
	s	3.8	5.6	3.2	4.8	3.7	4.7
Lean Body Mass (kg)	x̄	32.6	33.7	39.4	42.0	40.9	39.8
	s	7.1	5.0	4.9	6.1	4.4	4.2

The standard deviations of the errors of estimate of fat weight are 3.1 kg and 2.3 kg in males and females respectively. That is, two-thirds of the errors of estimate fell within a range of 6.2 and 4.6 kg.

We next examined the prediction errors which resulted from applying the equations derived for the total sample by city of residence, i.e., Minneapolis or Philadelphia. The results are given in Table 4, where it is immediately apparent that the errors of estimate, when calculated separately by city, are conand the percent body fat calculated from body density using the forn of BROŽEK et al. (1963):

$$\text{Percent Body Fat} = \frac{4.570}{D} - 4.142$$

where D = body density, expressed in gm/ml.

Because of the dangers of over-determination, we did not utilize all o anthropometric variables which had been measured. Rather, we atten to use the minimal number of measurements, those obtained easily on sub under varying conditions. After analyzing the correlation matrix forme the body measurements, we chose, as predictor variables, the thickness c triceps skinfold and Quetelet's Index (weight/height^2). Since our sul spanned a six-year age range in which body composition is known changing rapidly (PAŘÍZKOVÁ 1977, TANNER 1962), the age of each indi was also used as a predictor variable.

For the dependent variable we decided to use the body fat weight. Th cent body fat was not used because of its lower correlations with an metic dimensions while density was not chosen because of the difficu interpreting variability in meaningful units of body composition.

The predictor variables were entered sequentially into a linear reg model of the form:

$$\text{Fat Weight} = \text{Age} + \text{Quetelet's Index} + \text{Triceps}$$

and optimal regression weights derived for each sex.

Validation of these equations was accomplished by means of the Ja technique (MOSTELLER—TUKEY 1977). The sample was divided ran by sex, into 10 groups. Separate regression analyses were carried combinations of nine groups and validated on the tenth, until all combinations had been analyzed. This resulted in 10 separate vali each one on 10% of the sample; thus each of the 235 subjects partici this validation procedure once. The error of estimate was calculatec mean error of the 10 validations, again by sex.

Results

Table 1 presents the means and standard deviations of selected a metric and densitometric variables. The values are not notably differ those found by other investigators and confirm that this sample is not for any reason. Table 2 presents the prediction equations resulting analysis of the total sample. In males, 72% of the variance in fat weight explained by this model while, in females, the percentage is somewh 76.8%. These values correspond to multiple r's of .849 and .876 res In males, the regression weighting for Quetelet's Index is somewl than that for the triceps skinfold, while, in females, Quetelet's Index is considerably more than the triceps fold. In both sexes, each regressi is significantly greater than zero.

Table 3 gives the results of validating this approach using the technique. The mean errors of estimate are only about .01 kg in b

Table 2

Equations for predicting fat weight in white American youths, 12—17 years*

Variable	Regression Weight		Units
	Males (n = 169)	Females (n = 66)	
Constant	−1.024	−15.869	—
Age	−0.492	+0.355	yr. + decimals
Quetelet's Index	+0.584	+1.109	kg/m²
Triceps Skinfold	+0.668	+0.170	mm
R^2	0.720	0.768	—

* Predicted fat weight in kg

Table 3

Mean errors of 10 validations each of 10% of sample

Sex	n[a]	$\bar{x}$[b]	s[c]
Males	10	0.008	3.099
Females	10	0.012	2.300

[a] number of validations; sample size for each: males, 16 or 17, females, 6 or 7
[b] mean of predicted-actual fat weight
[c] standard deviation of sample means

Table 4

Mean error of predicted fat weight by city[a]

City of Residence	n	$\bar{x}$[b]	s
Males			
Philadelphia	121	−0.489	2.919
Minneapolis	48	+1.232[c]	3.330
Females			
Philadelphia	25	−0.568	2.552
Minneapolis	41	+0.346	2.056

[a] fat weights predicted from equations of Table 2
[b] mean predicted-actual fat weight in kg
[c] significantly different from zero, p = .02

siderably higher than for the combined sample. In three of the four sex/city groups, these errors cluster around one-half kilogram, though these three mean are not significantly different from zero. However, in the case of Minneapolis males, the mean error of predicted fat weight is +1.232 kg, a value which is significantly different from zero at a probability of 0.02. The standard deviations of the errors of estimate, calculated by city (Table 4), did not differ from the SD's for the sample as a whole (Table 3).

Discussion

The results of this analysis would seem to indicate that suitable estimates of whole body composition may be made from the equations presented here, for youth in the 12 to 17 year age range. This is suggested by the validation data of Table 3, which indicated quite low mean errors of prediction.

However, a closer examination of the analyses suggests that there may be problems in the use of prediction equations for adolescents. The first such problem is indicated by the values of the standard deviations of the errors of estimate. In males, the SD's approximate 3 kg and in females, 2.3 kg. In other words, an estimate of fat weight in an individual subject, using these equations, can be expected to be accurate to within a ± 3 or ± 2.3 kg.

We may express the error of estimate for individuals in another way. If we combine our sample, giving a maximum of 235 subjects, we find that the standard deviation of the error of estimate is 2.966 kg. For all subjects, sexes combined, the mean fat weight determined by densitometry was 11.075 kg. If we use the one standard deviation value as a reference, the error of prediction of fat weight in an individual is 2.966/11.075, or $\pm 27\%$. Clearly, an error of 27% is unacceptable in human biological research. We must therefore conclude that it is not possible to derive prediction equations for individuals of this age range which allow us to estimate their body composition with a suitable degree of accuracy.

On the other hand, one may argue that, even if predictions in individuals are not justified, that it may be possible to make predictions for groups, i.e., to predict the mean fat weight of a sample from their body measurements. While it is true that the mean errors from the validation procedure (Table 3) were quite low, the errors were higher when the sample was subdivided by city. And, in fact, in one of the four subgroups, the mean error was significantly greater than zero.

It is somewhat surprising that the mean errors were so much higher when the sample was subdivided by city of residence. While Minneapolis and Philadelphia are hundreds of kilometers from each other, and occupy different climatic zones, the subjects of both sub-groups are of predominant European ancestry and better results might have been expected intuitively. Two reasons for this difference are immediately apparent. First, the two groups (Philadelphia and Minneapolis subjects) might differ enough biologically due to ethnic and environmental factors to display differences in the relationships between anthropometry and body composition. Second, despite our efforts, there may have been enough systematic difference in the determination of body density or in the measurement of the anthropometric variables to cause a difference. Whatever the case, this argues that prediction equations derived from one group may be applied, with any confidence, only to that specific population from which they were derived. To apply them to any other population, no matter how biologically close they might be thought to be, runs the risk of systematically biasing the results of one's research.

Other investigators have commented on the specificity of equations for predicting body composition. Hughes et al. (1981) applied these equations to a sample of 45 12–14 year old Mexican-American boys, on whom densities had been calculated by underwater weighing. They found that the equations overestimated the percent body fat by 21% and the fat weight by 8.9 kg.

FLINT et al. (1977) concluded that it may be impossible to generalize prediction equations from one group to another. In another study, SATWANTI et al. (1977) applied 12 separate formulae, obtained from the literature, to data from 65 young adult Indian females. They found that, in each case, the formulae systematically underestimated body density and none could be used to generate usably-accurate estimates of fatness in their subjects.

It seems certain that the problems discussed here are especially acute in adolescents. Body composition is known to be changing rapidly during this time and inter-individual variability is increased by other factors, such as the rate of biological maturation (JOHNSTON and MALINA 1966). In addition, where there is significant under- or overnutrition, illnes and disease, and variation in daily levels of energy expenditure, estimates would be expected to be more biased.

Thus, it seems inadvisable to attempt to utilize prediction equations for estimating body fatness in adolescents from their anthropometry. To be sure, such estimates are inadmissible for individuals in view of the very high errors associated with individual predictions. The nature of the population specificity of any equations indicates that significant systematic errors may also be expected when such equations are used to predict mean values for body composition variables. At this time, it would seem better for investigators to continue to utilize the anthropometric dimensions themselves. Even though body measurements are indirect, their judicious use will result in fewer errors than the utilization of prediction equations.

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