January 1984

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Estimation of Body Density in Adolescent Athletes

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ABSTRACT

National samples of 141 male and 133 female highly-trained adolescent athletes were studied to derive anthropometric-based equations predicting body density. Anthropometric measures included skinfold thicknesses at seven sites, circumferences at 14 sites, and diameters at nine sites. Criterion measures of body density were determined by underwater weighing with corrections for residual lung volume based on the oxygen dilution method. Variable selection procedures included factor analysis followed by forward-stepping regression and polynomial analysis. For both the male and female samples, two quadratic equations utilizing either the sum of three or seven skinfold measures were derived. Within the male sample, high validity coefficients (R = 0.81 − 0.82) and low standard errors (SEE = 0.0055 − 0.0056 $g \cdot ml^{-1}$) were shown with these equations. Similar results were demonstrated with the equations for females (R = 0.82 and SEE = 0.0060 $g \cdot ml^{-1}$). Cross-validation on independent samples of male (n = 66) and female (n = 46) adolescent athletes further confirmed these findings. In the cross-validation sample of males, predicted scores were highly correlated with actual body density (r = 0.86 − 0.87) and the total error of prediction ranged from 0.0057 to 0.0061 $g \cdot ml^{-1}$. Among the females, these values were r = 0.82 − 0.83 and total error = 0.0058 to 0.0063 $g \cdot ml^{-1}$. These results indicate that within reasonable limits of error, the sum of three or seven skinfolds may be used to make estimates of the body density of adolescent male or female athletes.

Appraisal of body composition can serve as a valuable aspect characterizing either the status of preparation for competitive athletic participation or the nature of biological variations differentiating athletes from other groups. There are a variety of techniques for such appraisal, but in many instances the use of anthropometric measures to estimate body composition serves as the only practical means available. However, while a large number of equations have been derived to relate measures of circumferences, diameters, and/or skinfold thicknesses into estimates of body density, relative fat, or other aspects of body composition, most have been found to be "population-specific" in nature (Flint et al. 1977; Katch and Michael, 1969; Lohman, 1981; Jackson and Pollock, 1977). In this regard, most equations are limited to estimation of characteristics in groups similar to the original derivation samples. A previous study of

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Human Biology, September 1984, Vol. 56, No. 3, pp. 439-448.

young athletes has shown that large errors in estimation of body density result when equations which were derived from general populations are applied to more highly conditioned subjects (Thorland et al. 1984). With the absence of any anthropometric technique designed to estimate the body density of adolescent participants of different sports, the present study was conducted to generate such new equations and to determine their cross-validity on other young athletes.

Methods and Materials

Subjects

Four samples of subjects were utilized. To derive new equations, two validation samples consisting of adolescent male and female athletes were respectively employed. These athletes were recruited from national championship competition in the events of track and field, gymnastics, diving, and wrestling. Morphological characteristics, by sport, have been previously described (Thorland et al. 1981). Cross-validation of the new equations utilized a sample of male high school wrestlers and a sample of adolescent females from a track and field training camp. A full explanation of all procedures was given to each subject and written consent from both the subject and parents was obtained.

Anthropometric measurements

Skinfold (SF) thicknesses were measured utilizing Lange calipers (10 $g \cdot mm^{-2}$, constant pressure). Employing standard locations (Behnke and Wilmore, 1974; deGaray et al. 1974), individual measures on the right side of the body were based on the average of duplicate trials at the triceps, scapula, midaxillary, supra-iliac, abdominal, thigh, and calf (medial) sites. All SF measures were taken by the same investigator, with a previous test-retest reliability in the performance of these techniques ranging from $r = 0.95 - 0.99$.

Additional anthropometric measures (Behnke and Wilmore, 1974) included circumferences at 14 sites (neck, shoulders, chest, abdomen 1, abdomen 2, hips, wrist, forearm, biceps flexed, biceps extended, thigh, knee, calf, and ankle) and diameters at 9 sites (biacromial, bideltoid, chest, bi-iliac, bitrochanteric, wrist, elbow, knee, and ankle). Also, height was determined to the nearest 0.1 cm and weight was measured to the nearest 0.11 kg, employing a wall scale with Broca plane and a physician's scale, respectively.

Body density determination

Body density was assessed from underwater weighing with corrections for residual lung volume. In the validation samples, residual lung volume was based on nitrogen washout procedures (Darling et al. 1940), employing an SRL Medical M 100 B Automated Pulmonary Function Laboratory. In the cross-validation samples, oxygen dilution procedures (Wilmore, 1969) were performed utilizing a Hewlett-Packard nitrogen analyzer (model 47302 A) connected to a Collins 10-liter survey spirometer. With either procedure, the subject was seated in a position similar to that assumed during underwater weighing and the representative residual lung volume score was based on the average of two to three trials. No differences in residual lung volumes were observed between the two male samples (validation vs. cross-validation) or between the two female samples.

Underwater weighing was performed in a 4250 liter tank in which a metal swing seat was suspended from a Chatillon 9 kg scale. Six to ten trials of the underwater weighing procedure were performed such that minimal differences (usually less than 0.15 kg) were normally observed during the last three to four repetitions. The average of the two to three highest scores (usually occurring during the last three of four repetitions) was then used as the representative underwater weight for each subject. For further interpretation of the results, relative fat was calculated utilizing the formula of Brozek, et al. (1963).

Statistical analysis

Body density (BD) from underwater weighing served as the criterion value against which anthropometric predictions of body density (PBD) were derived. To reduce the size of the variable pool, factor analysis was utilized isolating those anthropometric variables most closely related to the fat and lean components of body density (Jackson and Pollock, 1976). Given that skinfold measures were found to be common to the same compositional factor, values were summed prior to further analysis. This summing of skinfold measures also served to reduce the potentially confounding effects of multiple collinearity of dependent variables that could arise in subsequent analyses. A forward-stepping regression was then used to select anthropometric variables predictive of BD. Following this, polynomial analysis was employed to determine the linear or curvilinear function best describing the relation between BD and the selected independent variables.

To test whether fewer skinfold measures could be employed to accurately predict BD, individual SF measures were selected by a forward-stepping multiple correlation algorithm based on their associations with BD. In both the male and female samples, selection of three skinfold measures yielded correlations with BD that were not significantly increased with the entry of additional SF measures. In the males, these skinfold measures were the triceps, scapula, and midaxillary, while in the females they consisted of the triceps, scapula, and supra-iliac. Utilizing these sums of three SF measures, in place of the sum of seven SF values originally evaluated, variable selection and polynomial analysis, as described above, were again utilized to derive additional equations predicting BD.

Cross-validation of the derived equations consisted of evaluation of PBD versus BD results in the other samples of subjects. Such results included calculation of constant error (mean difference), bivariate correlation (r), standard error of estimate ($SEE = SD\sqrt{1 - r^2}\sqrt{(n - 1)/(n - 2)}$), and total error based on $\sqrt{[\Sigma(PBD-BD)^2/n]}$. Distribution characteristics were also assessed by comparison of standard deviations (SD) of the PBD and BD scores for each sample.

Results

Descriptive characteristics of the validation and cross-validation samples are presented in Table 1. Within both the male and the female samples, the cross-validation groups were slightly greater in relative fat levels and skinfold thicknesses than the validation groups. Among all samples, the subjects were primarily white (92 to 97% of sample) and ranged in age from 14 to 19 yrs for the males and from 11 to 19 yrs for the females.

Factor analyses of anthropometric variables yielded results similar to those of normal adult populations reported by Jackson and Pollock (1976). In this regard, skinfolds were shown to measure a common factor related to body fatness, with selected circumferences being associated with a second fat-related factor. However, within the present samples these circumferences consisted of only the abdomen 1 measure for the males, while for the females both the abdomen 1 and thigh measures were selected. Subsequent forward-stepping regression analyses employing the above measures revealed that these circumferences did not significantly increase the variance accounted for in BD after entry of the sum of SF measures. Therefore the final prediction equations were limited to the use of the sum of SF measures as the only independent variables.

Table 1

Physical Characteristics of Samples[a]

Variable	Males Validation	Males Cross-validation	Females Validation	Females Cross-validation
n	141	66	133	46
Age (yr)	17.43 ± 0.96	16.60 ± 0.82	16.51 ± 1.39	16.82 ± 1.20
Height (cm)	176.52 ± 8.60	171.24 ± 6.84	166.02 ± 7.26	168.28 ± 7.90
Weight (kg)	67.45 ± 11.30	63.24 ± 10.33	54.51 ± 7.93	58.98 ± 10.42
Body density ($g \cdot ml^{-1}$)	1.0798 ± 0.0096	1.0726 ± 0.0112	1.0661 ± 0.0105	1.0599 ± 0.0103
Relative fat (%)	9.04 ± 3.84	11.89 ± 4.46	14.51 ± 4.27	17.02 ± 4.24
Skinfolds (mm)				
Triceps	7.80 ± 2.84	9.57 ± 3.00	10.88 ± 3.29	13.08 ± 3.49
Scapula	8.76 ± 2.48	9.40 ± 2.46	8.26 ± 2.63	9.38 ± 3.16
Midaxillary	6.88 ± 2.76	8.88 ± 3.40	8.72 ± 3.16	9.09 ± 3.68
Supra-iliac	9.20 ± 4.06	12.61 ± 4.50	9.72 ± 3.84	14.37 ± 5.06
Abdominal	10.02 ± 4.18	13.14 ± 4.56	10.69 ± 3.70	14.03 ± 5.40
Thigh	8.53 ± 2.40	8.88 ± 2.33	12.62 ± 2.67	14.97 ± 4.26
Calf	7.85 ± 2.67	7.54 ± 1.42	10.56 ± 2.51	10.22 ± 3.79
Sum of seven	59.08 ± 18.47	70.04 ± 19.48	71.49 ± 18.62	85.11 ± 24.46
Sum of three[b]	23.44 ± 7.56	27.82 ± 8.28	28.85 ± 8.88	36.82 ± 10.56

[a]Values are $\bar{X}$ ± SD.

[b]Sum of three SF for males is triceps + scapula + midaxillary and for females is triceps + scapula + supra-iliac.

Table 2

Equations Estimating Body Density

Equation	R	SEE
Males		
$BD = 1.1091 - 0.00052\ (\Sigma_7 SF) + 0.00000032\ (\Sigma_7 SF)^2$	0.82	0.0055
$BD = 1.1136 - 0.00154\ (\Sigma_3 SF) + 0.00000516\ (\Sigma_3 SF)^2$	0.81	0.0056
Females		
$BD = 1.1046 - 0.00059\ (\Sigma_7 SF) + 0.00000060\ (\Sigma_7 SF)^2$	0.82	0.0060
$BD = 1.0987 - 0.00122\ (\Sigma_3 SF) + 0.00000263\ (\Sigma_3 SF)^2$	0.82	0.0060

Key: $\Sigma_7 SF$ = Sum of triceps, scapula, midaxillary, supra-iliac, abdominal, thigh, and calf skinfolds.
$\Sigma_3 SF$ (for males) = Sum of triceps, scapula, and midaxillary skinfolds.
$\Sigma_3 SF$ (for females) = Sum of triceps, scapula, and supra-iliac skinfolds.

Within both the male and female samples, polynomial analyses revealed that the relations between BD and the sums of SF measures were quadratic ($p < 0.05$), with corresponding increases in R^2 of 0.01 or greater when compared to linear models. The resultant equations are presented in Table 2. Among either the male or female samples, the equations employing the sum of three SF demonstrated accuracy of prediction (SEE) similar to that of the equations employing the sum of seven SF. For the males these SEE values were equivalent to 2.17 to 2.21% fat, while for the females they were equivalent to 2.43% fat.

The results of the cross-validation of the equations on independent samples of subjects are presented in Table 3. For both the males and females, the equations employing the sum of seven SF demonstrated slightly better results than those of the equations using the sum of three SF. Analysis of the results among the males revealed validity coefficients of high magnitude with relatively low values for the expressions of error. Converted to units of relative fat, the constant error of the two male equations ranged from 0.60 to 0.80% fat and SEE ranged from 2.24 to 2.32% fat, with total error (the combined effect of constant error and SEE) equivalent to 2.28 to 2.44% fat. The results among the females also

Table 3

Cross-validation of Equations Estimating Body Density[a]

Equation	Constant Error	r	SEE	Total Error
Males:				
Σ_7SF	0.0015	0.87	0.0056	0.0057
Σ_3SF	0.0020	0.86	0.0058	0.0061
Females:				
Σ_7SF	−0.0004	0.83	0.0058	0.0058
Σ_3SF	−0.0022	0.82	0.0060	0.0063

[a]Error scores are $g \cdot ml^{-1}$.

demonstrated relatively high levels of validity and low error scores. In equivalent units of relative fat, the constant error ranged from 0.16 to 0.90% fat, SEE ranged from 2.37 to 2.45% fat, and total error ranged from 2.37 to 2.58% fat for the sum of seven SF and sum of three SF equations, respectively.

Within all samples, error scores were independent of age effects. Basing individual error on delta scores (PBD-BD), correlations between age and delta values ranged from $r = -0.14$ to 0.12 among the male and female groups.

As a further evaluation of the accuracy of the equations, the standard deviations of the PBD scores were compared to those of the BD scores. As Table 4 reveals, within all groups the standard deviations of the predicted scores were similar to those of the actual scores. These results

Table 4

Standard Deviations of Actual and Predicted Body Density Scores[a]

	Males		Females	
	Validation	Cross-validation	Validation	Cross-validation
Actual score SD	0.0096	0.0112	0.0105	0.0103
Predicted score SD				
Σ_7SF	0.0087	0.0092	0.0092	0.0113
Σ_3SF	0.0092	0.0101	0.0093	0.0105

[a]Values are $g \cdot ml^{-1}$.

indicate that the equations were effective in yielding group distribution characteristics equivalent to those resulting from the original BD scores.

Discussion

The results of this study reveal that the sum of three or seven skinfold measures can be used to accurately estimate the body density of either adolescent male or female athletes. Although the original derivations of these equations were based on samples that were extremely well-conditioned and highly proficient in their respective competitive activities, the cross-validation results indicated that these equations may also be equally well applied to groups typical of most adolescent athletes.

The magnitude of error demonstrated by these equations compares favorably to that of other equations predicting body density. In this regard, Lohman (1981) has shown that for most general populations SEE values range from 0.0070 to 0.0108 $g \cdot ml^{-1}$, while in more specific populations (such as athletes) SEE values may be as low as 0.0060 $g \cdot ml^{-1}$. Therefore, the SEE values observed in the present study approximate the lower limits of error that would be expected for estimation of BD in a sample of this nature.

The results of the polynomial analyses further confirm previous findings that relations between sums of SF measures and BD scores are curvilinear (Allen et al. 1956; Durnin and Wormersley, 1974; Jackson and Pollock, 1978). As Jackson and Pollock (1978) have previously noted, description of the relation between sum of SF measures and BD as a quadratic function reduces the error in predictions of extreme BD values. The impact of such error becomes apparent when equations derived from other populations, differing substantially in BD distributions, are cross-validated on lean young athletes. Specifically, in a previous study (Thorland et al. 1984) it was shown that when linear or log-based SF equations predicting BD for general populations of adolescents (Durnin and Wormersley, 1974; Parizkova, 1961) were applied to the validation samples used in the present study, total error scores ranged from 0.0113 to 0.0277 $g \cdot ml^{-1}$ (4.48 to 11.14% fat) for the males and from 0.0143 to 0.0214 $g \cdot ml^{-1}$ (5.83 to 8.78% fat) for the females. Yet, quadratic functions of SF measures (Jackson and Pollock, 1978; Jackson et al. 1980), derived from adult populations, revealed substantially lower total error levels when used to predict BD in these young athletes; being as low as 0.0076 $g \cdot ml^{-1}$ (3.00% fat) for the males and 0.0066 $g \cdot ml^{-1}$ (2.67% fat) for the females. Therefore, the lack of substantial increases in error for the prediction of BD in the cross-validation groups of the present study further reflects the apparent stability of quadratic relationships between sum of SF measures and BD across various samples.

While the results of this study provide support for the use of the new equations for estimation of BD in adolescent athletes, some limitations to general applications are warranted. Although total error was relatively low and ranged from 0.0067 to 0.0069 $g{\cdot}ml^{-1}$ for black males and was 0.0059 $g{\cdot}ml^{-1}$ for black females, the limited sampling of such subjects suggests the need for additional study with larger groups. Also, it remains unknown whether these equations would provide high levels of accuracy if applied to estimation of BD in lean but non-athletic adolescents or to general populations of this age group which display greater variance in BD. Underlying this is the question of whether the relationship between body density and the sums of skinfold measures seen in these young athletes is unique or simply at the extreme of a bivariate distribution described by a function common to many other groups in this age range.

The equations derived in this investigation represent methods by which the body composition characteristics of young athletes may be estimated in the field. With appropriate care in the means by which skinfold measures are taken, utilization of these equations may yield estimates of body density at a level of accuracy appropriate for general screening purposes consistent with athletic training practices or for profiling group characteristics.

Received: 12 May 1983; revision recieved: 13 October 1983.

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