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Skinfold Equations for Estimation of Body Fatness in Children and Youth

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Abstract The purpose of this study was to assess the predictability of body fatness as determined by three separate approaches. (1) body density from hydrostatic weighing and functional residual volume alone (PFD); (2) body density and water (PFDW); (3) body density, water and bone mineral (PFDWB). Bone mineral was estimated from radius and ulna measurements using photon absorptiometry, and total body water was estimated using deuterium oxide dilution. Nine skinfolds were taken with a Harpenden caliper. A 4 × 2 × 2 factorial plan was used representing four maturation groups (based on secondary sex characteristics) males and females, black and white subjects. The sample consisted of 310 subjects children and adults ranging in age from 8–29 years. In the prepubescent and pubescent groups of children, systematic differences were found among methods with the PFD alone producing higher mean density values than the other two estimates.

Constants were fitted by the least squares method in a step down multiple regression analysis to determine which skinfold measurements most accurately predicted PFDWB. The systematic effects of racial group, sex, and maturation were also included in the analysis. The R^2 and SEE from sum of triceps and calf and sum of triceps and calf squared plus design variables in prepubescent group were substantially lower for each of the three PFD estimates compared to the other three groups. When PF estimate was determined from PFDWB rather than PFD alone the R^2 increased from 62% to 77% and the SEE dropped from 4.5 to 3.9%, lending support to the concept that constants used to estimate fat in adults tend to overestimate body fatness in children. Curvilinear equations for the prediction of PFDWB are presented for triceps and subscapular skinfolds and linear equations for triceps and calf skinfolds taking into account the effects of maturation level, race and sex. These equations may provide more accurate estimates of PF than those currently available, since they take into consideration the use of a multicomponent approach to body composition and account for the chemical immaturity of children.

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The accurate estimation of body fatness from skinfolds in children and youth is limited by several problems which have not been adequately resolved (Lohman et al. 1984b; Lohman 1986; Boileau et al. 1985; Boileau et al. 1988; Mukherjee and Roche 1984; Forbes 1972, 1978). First, there are several groups of children for which equations have been developed (Parizkova 1961a; Young et al. 1968; Lohman et al. 1984b; Harsha et al. 1978; Boileau et al. 1981, 1985). These equations, however, have not been cross-validated on other samples of children such as those who are obese or highly active, or children at different maturational levels. A second problem limiting the accurate estimation of body fatness from skinfolds is that children are chemically immature, which means that equations developed on prepubescent children which use conversion constants derived from adult samples may overestimate body fatness by 3–6% fat and underestimate lean body weight (Lohman et al. 1984b).

A third complication which occurs in estimating the body fatness of children and youth is that there is a change in the chemical composition of the fat-free body (FFB) as the child passes through puberty. Thus, estimates of body fatness may reflect the changing FFB composition rather than change in actual fat content. An example of this problem can be seen from the data presented by Harsha et al. (1978). Equations based on a 6 to 16 year old population are applicable to neither the 6 to 9 year old nor to the 14 to 16 year old populations. To solve this difficulty, estimates of body fatness need to be developed using a multicomponent approach to body composition measurement rather than the traditional two-component model.

The purpose of this study was to assess the predictability of body fatness as determined by three separate approaches: (1) body density from hydrostatic weighing and functional residual volume alone (D); (2) body density and water (DW); and (3) body density, water and bone mineral (DWB). The hypothesis for the study was that improved estimates of percent fat can be achieved in children and youth when total body water and bone mineral in addition to body density, are taken into account.

Materials and Methods

The 310 subjects in this study included four maturation groups of black and white males and females arranged in 4×2×2 factorial plan. The study was conducted in Illinois (182) and replicated in Arizona (128). There were sixty-six prepubescent children (50 boys and 16 girls); fifty-nine pubescent children (30 boys and 29 females); 117 postpubescent (58 males and 59 females); and 68 adults (36 males and 32 females). The maturational level of the subjects was assessed by the Tanner Scale (1962) of puberral srage development to classify each subject as prepubescent (stages 1 and 2), pubescent (stage 3), postpubescent (stages 4 and 5) or adult (stage 6 and higher). The Illinois sample (IL) was

recruited from two senior high schools, two junior high schools and several elementary schools, from participants in a Sports Fitness Program, and from the University of Illinois. The Arizona sample (AZ) was recruited from elemenrary, junior bigh and seniot high schools of two school disrricts as well as the University of Arizona. The project was approved by both rhe University of Illinois and University of Arizona Institutional Review Boards, and a written informed consent was obrained for each subject and from rhe guardian of each minor child prior to participation. The srudy has been previously described (Slaughter et al. 1984; Boileau et al. 1984; Lohman et al. 1984a).

Body densiry was measured by underwarer weighing with the body volume estimate from underwarer weight corrected for pulmonary residual volume (Boileau et al. 1981). For the Illinois sample residual volume was derermined at the time of underwater weighing; for the Arizona sample residual volume was determined on land. The differences between means for body density between Arizona and Illinois was .003 g/cc for all groups wirh Arizona having higher body density values in all cases. In spite of the group mean differences between the two samples the pattern of change in the relationship of skinfold to body density between maturation levels was similar. Therefore the data for both samples were combined for future analysis.

Body water was measured by deuterium oxide dilution using a modification of the metbod of Byers (1979) and described by Boileau et al. (1984). Bone mineral measurements were made on both rhe right and left radius and ulna using photon absorptiometry (Cameron and Sorenson 1963) a Norland Cameron Bone Mineral Analyzer as described by Lohman et al. (1984a).

Nine skinfold measurements (triceps, biceps, subscapula, midaxillary, suprailiac, anterior suprailiac, abdominal, mid-thigh and medial calf) were taken on the right side of the body by a Harpenden caliper and recorded to the nearesr 0.1 mm. Three complete sets of measurement were taken consecutively. The mean of the three measurements was used as the representative value for each site. The specific sites are described by Slaughrer et al. (1984). The equations used for the prediction of percenr body fat were:

(1) PFD (Siri, 1961) = [(4.95/BD) − 4.50] × 100
where BD = body density (g/cc)

(2) PFDW (modificarion of Siri, 1961) =
[(2.057/BD) − .800 (PWBWT) − 1.286] × 100
where PWBWT = Total Body Water (L)/Body Weighr (kg)

(3) PFDWB (Boileau et al., 1985) =
[(2.747/BD) − .727 (PWBWT) + 1.146 × MW − 2.053] × 100
where MW = Total Body Mineral (kg)/Body Weight (kg)
Total Body Mineral = Mineral Conrent of Fat-Free Body × Fat-Free Body Weight,
and Mineral Content of FFB = 2.1 × Radius Bone Mineral + 4.05
and FFB = Body Weight − (PFDWB × Body Weight)

The development and derivation of these formulas are described by Boileau et al. (1985) and Lohman (1986).

Constants were fitted by the least-squares method in a multiple regression analysis to determine which skinfold measures most accurately predicted PF from each of the three approaches. The systematic effect of racial group, sex, maturation and sample was also included in the analysis (design variables). The recommended equations for the prediction of PFDWB from triceps and subscapular skinfolds were cross-validated on samples from the literature to test for external validity.

Results

The physical characteristics of subjects in this sample (Table 1) are similar to those found in the literature for children of equivalent ages (Parizkova 1961a; 1961b; Boileau et al. 1981; Young et al. 1968); for youth (Parizkova 1961a; Young et al. 1968; Katch and Michael 1969); and for adults (Wilmore and Behnke 1969; 1970; Lohman et al. 1978; Katch and McArdle 1973).

The sum of triceps and subscapular skinfolds (mm) are also reported in Table 1. For the 8–11 year old males, the mean triceps and subscapular measurements were 1 to 3 mm larger at a given age than the data from a National Health Survey (Johnston et al. 1972; 1974). For other age groups of males and females the mean of the sum of triceps and subscapular was within 1 mm of the National Health Survey for each age group.

The PFD (percent fat from body density), the PFDW (percent fat from body density and water) and PFDWB (percent fat from density, water and bone) for each of the maturational groups are presented in Table 2. In the prepubescent male group, the PFD was 23.5, 20.4 PFDW and 19.0 PFDWB. In the pubescent male group the PFD was 20.7, compared to 18.6, PFDW, and 17.3 PFDWB. In the pubescent female group, PFD was 27.9, 24.8 PFDW and 23.7 PFDWB. In the postpubescent and adult groups the three estimates of percent fat for both males and females were found to be quite similar, suggesting that the FFB composition had stabilized (Boileau et al. 1985; Lohman et al. 1984b).

Constants were fitted by the least squares method in a step down multiple regression analysis to determine which skinfold measurements most accurately predicted PFD, PFDW, and PFDWB (Table 3). The systematic effects of racial group, sex, and maturation were also included in the analysis (design variables). In general two skinfolds were satisfactory in predicting body fatness.

The coefficients of determination and standard errors of estimate from the sum of triceps and calf and the sum of triceps and calf squared plus the design variables in the prepubescent group were substantially lower for each of the three

Table 1. Physical Characteristics of Subjects by Maturational Groupings (N = 310)

Maturational Level	Sex	Age (yr)		Height (cm)		Weight (kg)		Body Density (g/cc)		Sum of Triceps and Subscapular (mm)		Sum of Triceps and Calf (mm)	
		$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD
Prepubescent N = 66	Male (50)	9.8	1.3	139.2	8.3	33.4	7.0	1.049	.016	17.7	6.9	20.7	8.5
	Female (16)	10.0	1.0	140.6	7.3	34.6	6.1	1.036	.012	22.0	5.3	26.7	7.0
Pubescent N = 59	Male (30)	12.2	1.4	154.4	10.0	44.9	8.0	1.052	.019	19.5	7.5	22.8	12.6
	Female (29)	11.4	1.9	149.8	9.2	43.2	8.3	1.036	.016	25.7	9.8	28.8	10.4
Postpubescent N = 117	Male (58)	15.8	1.6	172.2	8.0	64.0	11.2	1.065	.014	17.7	7.2	17.4	7.4
	Female (59)	15.3	1.6	167.7	6.5	56.6	8.2	1.041	.013	26.8	9.2	29.4	9.0
Adult N = 68	Male (36)	23.1	2.6	177.1	6.7	74.6	13.8	1.063	.014	20.2	9.9	17.0	9.2
	Female (32)	22.5	2.9	164.0	8.0	60.3	9.0	1.038	.013	28.9	8.8	29.7	7.9

Table 2. Means and Standard Deviations of Percent Fat By Maturational Groupings (N = 310)

Maturational Level	Sex	Percent Fat from Density[a] $\bar{X}$	Percent Fat from Density[a] SD	Percent Fat from Density[b] and Water $\bar{X}$	Percent Fat from Density[b] and Water SD	Percent Fat from Density Water and Bone Mineral[c] $\bar{X}$	Percent Fat from Density Water and Bone Mineral[c] SD
Prepubescent N = 66	Male (50)	23.5	7.4	20.4	8.2	19.0	8.1
	Female (16)	27.8	5.4	24.4	6.8	23.2	6.6
Pubescent N = 59	Male (30)	20.7	8.4	18.6	7.2	17.3	7.3
	Female (29)	27.9	7.1	24.8	6.8	23.7	6.8
Postpubescent N = 117	Male (58)	14.7	6.4	15.1	6.4	14.0	6.2
	Female (59)	25.4	5.8	24.7	6.1	23.6	6.0
Adult N = 68	Male (36)	15.8	6.4	17.2	7.8	16.4	7.4
	Female (32)	27.0	6.1	27.2	6.4	26.2	6.4

[a]PFD = [(4.95/BD) − 4.50] × 100
[b]PPFDW = [(2.057/BD) − .800 (PWBWT) − 1.286] × 100
[c]PFDWB = [(2.747/BD) − .727 (PWBWT) + 1.146BMW − 2.0503] × 100

estimates of PF compared to the orher three maturational groupings. However, when the PF estimate was determined from DWB rather than D alone the amount of variance accounred for increased from 62% to 77%. In addition, rhe SEE dropped from 4.5 to 3.9%. The same findings were seen for the sum of triceps and subscapular esrimates.

In the pubescent group, the triceps and calf combination yielded a coefficients of determination of 72% for PFD alone with a SEE of 4.5%; and a coefficienr of determination of 80% for rhe PFDWB with a SEE of 3.4%. For the triceps and subscapular combination, the coefficient of determination for the estimate of PFD was 74%, with a SEE of 4.3%; and for the PFDWB, 82% with a SEE of 3.2%. In borh the postpuhescent and adult groups the estimates of PF from the three methods were similar.

Table 3. Prediction of Percent Fat Using Three Different Approaches from Sum of Two Skinfolds[a]

		Prepubescent		Pubescent		Postpubescent		Adult		Total Sample	
Independent	*Dependent*	R^2x	SEE	R^2x	SEE	R^2x	SEE	R^2x	SEE	R^2x	SEE
Sum Triceps + Calf plus design variables[b,c]	PFD[d]	62	4.5	72	4.5	81	3.5	82	3.6	77	3.9
	PFDW[e]	77	3.9	77	3.6	74	4.0	77	4.2	75	4.0
	PFDWB[f]	77	3.9	80	3.4	77	3.7	79	3.9	78	3.8
Sum Triceps + Subscapular plus design variables[b]	PFD[d]	66	4.3	74	4.3	74	4.1	82	3.5	75	4.1
	PFDW[e]	80	3.7	80	3.4	73	4.1	77	4.2	76	4.0
	PFDWB[b]	80	3.6	82	3.2	76	3.8	80	3.8	78	3.7

[a]N = 66 prepubescent, 59 pubescent, 117 postpubescent and 68 adult
[b]Design variables include: maturation (linear, quadratic and cubic, sex, race and sample)
[c]Also sum of triceps + calf squared was included in the analysis.
[d]PFD = [(4.95/BD) − 4.50] × 100
[e]PFDW = [(2.057/BD) − .800 (PWBWT) − 1.286] × 100
[f]PFDWB = [(2.747/BD) − .727 (PWBWT) + 1.146 MW − 2.0503] × 100

Another method of studying whether the relationship between skinfolds and percent fat improves when bone and water are taken into account is to examine the F ratios of the regression coefficients for the design variables of sample, sex, race, sex × race, and maturation (linear, quadratic and cubic effects) in addition to the sum of skinfolds for each of the methods of estimating percent fat (Table 4). When the sum of triceps and calf skinfolds are used to predict PFD, six of the regression coefficients (besides skinfolds) are significant (sample, sex, sex × race, and the three effects of maturation). However, when estimating PFDWB, only two of the regression coefficients in addition to skinfolds remain significant. When the sum of triceps and subscapular skinfolds are used to predict PFD, all seven of the regression coefficients (besides skinfolds) are significant (sample, sex, race, sex × race, and the three effects of maturation). Again, when estimating PFDWB, only four of the regression coefficients other than the two skinfold sites remain significant.

The effect of maturation on the change in the skinfold-body fat relationship was found to be larger for males than females (Table 5). The difference of 3% fat (DWB) between the prepubescent male and the adult male contrasted with rhe 1% fat (DWB) difference for females for a given triceps plus subscapulat thickness. Because of the smaller sample size in the prepubescent female group, the change in the skinfold to percent fat relationship was not as precisely estimated for females as for males. For the triceps and calf combination a 1% change over maturation groups was found, with PF for a given skinfold lower in

Table 4. Prediction of Percent Fat from Sum of Two Skinfolds and Design Variables[a]

	PFD[c]		PFDWB[d]		PFDWB[e]	
	Σ *Triceps + Calf (mm)*	Σ *Triceps + Subscapular (mm)*	Σ *Triceps + Calf (mm)*	Σ *Triceps + Subscapular (mm)*	Σ *Triceps + Calf (mm)*	Σ *Triceps + Subscapular (mm)*
Sum of two skinfolds	54.5*[b]	76.9*	35.0*	102.2*	42.0*	117.1*
Sum squared	6.6	18.3*	.6	25.4*	1.0	29.0*
Maturation, linear	27.7*	84.2*	.1	17.2*	1.1	13.4*
Maturation, quad	9.2*	5.7*	9.8*	6.5*	11.4*	7.6*
Maturation, cubic	5.5*	5.1*	.9	.7	1.1	.9
Sex	15.5*	48.9*	3.4	18.1*	3.4	20.1*
Race	.2	12.9*	.15	10.9*	.0	12.3*
Sex × Race	10.2*	5.4*	2.6	.3	4.2*	.8
Sample	9.3*	18.4*	.16	.6	.01	2.0

[a]N = 310
[b]*p < .05
[c]PFD = [(4.95/BD) − 4.50] × 100
[d]PFDW = [(2.057/BD) − 4.50] × 100
[e]PFDWB = [(2.747/BD) − .727 (PWBWT) + 1.146 (MW) − 2.0503] × 100

the pubescent and postpubescent groups than in the prepubescent and adult groups. Because differences among maturation groups were small, it was unnecessary to have separate equations for each maturational group (Table 6).

The relation of sum of skinfolds to PFDWB was not significantly affected by racial group, except for males when triceps and subscapular was used. For a given skinfold thickness, black males are 1.9% less fat than white males (Table 5). For females using both combinations of skinfolds, and for the triceps plus calf combination for males no significant differences between racial groups were found and because the difference was less than 1% between groups, no adjustments were made for race in the equations in Table 6.

Based on the results of Tables 4 and 5, quadratic equations for the prediction of PFDWB are provided for triceps and subscapular skinfolds, and linear equations for triceps and calf skinfolds and these equations are found in Table 6. No change in intercept is needed for children or young adults because small differences in maturation were found for triceps and calf in both sexes and for triceps and subscapular in females. For males, the sum of triceps and subscapular

Table 5. Adjusted Means for Percent Fat (DWB) Holding Skinfolds Constant Within Sex, Race and Maturation

	Σ *Triceps plus Subscapular*[a,b]		Σ *Triceps plus Calf*	
Group	*Black*	*White*	*Black*	*White*
Males				
Prepubescent	16.9	18.8	16.1	16.8
Pubescent	15.3	17.1	14.9	15.6
Postpubescent	13.4	15.3	14.7	15.4
Adult	13.9	15.8	17.0	17.7
Females				
Prepubescent	24.5	25.6	24.9	23.9
Pubescent	23.5	24.5	24.5	23.5
Postpubescent	22.5	23.5	24.0	23.0
Adult	23.5	24.6	25.9	24.9

[a]Significant effects of race was found only for males with the triceps + subscapular combinations, p = < 05
[b]Significant effect of maturation was found within group and for both skinfold combinations: p = < .05

Table 6. Recommended Equations for Prediction of PF from Sum of Two Skinfolds

Skinfolds (mm)	*Regression Coefficients (Σ 2)*	*Regression Coefficients (Σ 2)2*	*Intercept*[a,b]	*SEE, PFDWB*
Triceps and Subscapular[c]				
Males	1.21	−.008	1[b]	3.6
Females	1.33	−.013	−2.5	3.9
Triceps and Calf (mm)				
Males	.735	—	1.0	3.8
Females	.610	—	5.1	3.8

[a]All intercepts were increased in all groups by 1.4% because of lower mean body density (.003 g/cc) in this validation sample as compared to body densities adjusted to the same age and skinfolds of other children and youth (Harsha et al., 1978; Boileau et al., 1981; Mukherjee & Roche, 1984 and Lussier and Buskirk, 1977.
[b]Intercept in males varies for maturation level and racial group as follows: For black males: prepubescent −3.5; pubescent −5.2; postpubescent and adult −6.8. For white males: prepubescent, −1.7; pubescent, −3.4; postpubescent and adult, −5.5.
[c]Equations are linear for sum of skinfolds greater than 35 mm = for males, PFDWB = .783 (triceps + subscapular) + 1.6. For females, PFDWB = .546 (triceps + subscapular) + 9.7.

relationship with PFDWB does vary with maturation, and this is shown in the footnote of Table 6.

All intercepts in Table 6 were increased by 1.4% because of the lower body density in the present sample as compared to the mean of four other samples in the literature. In these samples when age and skinfolds (triceps and subscapular) were held constant, a density difference of .003% was found. For example, a skinfold thickness of 18 mm for 10 year old males corresponds to a density of 1.050 g/cc in the other samples as compared to 1.047 g/cc in the present sample.

Discussion

Recent studies have shown the need to examine the application of present body composition techniques to the estimation of body fatness in children and youth (Boileau et al. 1985; Lohman 1986; Boileau et al. 1988). For the most part, estimates of percent fat have been based on the assumption that the young child is near chemical maturity and that the constants developed for adults using the two-component system (Lohman 1986) can be applied to children.

Slaughter et al. (1984) found that significant changes ($p < .05$) in the relation of skinfolds to density occur from prepubescence to pubescence and from pubescence to postpubescence. These results have important implications for estimating body fatness in children from anthropometry-density relationships, since adult anthropometric equations underestimate the body density of children and thus overestimate body fatness.

To study this problem further, PF was estimated using three approaches: from density alone (PFD), from density and water (PFDW) and from density, water and bone (PFDWB). In the prepubescent and pubescent groups of children, systematic differences were found among methods, with the PF from density alone producing higher values (Table 2). This fact lends support to the concept that constants used to estimate fat in adults tend to overestimate body fatness in children. The PFDWB estimates in the postpubescent and adult groups are quite similar, indicating that the FFB may have approached chemical maturity. Also, in the prepubescent and pubescent groups, PF estimated from density, water and bone can be more closely predicted from skinfolds than PF from density alone. In the postpubescent and adult groups, the amount of variance accounted for is similar for all three methods.

This study attempts to correct for three major problems evident in past research which have used anthropometric dimensions to provide estimates of body fatness in children and youth. These problems are outlined in a recent review by Lohman (1986). When the PFD is estimated, six out of the seven of the design variables are significant [maturation (linear, quadratic and cubic), sex, sex × race and sample] in addition to the sum of triceps and calf skinfold. When triceps and subscapular skinfolds are used to predict PFD all seven design variables [maturation (linear, quadratic and cubic), sex, race, sex × race, and sample] are significant along with the skinfolds. However, when estimating PFDWB, only two of the design variables remain significant when using triceps and calf, compared to four from triceps and subscapular. In addition, the amount of variance accounted for is increased and the SEE is decreased (Table 3). These results strongly suggest that changes in the density of the fat-free body (FFB_d) alter the apparent relation of percent fat to skinfolds. When changes in the fat-free body density are accounted for by estimating PFDWB, the effects of maturation and racial groups are reduced (Table 3).

The recommended equations for predicting percent fat from skinfold equations for children and youth may provide more accurate estimates of PF than those currently available (Table 6), since they take into consideration the use of a multicomponent approach to body composition and account for the chemical immaturity of children. The skinfold equations shown below are recommended for predicting body fat in children 8–18 years of age and they are as follows:

For Triceps and Calf

Males: PFDWB = .735 (triceps + calf) + 1.0
Females: PFDWB = .610 (triceps + calf) + 5.1

For Triceps and Subscapular

Prepubescent White Males: PFDWB = 1.21 (triceps + subscapular) − .008 (triceps + subscapular)^2 − 1.7
Prepubescent Black Males: PFDWB = 1.21 (triceps + subscapular) − .008 (triceps + subscapular)^2 − 3.2
Pubescent White Males: PFDWB = 1.21 (triceps + subscapular − .008 (triceps + subscapular)^2 − 3.4
Pubescent Black Males: PFDWB = 1.21 (triceps + subscapular) − .008 (triceps + subscapular)^2 − 5.2
Postpubescent White Males: PFDWB = 1.21 (triceps + subscapular) − .008 (triceps + subscapular)^2 − 5.5
Postpubescent Black Males: PFDWB = 1.21 (triceps + subscapular) − .008 (triceps + subscapular)^2 − 6.8
All Females: PFDWB = 1.33 (triceps + subscapular) − .013 (triceps + subscapular)^2 − 2.5

For a sum of tricep and subscapular greater than 35 mm, the following equation should be applied.

All Males PFDWB = .783 (triceps + subscapular) + 1.6
All Females PFDWB = .546 (triceps + subscapular) + 9.7

Table 7. Cross-Validation of New Equations for Triceps and Subscapular Skinfolds

	Mean Age yrs	Density g/cc Body	FFB	Two Skfs. (mm)	PFD[a]	PF[a,b]	Authors
				Children			
Males	9.9	1.054	1.084	18.3	13.9	17.2	Boileau et al. (1981)
	11.7	1.046	1.087	23.0	19.0	19.6	Harsha et al. (1978)
	11.6	1.058	1.087	16.1	13.3	13.4	Mukherjee & Roche (1984)
Females	12.0	1.034	1.086	29.5	24.3	25.4	Harsha et al. (1978)
	11.9	1.040	1.086	26.4	21.4	23.6	Mukherjee & Roche (1984)
	[c]	1.0370	1.082	22.0	21.9	20.5	Young et al. (1968)
	[d]	1.0372	1.092	26.4	24.6	24.6	Young et al. (1968)

Sample	Age Range (yrs)	Density Body g/cc	Two Skinfolds (mm)	PFD[a]	PF[a,b]	Authors
			Adults			
Males	19.3	1.065	26.7	15.3	20.0	Katch & McArdle (1973)
	18–22	1.068	27.5	13.4	20.6	Pollock et al. (1976)
	18–26	1.075	16.9	10.9	11.6	Sloan (1967)
	24	1.064	21.8	15.2	16.0	Durnin & Womersley (1974)
	22.0	1.066	22.0	14.6	16.1	Wilmore & Behnke (1969)
Females	20.3	1.039	40.4	25.6	30.0	Katch & McArdle (1973)
	18–22	1.043	34.1	24.8	27.7	Pollock et al. (1975)
	23	1.037	29.0	27.2	25.1	Durnin & Womersley (1974)
	21.4	1.041	26.0	25.7	23.3	Wilmore & Behnke (1970)

[a]PFD = [4.95/BD − 4.50] × 100
[b]Skinfold equations are found in Table 6
[c]Non-menarche girls
[d]Menarche girls

The new body fat equations are curvilinear for triceps and subscapular but not for the triceps and calf. This is explained by the curvilinear relation of subscapular skinfold and body density, as contrasted with the linear relation for the triceps skinfold and body density. The change in the tricep plus subscapular skinfold to the body fat relation (intercept change) with maturation is consistent with the findings of Baumgartner et al. (1986) who showed an increase in the relative thickness of trunk skinfolds when compared to extremity skinfolds in males but not females during adolescence. The adjustment in the intercept of the recommended equations appears to be needed because of the slightly lower density values (.003 g/cc) found for in the present sample under which the equation was derived. This should lead to improved cross-validation results.

Because many studies have reported mean triceps and subscapular skinfolds and body density, mean PF can be estimated using the new equations developed in Table 6 and compared with PF estimated from body density in other samples. If the new equations predict the fat content of the original sample, using the mean skinfolds of the original sample, then the new equations may have some external validity especially for individuals near the population mean. Comparing the fat contents by the two approaches in adults, general agreement is found for most samples (Table 7). In two samples where agreement is not found, i.e., Katch and McArdle (1973) and Pollock et al. (1975, 1976) for both male and female samples, the Lange caliper was used. Since the new equations were developed using the Harpenden skinfold caliper and since it has been shown that the Lange caliper produces higher readings than the Harpenden (Lohman et al. 1983) part of the observed differences may be associated with the higher skinfold reading of the Lange caliper.

Since in our previous work we have shown that the fat-free body density is lower in children one cannot use the original Siri's equation (1961) to estimate body fatness from body density. For the purpose of estimating percent fat for each of the three groups of children from the literature (Table 7) a fat-free body density value was assigned based on age (Lohman 1986). Thus the new equations appear to be estimating the body fat content in several samples of children and adults without a large systematic error. Further efforts to cross-validate these equations must employ a multicomponent body composition approach as well as a large sample size.

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