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Body composition of elite American athletes

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ABSTRACT

Five hundred twenty-eight male athletes participating in 26 Olympic events and 298 female athletes participating in 15 Olympic events underwent determination of body fat percentage (% fat) and lean body mass (LBM) via hydrostatic weighing and/or anthropometric methods. All groups of athletes were below the average values for % fat of college age men and women of 15% and 25%, respectively. In general, athletes involved in a sport where their body weight is supported, such as canoe and kayak (males, 13.0 ± 2.5%; females, 22.2 ± 4.6%) and swimming (males, 12.4 ± 3.7%; females 19.5 ± 2.8%), tended to have higher % fat values. Athletes involved in sports where a weight class has to be made to compete, such as boxing (males, 6.9 ± 1.6%) and wrestling (male, Junior World Freestyle 7.9 ± 2.7%), events such as the 100, 200, and 400 meters in athletes (male 100 and 200 meters, 6.5 ± 1.2%; female 100, 200 and 400 meters, 13.7 ± 3.6%) that are very anaerobic in nature and extremely aerobic events such as the marathon (males, 6.4 ± 1.3%) demonstrated lower % fat values. Athletes involved in sports where body size is a definite advantage, such as basketball (males, 84.1 ± 6.2 kg; females, 55.3 ± 4.9 kg) and volleyball (males, 75.0 ± 6.6 kg; females, 58.4 ± 4.5 kg) tended to have a larger LBM.

Percentage of body fat (% fat) and lean body mass (LBM) have become very popular terms among athletes and coaches in recent years. The body composition of athletes, especially elite athletes, has also received a great deal of attention from the scientific community. Tables 1 and 2 represent a brief overview of selected studies concerning the body composition of elite male and female athletes.

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The two most popular methods of determining body composition are anthropometric equations and hydrostatic or underwater weighing. The purposes of this study are to present body composition data of various groups of elite American athletes, determined either anthropometrically or via hydrostatic weighing methods, and to compare % fat values of groups of athletes determined both anthropometrically and hydrostatically.

MATERIALS AND METHODS

Five hundred twenty-eight elite male athletes, participating in 26 Olympic sports, and 298 elite female athletes, participating in 15 Olympic sports, underwent determination of body composition via hydrostatic and/or anthropometric means at the U.S. Olympic Training Center, Colorado Springs, CO. All of the athletes participating in this study were selected by their sport's national governing body to participate in a training camp conducted at the training center. These athletes, therefore, can be assumed to be elite American athletes for their particular sports and/or age group.

Percent fat of 10 and 8 groups of female and male athletes, respectively, was determined both hydrostatically and anthropometrically. A dependent t-test was utilized to determine if a significant difference ($P < 0.05$) existed between the % fat values determined via hydrostatic and anthropometric means.

Hydrostatic weighing

The Brozek[7] equations were used to predict % fat and LBM from body density determined hydrostatically. Residual volume was predicted from the vital capacity of the subject.[58] Vital capacity and actual body weight were determined immediately prior to the hydrostatic weighing procedure. Six hydrostatic weighings were performed on each subject, with the mean of the highest two trials being considered the actual hydrostatic weight in the calculation of % fat and LBM.

TABLE 1
Male athletes' body composition from selected studies

Sport	Reference	Caliber of athlete	No. in study	Method	Age (years)	Wt. (kg)	% Fat	LBM (kg)
Cross-country runners	5	Collegiate	12	H_2O[a]	—	64.6	9.9	58.2
	12	Collegiate	9	A[b]	18–23.2[c]	66.3	7.13	—
	33	Elite age group	8	A	10.5	31.9	15.8	26.8
Distance runners	3	—	3	H_2O	32.0	66.9	7.9	61.5
Long distance runners	41	Elite Finnish	8	A	26.2	66.2	8.4	60.9
Marathoner	13	National	114	A	26.1	64.2	7.8	—
Athletics	55	Jr. Olympic	24	H_2O	17.8	70.6	8.4	64.6
Sprints and hurdles								
Middle distance	55	Jr. Olympic	47	H_2O	17.7	62.9	7.3	58.3
800-Meter run	41	Elite Finnish	6	A	24.6	72.3	12.4	62.9
Jumps and vaults	55	Jr. Olympic	16	H_2O	17.6	69.2	8.5	63.3
Throws	55	Jr. Olympic	18	H_2O	17.5	87.3	13.9	74.9
Shot put	1	Olympic champion	2	A	—	111.4[d]	17.4[d]	91.9[d]
	14	National and international	5	H_2O	27.0	112.5	16.5	—
Discus throw	14	National and international	7	H_2O	28.3	104.7	16.4	—
Canoeing	41	Elite Finnish	8	A	23.7	79.6	12.4	68.9
Cyclists (road)	8	U.S. Nat. team	8	H_2O	—	67.1	8.8	—
	8	U.S. Jr. Nat. team	25	H_2O	—	68.6	10.3	—
Ice hockey	54	Collegiate	11	A	21.0	71.2	8.4	—
	41	Elite Finnish	13	A	22.5	77.3	13.0	65.3
Rowing								
Heavy weight	19	Elite U.S.	503	A	23.0	88.0	11.0	—
Light weight	19	Elite U.S.	120	A	21.0	71.0	8.5	—
Skiing								
Cross-country	22	U.S. Nat. team	7	H_2O	26.3[d]	73.2[d]	8.9[d]	66.8[d]
	46	U.S. Nat. team	11	H_2O	22.8	71.8	7.2	67.1
	41	Elite Finnish	17	A	25.6	69.3	10.2	60.3
	36	Collegiate	10	A	21.2	66.6	12.5	58.2
	23	U.S. Nat. team	10	A	22.7	73.2	7.9	67.7
Skiing (Alpine)	41	Elite Finnish	6	A	21.2	70.1	14.1	60.8
	23	U.S. Nat. team	12	A	21.8	75.5	10.2	67.7
Speed skating	41	Elite Finnish	6	A	21.0	76.5	11.4	65.7
Swimming (sprint)	4	Collegiate	24	H_2O	18–24	75.4	9.5[e]	—
Middle distance	4	Collegiate	24	H_2O	18–24	74.2	11.8[e]	—
	37	Collegiate	7	TB[f]	20.6	78.9	5.0	75.0
	51	Elite	13	H_2O	21.8	79.1	8.5	72.4
Volleyball	38	U.S. Nat. team	8	H_2O	26.1	85.5	12.0	76.5
Wrestling	40	'56 U.S. Olympic team	7	H_2O	—	80.2	14.0	66.7
Freestyle								
	45	Collegiate	35	H_2O	19.6	74.8	8.8	67.9
	18	U.S. Nat. team	9	A	27.0	75.7	9.8[g]	68.23
	35	Contenders for '72 Olympic team	—[h]	A	24.3	77.7	8.3	—
	28	Collegiate	19	H_2O	20.3	72.2	10.5	64.6
	52	All American	5	A	21.3	71.9	3.7	—
(44.5–60 kg)	26	High school	29	A	15.9	—	4.5	—
(60–71 kg)	26	High school	37	A	16.7	—	5.3	—
(76.4–94.5 kg)	26	High school	28	A	16.8	—	11.7	—
	53	H.S. State finalists	582	A	17.8	65.1	6.7[i]	—
	53	Average high school	834	A	15.9	64.7	10.2[i]	—

[a] Hydrostatic weighing.
[b] Anthropometric.
[c] Range.
[d] Calculated from given data.
[e] Calculated from given body density with Brozek equation.
[f] Total body water.
[g] Calculated from given LBM and total body weight.
[h] *N* less than 29.
[i] Calculated from given data with Sloan equations.

TABLE 2
Female athletes' body composition from selected studies

Sport	Reference	Caliber of athlete	No. in study	Method	Age (years)	Wt. (kg)	% Fat	LBM (kg)
Athletics	60	National and international	11	H_2O^a	32.4	57.2	15.2	48.1
Distant runners	61	U.S. national	28	H_2O	25.0	54.3	16.9	45.0
Middle distance	55	Jr. Olympic	41	H_2O	16.6	51.4	12.5	44.9
Sprinters and middle distance	61	U.S. national	4	H_2O	18.3	57.8	11.1	51.3
Sprinters (100–200 m)	32	Collegiate	24	A^b	20.1	57.0^a	19.2^a	—
Sprints and hurdles	55	Jr. Olympic	26	H_2O	16.7	56.4	13.4	48.8
Jumpers and hurdles	32	Collegiate	11	A	20.3	59.4^a	20.8^a	—
Jumps	55	Jr. Olympic	13	H_2O	17.4	57.1	12.9	49.7
Pentheletes	31	National and international	9	H_2O	21.5	65.4	11.0	58.2
Discus and javelin	32	Collegiate	11	A	21.1	70.8^c	24.9^c	—
Shot putters	32	Collegiate	9	A	21.5	78.0^a	28.0^a	—
Throwers	6	U.S. national	4	H_2O	16–23	78.6	23.9	58.9
	61	U.S. national	9	H_2O	18.8	80.8	27.0	58.9
	55	Jr. Olympic	16	H_2O	17.2	68.0	22.0	53.0
Basketball	19	Jr. Nat. team	12	A	18.0	66.8	20.7	—
	42	Collegiate	21	H_2O	19.1	62.6	20.8	49.5
Cylists (road)	8	U.S. Nat. team	7	H_2O	—	61.3	15.4	—
Gymnastics	44	Collegiate	14	H_2O	20.0	51.1	15.5	43.7
	43	Collegiate	44	H_2O	19.4	53.7	15.3	45.4
Rowers	19	Elite	40	A	23.0	68.0	14.0	—
Skiing								
Cross-country	41	Elite Finnish	5	A	24.3	59.1	21.8	47.0
	46	U.S. Nat. team '75	5	H_2O	23.5	56.9	16.1	48.6
Alpine	23	U.S. Nat. team	13	A	19.5	58.8	20.6	46.6
Swimmers	25	Collegiate	5	H_2O	—	60.3	23.2	—
	51	Czech. State repres. team	10	H_2O	19.5	63.9	19.2	51.6
Sprint	61	Collegiate	4	H_2O	—	57.1	14.6	48.7
Middle distance	61	Collegiate	7	H_2O	—	66.8	24.1	50.4
Distance	61	Collegiate	4	H_2O	—	60.9	17.1	50.4
Volleyball	34	Collegiate	34	A	—	64.2	19.0	52.1
	30	Collegiate	10	H_2O	20.5	61.0	19.5	49.1
	39	U.S. University Games team '79	14	H_2O	21.6	70.5	17.9	57.8

[a] Hydrostatic weighing.
[b] Anthropometric.
[c] Calculated from given figures.

The following series[7] of equations was utilized to determine the % fat and LBM via hydrostatic weighing:

$$BD = \frac{AB}{\frac{AB - HB}{WD} - RV}$$

$$\% \text{ fat} = \frac{(4.57 - 4.142)}{BD} \times 100$$

where LMB = AB − (AB × % fat), BD = body density, AB = actual body weight, HB = hydrostatically weighted body weight, WD = water density, and RV = residual lung volume.

Anthropometric determination

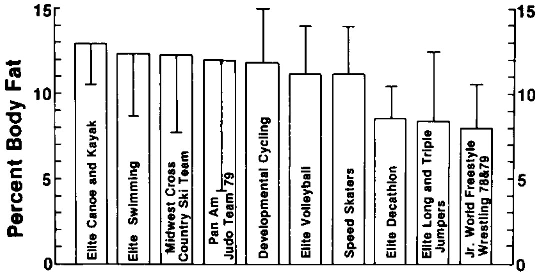
The Sloan[49] equations were utilized in the determination of body density for both males and females. Percent fat was then calculated utilizing the Brozek[7] equations. Experienced testers utilized a Lange skin fold caliper in the determination of all skin fold values. In men the skin fold sites measured were upper thigh and subscapular, and in women the suprailiac and triceps skin folds were determined. All skin folds were measured on the right side of the body and were determined as described by Behnke and Wilmore.[2]

The Sloan equation for men is: BD = 1.1043 − (0.00133 × thigh skin fold in mm) − (0.00131 × subscapular skin fold in mm). The Sloan Weir equation for women is BD = 1.0764 − (0.00081 × suprailiac skin fold in mm) − (0.00088 × triceps skin fold in mm).

RESULTS

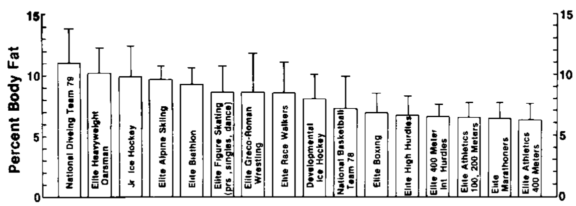
The % fat and LBM values determined via hydrostatic and anthropometric methods of the groups of male and female athletes are presented in Figures 1 through 4.

Percent fat values determined both hydrostatically and anthropometrically on groups of athletes are presented in Table 3. In 6 out of 10 groups of female athletes, there was a significant difference ($P < 0.05$) between the % fat values determined anthropometrically and hydrostatically. The Sloan anthropometric equation in all cases of female athletes



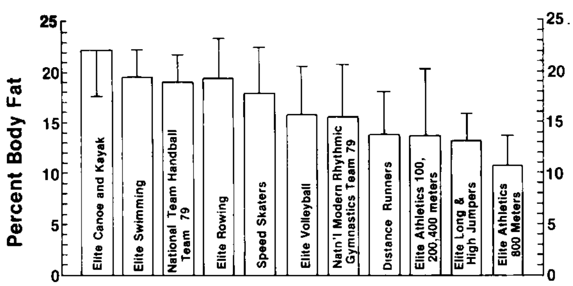
Mean % Fat	13.0	12.4	12.3	12.0	11.8	11.2	11.2	8.6	8.4	7.9
Standard Deviation	2.5	3.7	4.6	7.7	3.3	2.8	2.8	1.8	4.1	2.7
Mean L.B.M.	61.3	66.4	61.8	74.1	64.2	75.6	59.3	78.5	71.0	64.5
Standard Deviation	7.5	6.3	5.9	13.5	6.6	6.6	7.6	5.2	4.6	10.9
Mean Age (yrs.)	21.1	19.1	24.0	21.1	21.9	23.8	18.4	26.8	22.8	17.4
Standard Deviation	7.1	1.9	4.5	3.6	3.2	3.2	2.9	2.7	3.4	0.7
Number of Athletes	19	39	11	9	63	19	33	11	18	20

Figure 1. Males' hydrostatic weighing percent body fat.



Mean % Fat	11.1	10.2	9.9	9.7	9.3	8.7	8.7	8.6	8.1	7.3	6.9	6.7	6.6	6.5	6.4	6.3
Standard Deviation	2.7	2.1	2.6	1.1	1.4	2.1	3.1	2.5	2.0	2.6	1.6	1.7	0.9	1.2	1.3	1.3
Mean L.B.M.	61.6	75.8	61.5	64.6	60.9	60.5	70.2	62.4	56.0	84.1	62.3	73.1	70.0	66.7	55.0	69.7
Standard Deviation	4.7	6.3	7.2	5.1	4.5	5.2	13.2	4.0	6.1	6.2	12.8	4.0	3.1	5.7	4.8	4.7
Mean Age (yrs)	19.4	20.5	18.3	22.0	27.6	18.6	22.9	23.6	15.9	—	19.6	19.8	19.8	20.4	27.0	21.3
Standard Deviation	3.6	1.5	0.7	2.0	2.7	2.8	3.1	5.1	1.5	—	1.8	1.7	1.7	2.3	2.7	2.7
No. of Athletes	9	18	27	5	11	26	36	20	22	10	12	13	13	14	14	10

Figure 2. Males' anthropometric percent body fat.



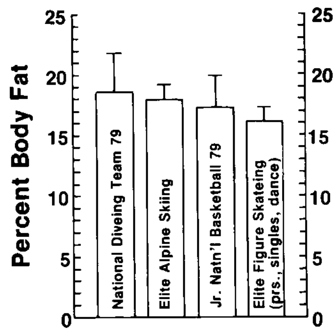
Mean % Fat	22.2	19.5	19.0	18.4	17.8	15.8	15.6	13.8	13.7	13.2	10.7
Standard Deviation	4.6	2.8	3.7	3.9	4.6	4.8	5.1	4.2	3.6	2.6	3.0
Mean L.B.M.	43.2	49.9	55.7	55.0	46.3	58.4	46.4	43.5	48.9	52.3	46.3
Standard Deviation	3.8	4.7	3.3	3.4	4.7	4.5	4.5	5.2	5.1	4.7	4.6
Mean Age(yrs.)	21.2	16.4	23.2	23.6	17.0	21.7	20.7	20.0	19.7	19.4	19.0
Standard Deviation	3.7	1.7	1.9	3.9	1.7	2.5	2.7	2.7	2.7	3.4	2.5
Number of Athletes	21	41	17	19	20	36	7	28	21	22	9

Figure 3. Females' hydrostatic weighing percent body fat.

over-predicted the % fat values in relation to the hydrostatically determined % fat values. This over-estimation ranged from 0.4% fat in swimmers to 5.9% in long jumpers, and averaged for the various groups 3.2% fat (SD = 2.1). In six out of eight groups of male athletes, a significant difference ($P < 0.05$) between the hydrostatically and anthropometrically determined % fat values was demonstrated. In all but one group of male athletes, the Sloan anthropometric equation underestimated the % fat in relation to the hydrostatically determined % fat values. This underestimation ranged from 0.95% fat in the Junior World Wrestlers to 6.07% fat in marathoners, and averaged for all groups 3.0% fat (SD = 1.8).

DISCUSSION

No group of athletes reported here equals or exceeds the average college age male and female % fat values of 15[21,38,49,59,60] and 25%[26,48,57] fat, respectively. Several groups



Mean % Fat	18.6	17.9	17.3	16.2
Standard Deviation	3.2	1.3	2.6	1.1
Mean L.B.M.	45.7	49.4	55.3	42.1
Standard Deviation	4.6	2.5	4.9	4.9
Mean Age (yrs.)	19.2	20.8	19.8	17.1
Standard Deviation	2.9	1.4	1.1	2.2
Number of Athletes	9	8	12	28

Figure 4. Females' anthropometric percent body fat.

TABLE 3
Comparison of % of body fat hydrostatically and anthropometrically determined

Group	No. of subjects	% Body fat	
		Hydrostatic (mean ± SD)	Anthropometric (mean ± SD)
Female			
Swimming	46	18.6 ± 4.7	19.0 ± 2.7
Track (400 m)	10	14.1 ± 3.4	15.9 ± 1.2
Speed skating	20	18.1 ± 5.0	18.8 ± 3.6
Team handball	17	18.2 ± 3.4	19.1 ± 2.4
National volleyball	13	12.3 ± 4.0	17.8* ± 3.5
Track (100 and 200 m)	9	11.8 ± 3.8	16.6* ± 1.4
Track (800 m)	9	10.7 ± 3.0	15.4* ± 1.4
High jump	11	14.3 ± 3.5	17.4* ± 1.5
Long jump	5	11.4 ± 2.2	17.3* ± 2.6
Rhythmical gym	7	13.1 ± 5.2	16.8* ± 2.0
Male			
Wrestling (Jr. World)	16	8.7 ± 3.0	7.8 ± 2.3
Decathlon	11	8.6 ± 1.8	7.4 ± 1.2
Cycling	42	11.3 ± 3.3	8.3* ± 2.1
Swimming	28	12.1 ± 3.3	10.1* ± 2.3
Speed skating	31	11.4 ± 3.2	7.7* ± 1.5
National volleyball team	12	10.3 ± 2.2	13.2* ± 1.7
Midwest cross-country skiing	11	12.3 ± 4.6	8.0* ± 2.3
Marathon	14	12.5 ± 4.4	6.4* ± 1.3

* Significant difference between hydrostatic and anthropometric % fat ($P < 0.05$).

of athletes do, however, approach the average college age male and female % fat values: male elite canoe and kayak, 13% fat; male elite swimming, 12.4%; male Midwest cross country ski team, 12.3%; female elite canoe and kayak, 22.2% fat; female elite swimming, 19.5%; and female national handball team, 19.0% fat. In general, the athletes that tend to have a higher % fat are involved in sports where the body weight is not supported by the athlete directly (canoe and kayak, swimming).

Essential fat in males is approximately 6%[45,53] and in females values ranging from 13[11] to 22%[17] fat have been reported. Many groups of athletes reported here are near or even below their sex's essential fat levels. In general, the athletes with low % fat values are involved in sports where the athlete must make a weight class to compete (boxing, wrestling), events that are very anaerobic in nature (100, 200 and 400 meters in athletics), and events that are extremely aerobic in nature (marathoners).

In general, athletes that tend to have large LBM are found in sports where body size is a definite advantage (basketball, volleyball, rowing), while extremely aerobic type athletes tend to have a low LBM (marathoners, race walkers).

Comparisons between the data presented here and previous studies are difficult. This is due in part to the use of the Sloan anthropometric equations here and various other anthropometric equations in previous studies, the use of the Brozek[7] equation in the present study, and the use of the various other equations (Siri,[47] Keys and Brozek[29]) to calculate the % fat from body density in previous studies and the questionability of comparing anthropometrically derived body composition variables to hydrostatically derived body composition variables. If such comparisons are made, however, in general the % fat values presented here for particular groups of athletes are of the same magnitude or slightly less than previously presented values. The LBM values presented here for a particular group of athletes are of the same magnitude or greater than previously presented values.

In 6 out of 10 groups of female athletes and 6 out of 8 groups of male athletes, where % fat was determined both via hydrostatic and anthropometric means, a significant difference ($P < 0.05$) existed between the two methods % fat values. This indicates that the Sloan anthropometric equations are population specific as has been previously demonstrated for various other anthropometric equations.[15,16,26,57,58]

It is of interest to note that in all groups of female athletes where % fat was determined both via hydrostatic means and via the Sloan equation, the Sloan equation over-predicted the % fat value in relation to the hydrostatic value. This over-prediction ranged from 0.4% fat in swimmers to 5.9% fat in long jumpers. In all but one group of male athletes where both hydrostatic methods and the Sloan equation were utilized to predict % fat, the Sloan equation underestimated the % fat values in relation to the hydrostatically determined % fat values. This underestimation ranged from 0.95% fat in Junior World Wrestlers to 6.0% fat in marathoners.

CONCLUSIONS

Extremely low % fat values, although theoretically an advantage in many sports, are not a necessity for success in many sports. In general, athletes involved in sports where their body weight is supported in some manner tend to have higher % fat values than athletes involved in extreme aerobic or extreme anaerobic type sports. The Sloan equations for prediction of body density are population specific and this must be taken into consideration when interpreting % fat values obtained via these equations.

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REFERENCES

1. Behnke AR: Physique and exercise. *In Exercise Physiology.* Edited by Falls HB. New York, Academic Press, 1968, pp. 359–386
2. Behnke AR, Wilmore JH: *Evaluation and Regulation of Body Build and Composition.* Englewood Cliffs, NJ, Prentice Hall, 1974
3. Behnke AR, Royce J: Body size, shape and composition of several types of athletes. *J Sports Med Phys Fitness 6:* 75–88, 1966
4. Bloomfield J, Sigererseth PO: Anatomical and physiological difference between sprint and middle distance swimmers at the university level. *J Sports Med Phys Fitness 5:* 76–81, 1965
5. Boileau RA, Lohman TG: The measurement of human physique and its effects on physical performance. *Orthop Clin North Am 8:* 563–581, 1977
6. Brown CH, Wilmore JH: The effects of maximal resistance training on the strength and body composition of women athletes. *Med Sci Sports 6:* 174–177, 1974
7. Brozek J, Grande F, Anderson J et al: Densitometric analysis of body composition: revision of some quantitive assumptions. *Ann NY Acad Sci 110:* 113–140, 1963
8. Burke ER: Physiological characteristics of competitive cyclists. *Physician Sportsmed 8:* 79–83, 1980
9. Buskirk ER: Nutrition for the athlete. *In Sports Medicine.* Edited by Ryan A, Allman F. New York, Academic Press, 1974
10. Conger RR, Macnab RBJ: Strength, body composition and work capacity of participants and non-participants in women's intercollegiate sports. *Res Q 38:* 184–192, 1967.
11. Coniff JC: All about fat. *The Runner 1:* 73–79, 1978
12. Costill DL: The relationship between selected physiological variables and distance running performance. *J Sports Med 7:* 61–66, 1967
13. Costill DL, Bowers R, Kammer WF: Skinfold estimates of body fat among marathon runners. *Med Sci Sports 2:* 93–95, 1970
14. Fahey TD, Akka L, Rolph R: Body composition and Vo2 max of exceptional weight-trained athletes. *J Appl Physiol 39:* 559–561, 1975
15. Flint MM, Drinkwater BD, Wells CC et al: Validity of estimating body fat of females: effects of age and fitness. *Human Biol 49:* 559–572, 1977
16. Forsyth HL, Sinning WE: The anthropometric estimation of body density and lean body weight of male athletes. *Med Sci Sports 5:* 174–180, 1973
17. Frisch RE, McArthur JW: Menstrual cycles: fatness as a determinant of minimum weight and height necessary for their maintenance or onset. *Science 185:* 959, 1974
18. Gale JG, Flynn KW: Maximal oxygen consumption and relative body fat of high-ability wrestlers. *Med Sci Sports 6:* 232–234, 1974
19. Hagerman FC, Hagerman FR, Mickelson TC: Physiological profiles of elite rowers. *Physician Sportsmed 7:* 74–83, 1979
20. Hagerman FC, Hagerman GR, Burke ER et al: Testing of the U.S. national junior women's basketball teams. *The Olympian* April: 11–13, 1979
21. Haisman MF: The assessment of body fat content in young men from measurements of body density and skinfold thickness. *Hum Biol 42:* 679–688, 1971
22. Hanson J: Maximal exercise performance in members of the U.S. Nordic ski team. *J Appl Physiol 35:* 592–595, 1973
23. Haymes EM, Dickenson AL: Characteristics of elite male and female ski racers. *Med Sci Sports Exerc 12:* 153–158, 1980

24. Katch FI, Michael ED: Body composition of high school wrestlers according to age and wrestling weight category. *Med Sci Sports Exerc 3:* 190–194, 1971
25. Katch FI, Michael ED, Jones EM: Effects of physical training on the body composition and diet of females. *Res Q 40:* 99–104, 1969
26. Katch FI, McArdle WD: Validity of body composition prediction equations for college men and women. *Am J Clin Nutr 28:* 105–109, 1975
27. Katch FI, McArdle WD: Prediction of body density from simple anthropometric measurements in college-age men and women. *Human Biol 45:* 445-454, 1973
28. Kelly JM, Gorney GA, Kalm KK: The effects of a collegiate wrestling season on body composition, cardiovascular fitness and muscular strength and endurance. *Med Sci Sports Exerc 10:* 119–124, 1978
29. Keys A, Brozek J: Body fat in adult man. *Physiol Rev 33:* 245, 1953
30. Kovlaeski JE, Parr RB, Hornak JE et al: Athletic profile of women college volleyball players. *Physician Sportsmed 8:* 112–118, 1980
31. Krahenbuhl GS, Wells CL, Brown CH et al: Characteristics of national and world class female pentathletes. *Med Sci Sports Exerc 11:* 20–23, 1979
32. Malina RM, Harper AB, Avent HH et al: Physique of female track and field athletes. *Med Sci Sports Exerc 3:* 32-38, 1971
33. Mayers N, Gutin B: Physiological characteristics of elite prepubertal cross-country runners. *Med Sci Sports Exerc 11:* 172–176, 1979
34. Morrow JR Jr, Jackson AS, Hosler WH et al: The importance of strength, speed and body size for team success in women's intercollegiate volleyball. *Res Q Exerc Sport 50:* 429-437, 1979
35. Nagel FJ, Morgan, JP, Hellickson RO, et al: Spotting success traits in Olympic contenders. *Physician Sportsmed 3:* 31–34, 1975
36. Niinimaa V, Dyon M, Shepard RJ: Performance and efficiency of intercollegiate cross-country skiers. *Med Sci Sports Exerc 10:* 91–93, 1978
37. Novak LP, Hyatt RE, Alexander JF: Body composition and physiologic function of athletes. *JAMA 205:* 764–770, 1968
38. Pollock ML, Hickman T, Kendrick Z et al: Prediction of body density in young and middle-aged men. *J Appl Physiol 403:* 300-304, 1976
39. Puhl J, Case S, Fleck S et al: Physical and physiological characteristics of elite volleyball players. *Res Q 53:* 257-262, 1982
40. Rash PJ, Hunt MB: A study of the calculated body composition of amateur wrestlers. *J Assoc Phys Ment Rehabil 13:* 90–93, 1959
41. Rusko H, Havu M, Karivien E: Aerobic performance capacity in athletes. *Eur J Applied Physiol 38:* 151-159, 1978
42. Sinning WE: Body composition, cardiovascular function, and rule changes in women's basketball. *Res Q 44:* 313-321, 1973
43. Sinning WE: Anthropomatric estimation of body density, fat, and lean body mass in women's gymnastics. *Med Sci Sports Exerc 10:* 243–249, 1978
44. Sinning WE, Lindberg GD: Physical characteristics of college age women gymnasts. *Res Q 43:* 226–234, 1972
45. Sinning WE: Body composition assessment of college wrestlers. *Med Sci Sports Exerc 6:* 139–145, 1974
46. Sinning WE, Cunningham LN, Rancaniello AP et al: Body composition and somatotype of male and female Nordic skiers. *Res Q 48:* 741-749, 1977
47. Siri WE: Body volume measurement by gas dilution. *In Techniques for Measuring Body Composition.* Edited by Brozek J, Henschel A. Washington, D. C.: Natl Acad Sci-Natl Res Council, 1961, pp. 108-117
48. Sloan AW, Burt JJ, Blyth CS: Estimation of body fat in young women. *J Appl Physiol 17:* 967-970, 1962
49. Sloan AW: Estimation of body fat in young men. *J Appl Physiol 23:* 311-315, 1967
50. Sprynarova S, Parizkova J: Functional capacity and body composition in top weight lifters, swimmers, runners, and skiers. *International Zeitschrift fur Angewandte Physiolgie 29:* 184–194, 1971
51. Sprynarova S, Parizkova J: Comparison of the functional circulatory and respiratory capacity in girl gymnasts and swimmers. *J Sports Med Phys Fitness 9:* 165–172, 1969
52. Stine G, Ratliff R, Shierman G et al: Physical profile of the wrestlers at the 1977 NCCA championships. *Physician Sportsmed 7:* 98–105, 1979
53. Tcheng TK, Tipton CM: Iowa wresting study: anthropometric measurements and prediction of a minimal body weight for high school wrestlers. *Med Sci Sports Exerc 5:* 1-10, 1973
54. Thompson CW, Buskirk ER, Goldman RF: Changes in body fat estimated from skinfold measurements of college basketball and hockey players during a season. *Res Q 27:* 418-430, 1956
55. Thorland WG, Johnson GO, Fagot TG et al: Body composition and somatotype characteristics of junior Olympic athletes. *Med Sci Sports Exerc 13:* 332-338, 1981
56. Wilmore JH, Brown CH: Physiological profiles of women distance runners. *Med Sci Sports Exerc 6:* 178-181, 1974
57. Wilmore JH: The use of actual, predicted and constant residual volumes in the assessment of body composition by underwater weighing. *Med Sci Sports 1:* 87-90, 1969
58. Wilmore JH, Behnke AR: An anthropometric estimation of body density and lean body weight in young women. *Am J Clin Nutr 23:* 267-274, 1970
59. Wilmore JH, Behnke AR: Predicability of lean body weight through anthropometric assessment in college men. *J Appl Physiol 25:* 349-355, 1968
60. Wilmore JH, Behnke AR: An anthropometric estimation of body density and lean body weight in young men. *J Appl Physiol 27:* 25-31, 1961
61. Wilmore JH, Brown CH, Davis JA: Body physique and composition of the female distance runner. *Ann NY Acad Sci 301:* 764-776, 1977