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Body Composition in Athletes: Assessment and Estimated Fatness

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The study of body composition attempts to partition and quantify body weight or mass into its basic components. Body weight is a gross measure of the mass of the body, which can be studied at several levels from basic chemical elements and specific tissues to the entire body. Body composition is a factor that can influence athletic performance and as such is of considerable interest to athletes and coaches. This article provides an overview of models and methods used for studying body composition, changes in body composition during adolescence and the transition into adulthood, and applications to adolescent and young adult athletes.

LEVELS OF BODY COMPOSITION

The study of body composition historically has been driven by the availability of methods to measure or, more appropriately, to estimate it. Since the early 1980s, considerable progress has been made in the development and refinement of techniques to estimate the composition of the body, so that virtually all components of the body can now be measured. This progress has resulted in the modification of the models that provide the framework for studying body composition.

Body composition can be approached at a variety of levels. The five-level approach provides a sound guide: atomic, molecular, cellular, tissue, and whole body [1,2]. The multilevel view provides a framework within which the lure and difficulty inherent in the study of body composition can be appreciated.

Basic chemical elements compose the *atomic* level. There are 106 elements in nature. About 50 are found in the human body, and with more recent technologic advances, all 50 can be measured in vivo. Oxygen, carbon, hydrogen, and nitrogen account for greater than 95% of body mass, and the addition of seven other elements–sodium, potassium, phosphorus, chloride, calcium, magnesium, and sulfur–accounts for 99.5% of body mass [2].

The *molecular* level of body composition focuses on four of five components: water, lipid (fat), protein, minerals, and carbohydrate. The last component,

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carbohydrate, occurs in small amounts in the form of glycogen, largely in the liver and skeletal muscle, and is not usually considered in estimates of body composition. The following equation is used:

$$\text{Body mass} = \text{water} + \text{protein} + \text{mineral} + \text{fat}$$

Most mineral is located in bone with a small fraction in other tissues. Historically, the relative contribution of each of the four components to body mass was derived from chemical analyses of human cadavers, although each can now be measured in vivo.

At the *cellular* level, body mass is viewed as composed of cells and substances outside of cells. The body cell mass (BCM) is defined by intracellular fluids and intracellular solids and is the metabolically active component of the body. Presently available methods do not permit measurement of cell solids in vivo. Extracellular fluids (ECF) and extracellular solids (ECS) compose the substances outside of the cells. The primary ECF are bone minerals and other components of connective tissues. Adipocytes are fat cells; they store lipids and comprise fat mass (FM). The equation is as follows:

$$\text{Body mass} = \text{BCM} + \text{ECF} + \text{ECS} + \text{FM}$$

At the *tissue* level, the study of body composition focuses on the contribution of specific tissues to body mass: skeletal muscle, adipose, bone, blood, viscera, and brain. Skeletal muscle, adipose, and bone tissues historically have been a primary focus in studies using traditional technologies, such as anthropometry and radiography. New technologies permit more refined assessment of these primary tissues (eg, the mineral content of bone tissue or subcutaneous versus internal adipose tissue).

The fifth level of body composition is the *whole body,* its size, shape, physique, and proportions. Anthropometry is the basic tool for estimating body size and configuration, although photographic techniques also have been used, especially for the study of shape and physique. The body mass index (BMI) (weight [kg]/height^2 [m]) and skinfold thicknesses are perhaps the most widely used anthropometric indicators at this level of body composition. Two other properties of the whole body are crucial in the study of body composition–volume and density.

MODELS OF BODY COMPOSITION

The two-component model historically has been the model of choice for partitioning body mass into meaningful components or compartments. This traditional approach has evolved into more complex models that include three, four, or more compartments.

Two Components

The two-component model partitions body mass into its lean (fat-free mass [FFM]) and fat (FM) compartments. The equation follows:

$$\text{Body mass} = \text{FFM} + \text{FM}$$

The term *lean body mass* is occasionally used, but FFM is more appropriate. Lean body mass is a more anatomic concept that includes some essential lipids, whereas FFM is a biochemical concept. This model has had the widest application in the study of body composition, including many studies of athletes. FM is the more labile of the two compartments; it is readily influenced by diet and training. A shortcoming of the two-component model is the heterogeneous composition of FFM; it includes water, protein, mineral (bone and soft tissue mineral), and glycogen.

Three Components

The three-component model includes FM and partitions FFM into total body water (TBW) and fat-free dry mass (FFDM). The equation is as follows:

$$\text{Body mass} = \text{TBW} + \text{FFDM} + \text{FM}$$

Water is the largest component of body mass, and most is located in lean tissues. FFDM includes protein, glycogen, and mineral in bone and soft tissues.

Four Components

With the development of techniques to measure bone mineral, the four-component model is a logical extension of the preceding model. FFDM is partitioned in bone mineral (BM) and the residual. The following equation is used:

$$\text{Body mass} = \text{TBW} + \text{BM} + \text{FM} + \text{residual}$$

Overview

All models include FM. It is the aspect of body composition that has received and continues to receive most attention. Excess FM can have a negative influence on physical performance and is often viewed by coaches and trainers as a major limiting factor in athletic achievements. Excessive fatness also is a major independent risk factor for several degenerative diseases.

FM, although often treated as a singular component of body composition, is heterogeneous. Fat, or more appropriately lipid, is physiologically divided into essential and nonessential lipids. Essential lipids are vital components of cells and are basic for a variety of physiologic functions; they constitute about 10% of total lipids in the body. The remaining lipids, 90% of total body lipids, are nonessential. They are triglycerides, which provide a storage form of available energy and perhaps thermal insulation [2]. The small amount of essential lipids in the body usually are not considered in estimates of body composition and usually are grouped with the residual component or with FM, depending on the model and method of assessment.

FFM is highly correlated with overall body size. Partitioning FFM into fractions has several problems. Error is inherent in the measurement of each component, and the more components included in a model increases the chances of error. The techniques available for the measurement of TBW, potassium, calcium, and sodium each have associated error. When measured, these properties must be converted to the body composition component of interest. The transformation of the measured property to the component is essentially mathematical and includes a variety of assumptions.

Multicomponent models are additive; it is assumed that the separately measured properties can be summed to provide an estimate of the whole. Thus, the measurement of body composition is essentially an estimate of body composition.

The different models of body composition have been largely developed on adults. They also assume that during periods of stable body mass, the various components exist in a steady state, which means that they are constant, or the relationships among components are constant. The assumption of constant relationships has permitted the development of procedures to estimate the different fractions of body mass in adults. The application of these procedures to children and adolescents, to adults in different stages of the life cycle, and to elite athletes requires care in interpretation of various estimates. The proportions of each component and the relationships among components change during growth and maturation and with aging. Systematic training for sport is an additional factor that influences body composition.

METHODS FOR ESTIMATING BODY COMPOSITION

Methods of estimating body composition in vivo are numerous and often quite complex (Table 1). The methods are sufficiently different in technique that one may inquire whether they provide reasonably similar estimates of body composition. The formulas for estimating FFM or FM, or components of FFM, and the assumptions underlying the procedures are based primarily on adults in the general population (ie, nonathletes). Their application to growing and maturing children and adolescents and to athletes may result in spuriously high or low estimates.

Several commonly used methods are briefly described. Three have been used regularly for some time–the measurement of body density (Db), TBW, and potassium concentration. Two more recent methods–dual-energy x-ray absorptiometry (DXA) and bioelectrical impedance analysis (BIA)–also are described. The specific protocols for each of these methods and their limitations are discussed in detail in Roche et al [3] and Heymsfield et al [4]. Anthropometric approaches also are briefly summarized.

Body Density—Densitometry

Density is mass per unit volume. The density of specific body tissues varies. The density of lean tissues ($\geq$1.100 g/cm^3) is greater than the density of water (1 g/cm^3) and fat (0.9007 g/cm^3). Density is inversely related to body fat

Table 1
Summary of methods used to estimate body composition

Underwater weighing, gas displacement	Estimates body density, which is converted to % Fat
Isotope dilution	Estimates total body water, which is converted to FFM; compartments of total body water also can be estimated
^{40}K whole-body counting	Estimates potassium content of body, which is converted to FFM
Dual-energy x-ray absorptiometry (DXA)	Estimates bone mineral, also lean and fat tissues
Bioelectrical impedance	Estimates FFM
Neutron activation analysis	Uses isotopes of nitrogen and calcium to estimate lean tissue and mineral
Uptake of fat-soluble gases	Estimates FM
24-hour urinary creatinine excretion	Estimates muscle mass
3-Methylhistidine excretion	Estimates muscle mass
MRI	Estimates of fat, muscle, and bone without ionizing radiation, plus chemical composition
CT	Estimates of bone, muscle, and fat
Ultrasound	Estimates of fat, muscle, and bone
Radiography	Estimates of fat, muscle, and bone
Anthropometry	Estimates of subcutaneous fat and predictions of FM and FFM

Data from Malina RM, Bouchard C, Bar-Or O. Growth, maturation, and physical activity. 2nd edition. Champaign (IL): Human kinetics; 2004.

content: The greater the proportion of fat, the lower the Db. A measure of Db permits an estimate of the percentage of body mass that is fat (% Fat).

The most common method for measuring Db is underwater (hydrostatic) weighing, but air or helium displacement techniques also are used. Two formulas are used most often to convert Db to % Fat:

$$\% \text{ Fat} = 4.570/\text{Db} - 4.142 \text{ [5]}$$

$$\% \text{ Fat} = 4.950/\text{Db} - 4.500 \text{ [6]}$$

The formulas and their underlying assumptions are derived from adults. The two equations give reasonably similar estimates of % Fat except for the very lean and very obese [7].

The estimate of % Fat is based on the assumption that the densities of the fat and fat-free components are known and are constant, and that adults are identical in composition except for variability in the proportion of fat. The proportions and chemical composition of the various components of FFM change with growth and maturation, in addition to interindividual differences in composition of FFM.

An estimate of FM is derived by multiplication and subtraction:

$$FM = \text{body mass} \times \%\,\text{Fat}$$

$$FFM = \text{body mass} - FM$$

Total Body Water—Hydrometry

Water is the largest component of the body, varying between 55% and 65% of body mass in normally hydrated young men, with lower values for women. The TBW of 70-kg young men can range from 38 to 45 kg of water. Emphasis is on normal hydration. TBW varies during the course of a day, depending on fluid intake and physical activity level, especially strenuous exercise. It also varies with severe protein-energy undernutrition and extreme obesity.

Most of the water in the body is in lean tissues. Water constitutes approximately 72% to 74% of FFM in normally hydrated adults, although the estimated water content of FFM has been reported to vary between 67% and 74%. In contrast, adipose tissue is relatively nonaqueous and contains a small proportion of water, about 20%.

The measurement of TBW provides an estimate of FFM. The process is based on two principles of isotope dilution: Certain substances distribute themselves evenly throughout a fluid space or compartment of the body, and the dilution of a known amount of substance, an isotope tracer, administered into an unknown volume or mass enables the calculation of the unknown volume or mass. The protocol consists of administering a known amount of a stable isotope tracer, allowing it sufficient time to dilute or mix, and then measuring its concentration after dilution and after correcting for the amount of the tracer lost from the body by excretion or exhalation. Three isotopes generally are used to measure TBW: deuterated water (^{2}H, deuterium), tritiated water (^{3}H, tritium), and ^{18}O-labeled water (heavy isotope of oxygen).

TBW usually is measured in the morning after an overnight fast. The isotope is administered to the subject based on body mass. Time is permitted for its equilibration with body water, usually 2 to 4 hours depending on the isotope. The concentration of the isotope in serum, urine, or saliva is measured. Assuming that the percentage of water in FFM is constant in adults, FFM is estimated as follows:

$$FFM = TBW/0.732$$

$$FM = \text{body mass} - FFM$$

TBW can be subdivided into water that is intracellular (ICW) and extracellular (ECW). Estimates of ICW and ECW in young men are 57% and 43% [8].

ECW usually is measured with the same isotope dilution principles as TBW with either chloride or bromide as the isotope. ECW is composed mainly of water in support and transport tissues: plasma, dense connective tissue (tendon, cartilage, bone), interstitial lymph, and transcellular fluids (cerebrospinal fluid, joint fluids). ICW corresponds closely to skeletal muscle mass, the work-producing tissue of the body, but is not exclusively composed of it. After estimating ECW, ICW usually is derived by subtraction:

$$ICW = TBW - ECW$$

Body Potassium—Whole Body Counting

Potassium occurs primarily in cells and especially in skeletal muscle tissue. Measurement of the concentration of potassium in the body can provide an estimate of FFM. This is done by measuring the amount of potassium-40 (^{40}K), a naturally occurring isotope of potassium that accounts for 0.0118% of the naturally occurring potassium in the human body [9]. The concentration of ^{40}K is measured with highly sensitive detection instruments, whole body counters, which count the gamma emissions of the naturally occurring potassium. A constant proportion of potassium in FFM is assumed, but there is a sex difference [10,11]. FFM is estimated as follows:

$$FFM = \text{mEq K}/68.1 \text{ in males}$$

$$FFM = \text{mEq K}/64.2 \text{ in females}$$

$$FM = \text{body mass} - FFM$$

More recent studies indicate variation in the potassium content of FFM, specifically values lower than the proportions indicated here [9]. Most of the available data for estimating body composition from measures of total body potassium use the constants reported by Forbes [10,11]. Total body potassium per unit FFM tends to decline with age in adulthood and shows differences between American blacks and whites [12,13].

Dual-Energy X-Ray Absorptiometry

DXA is used to measure bone mineral and soft tissue composition of the body. It provides estimates for the total body and of specific regions in the form of bone mineral, fat-free soft tissues (sometimes called bone-free lean tissue), and fat. The method requires a low radiation exposure, 0.05 to 1.5 mrem, depending on the machine and how quickly the total body scan is done [14]. The DXA unit measures the attenuation of the low-dose x-ray beam as it passes through different tissues of the body. How much of each photon beam is absorbed by the atoms in bone mineral and soft tissues of the body is recorded during the scan and converted to estimates of bone mineral and soft tissues [15]. The DXA instrument must be linked with appropriate computer algorithms to derive estimates of bone mineral, fat-free soft tissue, and fat tissue content of the total body. The algorithms also permit division of the body into anatomic segments–arms, legs, trunk, and head–to permit estimates of regional body composition.

The derivation of fat and fat-free soft tissue from DXA scans is based on the ratio of soft tissue attenuation of the low-energy and high-energy photon beams as they pass through the body. The attenuation of the low-energy and high-energy soft tissues is known based on scans of pure fat and fat-free soft tissues and theoretical calculations. It is assumed that the attenuation of fat and fat-free soft tissues is constant. The attenuation for fat is lower than that for fat-free soft tissues. Using these constants and the scans from the DXA unit, the amount of fat and fat-free soft tissue is calculated.

The derivation of bone mineral requires adjustment for the soft tissue overlying bone. DXA technology provides an estimate of total body bone mineral content (g) and total bone area (cm^3). The ratio of total body bone mineral to total bone area is used to estimate bone mineral density (g/cm^3). DXA basically measures the cross-sectional area of a scan (total bone area) and not bone volume; expressing bone mineral relative to bone area is only an approximation of bone mineral density.

Several types of commercially available DXA instruments are presently in use. Each type of unit has its own computer algorithms for deriving estimates of body composition, and there are inter-instrument differences. There is concern for the comparability of measurements, especially of soft tissue, from machines produced by different manufacturers. All of them assume that the attenuation characteristics of bone, fat-free soft tissue, and fat are known and constant [14].

Bioelectrical Impedance Analysis

The method of estimating body composition from BIA is based on the fact that lean tissue has a greater electrolyte and water content than fat. This difference in electrolyte content permits an estimate of FFM from the magnitude of the body's electrical conductivity or from the body's impedance to an electrical current as it flows from the source (usually the ankle) to the sink (usually the wrist) electrodes. FFM has low impedance and high conductivity, whereas FM, which has a relatively low water and electrolyte content, has high impedance and low conductivity.

BIA uses an imperceptible electrical current, which is introduced into the body via electrodes placed on the ankle. The injected current passes through the body, and the voltage that is produced is measured in voltage-sensing electrodes placed on the wrist [16,17]. The ratio of voltage to the current is impedance. Impedance to the flow of the current is related to the shape, volume, and length of the body, which is the conductor of the current. Because impedance is proportional to the geometry of the conductor, variation in body shape may be a factor in the application of BIA.

BIA measures the voltage for the path from the ankle to the wrist. It yields a measure of resistance, which is the major component of impedance. Resistance usually is converted to TBW, which is transformed into an estimate of FFM as described earlier. The equation used to convert resistance to TBW usually includes stature.

Several types of commercially available BIA units are presently in use, and there are differences among the units. They are portable (the size of a briefcase) and relatively inexpensive. BIA also is convenient, rapid, and noninvasive. As such, it is finding increased application for estimates of body composition. As with other methods, BIA has many underlying assumptions, which need to be verified.

Anthropometry

The use of anthropometric dimensions to estimate body composition has a long history [18,19]. Skinfold measurements are used most often to predict Db, which is converted to an estimate of % Fat. A variety of prediction equations incorporating skinfold measurements and other dimensions (height, limb and trunk circumferences, skeletal widths) are available. Most are based on samples of nonathlete adults, and several are based on children and adolescents, although equations for athletes also are available [19–23]. Prediction equations are sample specific and should be cross-validated. "Generalized" equations that adjust for age and the curvilinear relationship between skinfold thicknesses and Db also have been developed [24,25]. Equations based on advances in body composition methodology and multicomponent models also are available for the general population [26–28] and for female athletes [29].

Some degree of error is inherent in the measurement of body dimensions and body composition. Error associated with the measurements per se and with prediction equations should be noted. The standard error of estimate associated with available equations to predict body density generally ranges between 2% and 5%. For a discussion of error associated with anthropometry and the accuracy of body composition prediction equations, see Malina [30] and Sun and Chumlea [31].

More recently, the BMI has found increasing use as an alternative method for rapid assessment of body composition of athletes. The BMI is widely used in epidemiologic surveys of the weight status in adults: underweight (BMI $<$18.5 kg/m^2), overweight (BMI $\geq$25 $<$ 30 kg/m^2), and obesity (BMI $\geq$30 kg/m^2) [32]. It also is used as a screening device of overweight and obesity in children and adolescents [33,34]. The BMI is reasonably well correlated with total and percentage body fat in large and heterogeneous samples, although it has limitations especially with youth. Correlations between the BMI and FFM and FM are reasonably similar among youth, which would suggest that the BMI is an indicator of heaviness and indirectly of body fatness [35]. At the extremes of heaviness, the BMI is probably a reasonable indicator of fatness in the general population. Given the relatively large body size (height and mass) and relative leanness of athletes, the BMI has limitations with athletes.

Applications

The methods described provide an estimate of FFM and FM. Db is converted to % Fat; TBW, ^{40}K, and BIA (resistance) yield estimates of FFM. The other half of the two-component model is derived by subtraction. The three-component model involves the simultaneous measurement of Db and TBW to derive an estimate of % Fat, whereas the four-component model includes Db, TBW, and total body bone mineral to estimate % Fat. Multicomponent models provide the advantage of greater accuracy of estimates [36]. The cost and technical constraints of the required methodology often limit their applicability outside of the clinical or laboratory setting, however.

Most of the available body composition data for athletes are derived from the two-component model using Db. Data are less extensive for estimates derived from TBW, ^{40}K, multicomponent models, DXA, and BIA. The assumptions underlying the methods are based on nonathletic adults, and limitations of applications to youth and adult athletes need to be recognized. Fat estimates from densitometry are based on the assumption that the density of fat and lean tissues is constant. FFM estimates from TBW and ^{40}K are based on the assumption that the water and potassium contents of the FFM are constant. They also assume that the density of fat and lean tissues and the water and potassium contents of the FFM are the same in children, adolescents, and adults, which is not the case. An important issue in growing and maturing individuals is the age at which adult density, water concentration, and potassium concentration of FFM are achieved (see later).

BIA is finding increased application. The method is useful to describe the body composition of groups, but estimates have large errors within individuals, which limits its application. BIA is influenced by nutritional and hydration status and is not sensitive to acute changes in electrolytes and fluids. There also is significant variation between BIA machines produced by different manufacturers. The resistance (R) function of impedance is used most often with stature (length of the conductor) to estimate FFM, but there is uncertainty about the appropriate hydration factor to use in converting R to FFM. Other equations use R and stature, in conjunction with body mass, circumferences, and skinfold measurements to estimate FFM.

DXA is used most often to estimate bone mineral content and density. DXA measures of total body bone mineral content also are used in the four-component model to increase the accuracy of body composition estimates. The procedures require the measurement of Db, TBW, and bone mineral, and it is unclear whether the time and expense involved markedly improve the accuracy of the body composition estimates.

DXA also is being used more often to estimate FFM, FM, and % Fat. The accuracy of these estimates needs further verification relative to estimates derived from the more established methods of body composition assessment, specifically densitometry and hydrometry.

An important issue in all body composition studies is validation. How accurately does a given technique estimate the specific components of body composition? What is the appropriate criterion against which to compare estimates of body composition derived from the different methods and models? Do the different methods and models provide the same estimates of FFM, FM, and % Fat? The assessment of bone mineral content increases the accuracy of the four-component model over the three-component model. The instrument to measure bone mineral content is expensive, however: Is this expense justifiable given the small increase in the accuracy of the body composition estimates? These and other questions need to be considered in evaluating the application of new technologies and multicomponent models.

CHEMICAL MATURITY

If the principles and methods for estimating body composition are to be accurately applied to youth, including young athletes, it is important to determine when during growth are adult values for the primary components of FFM attained. When adult values are reached, chemical maturity is said to be attained. The concept of chemical maturity was introduced by Moulton [37]: "The point at which the concentration of water, proteins, and salts [minerals] becomes comparatively constant in the fat-free cell is named the point of chemical maturity of the cell."

During the interval of growth and maturation, approximately the first 2 decades of life, the relative contribution of water to body mass decreases, and corresponding contributions of solids–protein, mineral, and fat–to body mass increase. Growth is an accretive process, adding or accumulating solids at the expense of fluids. The relative contributions of protein and mineral to FFM also increase, whereas the relative contribution of water to FFM decreases.

The estimated composition of FFM from late childhood through adolescence into young adulthood is summarized in Table 2. With growth and maturation during adolescence, the relative contribution of solids (protein and mineral) to FFM increases, and that of water decreases. Sex differences are apparent. FFM in males contains relatively less water and relatively more protein and mineral compared with females. The sex difference also is reflected in the estimated potassium content and density of the FFM, which are greater in males than in females. The difference reflects the sex difference in muscle mass and bone mineral and persists into young adulthood. The gain in bone mineral between age 10 years and young adulthood reflects, to a large extent, the growth and maturation of the skeleton during the adolescent growth spurt. The relative mineral content of FFM in males increases from 5.4% at about 10 years to 6.6% at 17 to 20 years, a small increment (1.2%) that is, however, about 22% of the initial value at age 10. The corresponding increase in the relative mineral content of FFM in females is less, 5.2% to 6.1%, a relative increase

Table 2
Estimated composition of the Fat-free mass during the transition into adolescence, adolescence, and young adulthood

Age (y)	Compartments of the FFM (%) Water	Protein	Mineral	Potassium (g/kg)	Density (g/cm^3)
Males					
9–11	76.2	18.4	5.4	2.45	1.084
11–13	75.4	18.9	5.7	2.52	1.087
13–15	74.7	19.1	6.2	2.56	1.094
15–17	74.2	19.3	6.5	2.61	1.096
17–20	74.0	19.4	6.6	2.63	1.099
Females					
9–11	77.0	17.8	5.2	2.34	1.082
11–13	76.6	17.9	5.5	2.36	1.086
13–15	75.5	18.6	5.9	2.38	1.092
15–17	75.0	18.9	6.1	2.40	1.094
17–20	74.8	19.2	6.0	2.41	1.095

The protein content of the FFM in the estimates is derived by subtraction: 100 − water − mineral = protein.
Data from Lohman TG. Applicability of body composition techniques and constants for children and youths. Exerc Sport Sci Rev 1986;14:325–57.

of about 16% of the initial value in late childhood. It is apparent that chemical maturity of FFM is not attained until after the adolescent growth spurt, probably about 16 to 18 years in girls and 18 to 20 years in boys.

The information summarized in Table 2 represents *estimates* of the chemical composition of the FFM. The estimates are derived in part from limited biochemical cadaver analyses and from in vivo estimates of TBW, potassium, nitrogen, calcium, and bone mineral. Estimates also vary from laboratory to laboratory, which is not unexpected because different data, assumptions, and methods are used in their derivation. There are continued efforts to arrive at the more accurate estimates of the chemical composition of the FFM. Nevertheless, an important conclusion to be derived from these estimates and ongoing studies is that the chemical maturity of FFM changes during growth and maturation and is not attained until late adolescence or young adulthood. The equations and constants based on adult values and earlier studies are often adjusted for the chemical immaturity of the FFM in growing and maturing individuals.

CHANGES IN BODY DENSITY, TOTAL BODY WATER, AND TOTAL BODY POTASSIUM DURING GROWTH

The basic properties used for estimating body composition change with growth and maturation [35,38,39]. TBW and total body potassium, both of which are found primarily in lean tissue, follow a growth pattern similar to that of height and body mass with a clear adolescent spurt during which growth in TBW and total body potassium is greater in males than in females. Both reach a plateau at about 15 to 17 years in females and increase into the early 20s in males. Db has a different growth pattern. It declines in males from about 8 to 10 years, but then increases more or less linearly to about 16 to 17 years of age. In females, Db decreases from about 8 to 11 years, then increases only slightly, and finally reaches a plateau by about 14 years. Both sexes also show a slight decline in Db in late adolescence and young adulthood. Db is inversely related to body fat content, although not linearly. Males have greater Db than females at all ages and have a correspondingly lower % Fat.

GROWTH IN FAT-FREE MASS, FAT MASS, AND FAT PERCENTAGE OF BODY MASS

The growth patterns of FFM, FM, and % Fat from late childhood through adolescence into young adulthood have been described [35]. FFM follows a growth pattern similar to that of height and weight. Sex differences are small during childhood and become established during the adolescent growth spurt. Young adult values of FFM are reached earlier in females, about 15 to 16 years, compared with 19 to 20 years in males. In late adolescence and young adulthood, males have, on average, an FFM that is about 1.5 times larger than that of females. The average FFM of young women is about 70% of the mean value for men. The difference reflects the male adolescent spurt in muscle mass and the sex difference in adult height.

When FFM is expressed per unit height (kg/cm), the sex difference is relatively small in late childhood and early adolescence, but after 14 years of age, males have more FFM for the same height as females. The sex difference increases with age so that young men have an estimated 0.36 kg FFM/cm height, whereas young women have an estimated 0.26 kg FFM/cm height.

Estimated FM increases more rapidly in females than in males from late childhood through adolescence, but seems to reach a plateau or to change only slightly near the time of the adolescent growth spurt in boys (about 13–15 years). In contrast to FFM, females have, on average, about 1.5 times the FM of males in late adolescence and young adulthood.

Estimated % Fat is greater in females than in males from late childhood through adolescence into young adulthood. Percent Fat increases gradually through adolescence in the same manner as FM in females; it also increases gradually in males until just before the adolescent spurt (about 11–12 years) and then gradually declines. Percent Fat reaches its lowest point at about 16 to 17 years in males and then gradually increases into young adulthood. In contrast to estimates of FM, % Fat declines during male adolescence. The decline is due to the rapid growth of FFM and slower accumulation of FM at this time. As such, fat contributes a lesser percentage to body mass in male adolescence.

To illustrate the impact of adolescence on body composition, differences in estimates of body composition between early and late adolescence are summarized in Table 3. Corresponding data for a mixed-longitudinal sample of youth from the Fels Longitudinal Study are included for comparison [40]. The Fels data are derived from subjects who had at least six serial measurements of Db between 8 and 23 years. A multicomponent model that included

Table 3
Estimated differences in densitometric estimates of body composition from early to late adolescence

	Males	Females
Composite sample[a]		
FFM	32.5 kg	17.3 kg
FM	3.2 kg	7.1 kg
% Fat	−2.7%	+5.0%
Fels sample[b]		
FFM	31.3 kg	14.0 kg
FM	3.4 kg	7.4 kg
% Fat	−3.5%	+3.8%

[a] *Adapted from* Malina et al. [39] and Malina [38], compiled from the literature. Estimates are differences between 10–11 and 18–19 years.
[b] Estimated from Guo et al. [40], mixed-longitudinal data. Estimates are the differences between two age groups, 10–12 and 18–20 years.

age-specific and sex-specific estimates of the density and major components of FFM was used to derive % Fat, FM, and FFM [40]. Allowing for methodologic variation, the estimates are reasonably similar. Males gain almost twice as much FFM as females over adolescence, and females gain about twice as much FM as males. The net result is a decline in relative fatness in males and an increase in relative fatness in females.

A major portion of changes in body composition over adolescence is concentrated in the interval of rapid growth in height. Peak height velocity (PHV) occurs, on average, at 12 and 14 years of age in a sample of North American and European girls and boys [35]. Assuming 1 year each side of PHV, the interval between 11 and 13 years in girls and 13 and 15 years in boys provides an estimate of changes in body composition at this time (Table 4). The interval of maximal growth in height accounts for about 40% of the total adolescent gain in FFM and FM. Although these estimates are based on cross-sectional data from the literature, they correspond reasonably well with limited data from longitudinal studies. Czech boys, many of whom were athletes, gained

Table 4
Estimated changes in FFM, FM and % Fat during the interval of maximal growth in height during the adolescent spurt[a]

	Total gain/loss		Annual gain/loss	
	Females	Males	Females	Males
FFM	7.1 kg	14.3 kg	3.5 kg/yr	7.2 kg/yr
FM	2.8 kg	1.5 kg	1.4 kg/yr	0.7 kg/yr
% Fat	1.7%	−1.1%	0.9%/yr	−0.5%/yr

Based on the composite data summarized in Table 2.
[a] Adolescent spurt: ∼11–13 years in girls and ∼13–15 years in boys.

about 7.5 kg/y in FFM and 0.8 kg/y in FM and declined about 0.4%/y in % Fat near the time of PHV [41]. The decline in relative fatness is an effect of the larger increase in FFM, so that FM, although increasing slightly, contributes a small percentage of body mass at this time. In the mixed-longitudinal sample from the Fels study (see Table 2), peak gain in FFM was about 7 kg/y in boys, whereas no clear spurt in FFM was evident in girls [40]. In a separate analysis of adolescent changes in total body bone mineral content, peak gains occurred, on average, a bit more than one half of a year after PHV in both sexes. Estimated peak gain in BMC was, on average, greater in boys, 407 $\pm$ 93 g/y, than in girls, 325 $\pm$ 67 g/y [42]. Peak gain in bone mineral content occurred closer to the age of menarche, suggesting that adolescent growth in bone mineral is closely related to sexual maturation in girls [42].

BODY COMPOSITION OF ATHLETES

Why Estimate the Body Composition of Athletes?

It is important to know how the different components of body composition vary with age, sex, and maturity status, especially during adolescence. Likewise, it is important to understand the influence of systematic training for sport on body composition. Many discussions of body composition in athletes focus on relative fatness because of the potentially negative influence of excessive fatness on performance. Focus of such discussions is often on female athletes, usually in the context of low levels of fatness, late sexual maturation, menstrual irregularities, and disordered eating. Weight control and in many instances reduction are issues with many athletes. Associated concerns are potential metabolic complications with long-term weight reduction [23] and weight control behaviors that may lead to complications of disordered eating, particularly among female athletes. Among male athletes, there is concern for low levels of fatness of males in weight category sports, specifically wrestling.

Youth Athletes

The body composition of young athletes is influenced by their growth and maturity status. With few exceptions, young athletes of both sexes tend to be at or above median reference values in height and mass; exceptions are gymnasts of both sexes and female figure skaters. Elite young male athletes tend to be, on average, advanced in maturity status, although there is variation among sports. Earlier maturation in males is associated with larger size and FFM, greater strength and power, and a lower % Fat compared with average ("on time") and later maturing peers of the same chronologic age. The size, strength, and power associated with earlier maturation in males are an advantage in many sports. Elite young female athletes tend to be, on average, average and later in maturity status compared with peers of the same chronologic age. Later maturation in females is associated with smaller body size, a more linear physique, lower % Fat, and generally better performances compared with early maturing peers [35]. Discussions of the body composition of young athletes should consider individual differences in maturity status; studies rarely consider maturity-association variation among young athletes. Variation associated with individual differences in biologic maturation is a potential confounding factor in evaluating the body composition of young athletes.

Because FFM follows a growth pattern similar to that for height and mass, and FFM is highly correlated with height and mass, most studies of body composition of young athletes emphasize % Fat. As noted, excessive fatness tends to exert a negative influence on performances, especially performances that require the movement or projection of the body through space (ie, running, jumping, vaulting), in contrast to those that require projection of objects (ie, shot put, discus throw). Coaches of young athletes often focus on weight control and relative fatness. Middle school, high school, and collegiate wrestling currently set minimum weight or % Fat requirements (see later).

Estimates of the relative fatness of adolescent athletes in a variety of sports are shown relative to data for nonathletes in Fig. 1. The estimates are means based on densitometry with one exception; data for a sample of female gymnasts based on DXA also are included. Allowing for variation among samples and in methodology, athletes as a rule have a lower % Fat than nonathletes of the same chronologic age. Male athletes and nonathletes show a decrease in % Fat during adolescence; athletes have less relative fatness at most ages, but there is considerable overlap (Fig. 1A). In contrast, % Fat in female athletes tends to be reasonably stable across adolescence, whereas that for nonathletes increases with age (Fig. 1B). The difference in % Fat between female athletes

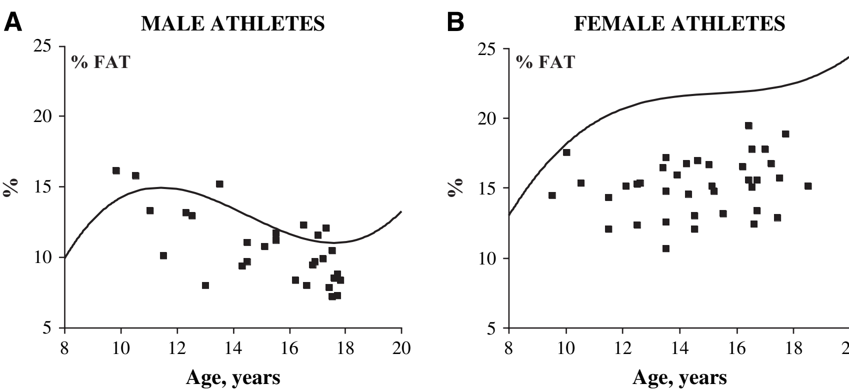

Fig. 1. Estimates of % Fat in samples of youth athletes. (*A*) Males. (*B*) Females. Male athletes include cyclists, wrestlers, gymnasts, runners, jumpers, and volleyball, ice hockey, and American football players. Female athletes include swimmers, runners, jumpers, gymnasts, and speed skaters. (See ref. [35] for sources of data. Data for the nonathlete reference from Malina et al [35,39].)

and nonathletes is greater than that between male athletes and nonathletes. Allowing for the sports represented, there seems to be more variation in % Fat among female than male athletes 14 to 18 years old.

Young Adult Athletes

Estimated % Fat in young adult male and female athletes in numerous sports is summarized in Tables 5 and 6. Most data are based on body density derived from hydrostatic weighing; estimates based on other methods are limited. Data for youth and adult track and field athletes by discipline are considered separately (see later).

The data summarized in Tables 5 and 6 provide an overview of estimated relative fatness and associated variation in young adult athletes in a variety of sports. Samples sizes are generally small, and many sports are not well represented. Corresponding estimates for % Fat predicted from skinfold measurements in national-level Polish athletes [43] and American intercollegiate female athletes in numerous sports are summarized in Tables 7 and 8, respectively. Within corresponding sports, % Fat of female athletes is, on average, greater than that of male athletes. Variation in % Fat by position or event within a sport is apparent for American football players (see Table 5), but is not marked among female basketball, volleyball, and track and field athletes, with the exception of the throwing events (Table 8).

The ethnic composition of samples of athletes is not usually reported; this is relevant given ethnic variation in body proportions and composition [13]. Ethnic variation in bone mineral content between American blacks and whites has been long documented [13] and influences estimates of Db via hydrostatic weighing [44]. Observations using more recent technology indicate that black women have a larger appendicular skeletal muscle mass than white women matched for age, body size, and menstrual status [45,46]. The ethnic difference is more marked in the upper than the lower extremity [45]. Limited data for American black and white males show less ethnic variation in limb musculature, but after adjustment for age, height, and mass, skeletal muscle mass of the legs is significantly larger in American blacks of both sexes. The ethnic difference also persists after adjusting for variation in relative leg length. Arm skeletal muscle mass also is significantly larger in American blacks of both sexes after adjusting for age and mass and for relative arm length [47].

The preceding observations on ethnic variation are based on nonathletes. Corresponding body composition data for athletes are limited. Estimated fatness (hydrostatic weighing) of collegiate football players is lower in black (14.7 ± 5.6%, $n = 55$) than white (19.0 ± 7.1%, $n = 35$) players [48]. Relative fatness estimated from skinfold measurements gives similar estimates, but BIA tends to overestimate % Fat based on Db, and near-infrared spectrophotometry tends to underestimate % Fat based on Db in black and white players [48]. Among female collegiate athletes, differences in estimated % Fat predicted from skinfold measurements between black and white athletes are, on average,

Table 5
Relative fatness (% Fat) in samples of male athletes in several sports

Sport	Age (y)			% Fat			Reference
	n	Mean	SD	Method	Mean	SD	
Badminton	7	24.5	3.6	HW	12.8	3.1	[21]
Baseball	10	20.8	9.9	TBW	14.2	6.7	[69]
Basketball	10	20.9	1.3	HW	10.5	3.8	[62]
Basketball	11	25.7	3.1	HW	9.7	3.1	[21]
Canoeing/kayaking	19	21.1	7.1	HW	13.0	2.5	[65]
Cycling	11	22.2	3.6	HW	10.5	2.4	[21]
Cycling	11	21.7	1.7	TBW	13.7	2.3	[66]
Cycling	13	24.1	3.1	HW	11.2	3.3	[67]
Cycling	63	21.9	3.2	HW	11.8	3.3	[65]
Field hockey	14	23.7	3.6	HW	10.3	4.4	[21]
Football by modality							
American football	21	19.9		^{40}K	9.5		[68]
American football	16	20.3	0.9	TBW	13.8	6.7	[69]
American football	65	17–23		HW	15.0	5.8	[70]
Defensive back	15			HW	11.5	2.7	
Offensive back, receiver	15			HW	12.4	5.3	
Defensive lineman	15			HW	18.5	4.4	
Defensive linebacker	7			HW	13.4	4.1	
Offensive lineman	13			HW	19.1	7.0	
American football							[71]
Defensive back	26	24.5	3.2	HW	9.6	4.2	
Offensive back, receiver	40	24.7	3.0	HW	9.4	4.0	
Quarterback, kicker	16	24.1	2.7	HW	14.4	6.5	
Defensive lineman	32	25.7	3.4	HW	18.2	5.4	
Defensive linebacker	28	24.2	2.4	HW	14.0	4.6	
Offensive lineman	38	24.7	3.2	HW	15.6	3.8	
American football, blacks	55	19.4	1.2	HW	14.7	5.6	[48]
American football, whites	35	19.7	1.5	HW	19.0	7.1	[48]
Australian rules	23	24.5	4.3	HW	8.0	3.0	[21]
Rugby union	16	24.2	3.3	HW	10.3	3.2	[21]
Soccer	9	24.8	1.9	TBW	6.2	1.9	[72]
Soccer	18	26.0	—	HW	9.6	—	[73]
Soccer	22	24.5	3.5	HW	6.9	3.3	[74]
Soccer	12	25.3	4.0	HW	9.7	3.0	[21]
Gymnastics	7	20.3	0.9	TBW	4.6	3.3	[69]
Gymnastics	8	20.2	2.7	HW	7.9	1.4	[21]
Ice hockey	27	24.9	3.6	HW	9.2	4.6	[75]
Lacrosse	26	26.7	4.2	HW	12.3	4.3	[21]
Rowing	8	24.7	3.2	TBW	7.3	1.3	[72]
Rowing	7	24.7	1.9	HW	11.2	1.4	[21]

(*continued on next page*)

Table 5
(*continued*)

Sport	Age (y)			% Fat			Reference
	n	Mean	SD	Method	Mean	SD	
Skiing	9	25.9	2.9	HW	6.3	1.9	[76]
Skiing, cross-country	11	22.8	1.9	HW	7.2	1.9	[75]
Skiing, cross-country	11	24.0	4.5	HW	12.3	4.6	[65]
Speed skating	33	18.4	2.9	HW	11.2	2.8	[65]
Speed skating	6	22.2	4.1	HW	7.4	2.5	[78]
Squash	9	22.6	6.8	HW	11.2	3.7	[21]
Swimming	7	20.6	1.2	TBW	5.0	4.5	[69]
Swimming	13	21.8	2.2	HW	8.5	2.9	[76]
Swimming	14	19.9	2.3	TBW	7.5	3.0	[72]
Swimming	39	19.1	4.5	HW	12.3	4.6	[65]
Volleyball	19	23.8	3.2	HW	11.2	2.8	[65]
Volleyball	11	20.9	3.7	HW	9.8	2.9	[21]
Water polo	10	25.8	4.6	TBW	8.8	2.6	[72]

Abbreviations: HW, hydrostatic weighing; TBW, total body water; ^{40}K, potassium 40.

quite small (see Table 8) and within the range of error associated with the prediction equation [49].

Adolescent and Young Adult Track and Field Athletes

Data on the size, physique, and body composition of track and field athletes in specific events within the sport are more extensive compared with other sports and span early adolescence through young adulthood. The literature dealing with track and field athletes is diverse and can be summarized in the framework of four general themes: (1) talent identification and selection; (2) interest in the growth, body composition, and functional characteristics of elite young athletes in a variety of sports; (3) increased popularity of distance running for children and adolescents; and (4) interest in the comparative morphology of athletes in general. The data often include estimates of % Fat based primarily on measured Db and predicted Db based on skinfold measurements; estimates based on other methods are limited [50]. The data permit evaluation of variation in % Fat by event. Estimates of mean % Fat are summarized in Figs. 2, 3, and 4 for sprinters and hurdlers, middle and long distance runners, and jumpers and throwers. Corresponding estimates for specific jumping and throwing disciplines, pole vaulters, race walkers, and decathletes are not extensive. Data for adolescents and young adults from the general population are included for comparison.

Most samples of male sprinters and hurdlers tend to be below the reference in % Fat from early adolescence into young adulthood, although there is some overlap during adolescence (Fig. 2A). In contrast, % Fat of female sprinters and hurdlers is well below the reference (Fig. 2B).

Estimates of % Fat among middle and long distance runners show considerable overlap within sex, although there seems to be more variation among

Table 6
Relative fatness (% Fat) in samples of female athletes in several sports

	Age (y)			% Fat			
Sport	*n*	Mean	SD	Method	Mean	SD	Reference
Badminton	6	23.0	5.3	HW	21.0	2.1	[22]
Basketball	18	22.9	2.6	HW	20.1	4.0	[22]
Canoeing/kayaking	21	21.2	3.7	HW	22.2	4.6	[65]
Field hockey	13	19.8	1.4	HW	21.3	7.1	[79]
Field hockey	17	22.6	2.3	HW	20.2	6.0	[22]
Field hockey	10	19.8	1.2	DXA	18.3	2.7	[80]
Gymnastics	5	19.0	3.8	TBW	12.9	1.4	[81]
Gymnastics	44	19.4	1.1	HW	15.3	4.0	[82]
Gymnastics	15	19.8	1.0	DXA	19.1	2.2	[80]
Gymnastics, rhythmic	7	20.7	2.7	HW	15.6	5.1	[65]
Handball, team	17	23.2	1.9	HW	19.0	3.7	[65]
Lacrosse	17	24.4	4.5	HW	19.3	5.7	[22]
Netball	7	23.7	4.2	HW	17.8	3.8	[22]
Rowing	19	23.6	3.9	HW	18.4	3.9	[65]
Rowing	22	20.4	1.9	DXA	21.9	2.3	[80]
Rowing, lightweight	5	19.4	7.5	HW	20.7	3.1	[22]
Rowing, heavyweight	7	20.5	3.4	HW	24.2	4.2	[22]
Skiing, cross country	5	23.5	4.7	HW	16.1	1.6	[77]
Soccer	10	24.4	4.5	HW	20.8	4.7	[83]
Soccer	11	22.1	4.1	HW	22.0	6.8	[22]
Soccer	10	19.8	0.9	DXA	21.8	2.7	[80]
Softball	14	22.6	4.0	HW	19.1	5.0	[22]
Softball	17	20.4	1.4	DXA	20.9	3.9	[80]
Speed skating	9	19.7	3.0	HW	16.5	4.1	[78]
Squash	6	27.4	5.6	HW	16.0	4.9	[22]
Swimming	19	19.2	0.8	HW	16.1	3.7	[20]
Tennis	7	21.3	0.9	HW	22.4	2.0	[79]
Volleyball	36	21.7	2.5	HW	15.8	4.8	[65]
Volleyball	13	23.0	2.6	HW	11.7	3.7	[84]
Volleyball	13	21.5	0.7	HW	18.3	3.4	[84]
Volleyball	11	22.8	3.4	HW	17.0	3.3	[22]

Abbreviations: HW, hydrostatic weighing; TBW, total body water.

females than males (Fig. 3). Most estimates for males are below the reference during adolescence into young adulthood (Fig. 3A). The reported estimate for a sample of 17-year-old male distance runners (2.6%) is spuriously low. As noted, % Fat of female middle distance and distance runners varies (Fig. 3B). Most values are below the reference value, but several approach the reference in later adolescence. In young adulthood, however, estimates of % Fat are considerably lower, especially in distance runners.

Estimated % Fat of field athletes in jumping and throwing events shows two distributions with little overlap (Fig. 4). The relative fatness of male jumpers is consistently below the reference from adolescence into adulthood. In contrast, % Fat of male adolescent throwers is consistently above the reference, reflecting

Table 7
Anthropometric estimates of predicted relative fatness (% Fat) in national level Polish athletes 19–26 years old

	Males	% Fat		Females	% Fat	
Sport	*n*	Mean	SD	*n*	Mean	SD
Basketball	24	10.4	2.5	31	20.1	4.8
Biathlon	10	10.8	2.0	10	17.2	3.9
Cycling	29	11.6	1.4	—	—	—
Fencing	21	12.0	3.4	15	21.9	4.5
Handball, team	23	12.7	3.1	29	21.9	4.7
Kayaking	29	9.6	2.7	26	16.3	4.3
Rowing	31	10.7	3.0	22	17.7	3.8
Skiing	13	9.6	1.5	10	17.0	1.8
Soccer	30	9.7	2.1	—	—	—
Swimming	—	—	—	13	15.5	2.5
Tennis	—	—	—	7	17.7	1.5
Volleyball	26	10.8	1.7	—	—	—

Relative fatness was estimated from predicted Db using three skinfolds after Piechaczek [85].
Data from Krawczyk B, Sklad M, Majle B. Body components of male and female athletes representing various sports. Biol Sport 1995;12:243–50.

in part their massiveness. Percent Fat tends to decline with age, however, among samples of throwers. Among young adult throwers, estimates for several samples are lower than corresponding values for adolescent throwers and fluctuate above and below the reference values (Fig. 4A).

Female jumpers have relative fatness levels consistently below the reference, and % Fat in young adult jumpers tends to be lower than that for adolescents (Fig. 4B). Percent Fat of female throwers varies above and below the reference in adolescence and young adulthood, which is in contrast to the trend in male throwers. In female jumpers and throwers, variation in % Fat is greater among young adults than among adolescents.

Estimates of % Fat in male track and field athletes except for throwers are generally below the reference. There is considerable overlap among mean estimates for sprinters and hurdlers, middle distance and distance runners, and jumpers, and all have % Fat that is generally lower than in samples of throwers. Trends in % Fat among adolescent track and field athletes should be viewed in two contexts: first, the decline in % Fat that accompanies the growth spurt and sexual maturation in males, and second, the decline in % Fat associated with systematic training [35].

In female track and field athletes, there is considerable overlap in mean estimates of % Fat among for runners of all disciplines and jumpers, and all are, on average, generally below the reference. Relative fatness of female throwers tends to be higher, but estimates fall above and below the reference.

Comparison of % Fat of male and female athletes within the same track and field events suggests several trends: (1) Percent Fat in male sprinters and

Table 8
Anthropometric estimates of predicted relative fatness (% Fat) in female university athletes by sport, event/position, and ethnicity

	Age (y)			% Fat	
Sport	*n*	Mean	SD	Mean	SD
Swimming	87	18.8	0.9	16.5	1.6
Freestyle	37	18.8	0.8	16.3	1.6
Backstroke	18	18.9	1.0	16.8	1.9
Breaststroke	17	18.7	0.7	16.4	1.3
Butterfly	9	19.1	1.0	16.4	1.9
Medley	6	18.9	1.4	17.5	0.8
Diving	19	19.5	1.6	17.4	2.6
Tennis	29	19.0	0.9	17.7	2.4
Golf	32	19.0	0.9	19.1	2.2
Basketball	57	19.5	1.2	16.4	2.2
Guard, white	13	19.4	0.9	16.9	2.1
Guard, black	7	19.6	1.2	14.9	1.2
Wing, white	6	19.3	0.9	16.1	1.4
Wing, black	11	19.8	1.5	15.5	1.7
Post, white	11	19.6	1.4	17.4	3.0
Post, black	9	19.6	1.6	17.1	2.5
Volleyball	47	19.1	0.9	16.9	2.7
Outside hitter	24	19.2	1.0	16.9	3.0
Middle blocker	12	18.7	0.7	17.8	2.6
Setter	6	19.2	0.8	17.0	1.9
Back row	5	19.2	0.5	14.9	1.3
Track and field	116	19.4	1.2	15.4	3.8
Sprint, white	5	21.1	1.4	14.1	0.3
Sprint, black	38	19.3	1.4	14.1	1.4
Middle distance, white	6	18.9	0.6	13.8	1.6
Middle distance, black	5	18.6	0.8	13.6	0.7
Distance, white	29	19.3	1.2	14.2	1.6
Jumps, white	9	19.3	0.9	15.1	1.8
Jumps, black	7	20.0	1.3	14.6	1.4
Throws, white	11	19.5	1.1	22.4	4.1
Throws, black	5	18.7	0.5	23.9	7.8

Relative fatness was estimated from predicted Db from the sum of four skinfolds skinfolds after Meleski et al [20]; see text.

Data from Malina RM, Battista RA, Siegel SR. Anthropometry of adult athletes: concepts, methods and applications. In: Driskell JA, Wolinsky I, editors. Nutritional assessment of athletes. Boca Raton (FL): CRC Press; 2002. p. 135–75.

hurdlers is only slightly lower than and overlaps the male reference, whereas corresponding estimates of % Fat in female athletes in these events are well below the female reference. (2) Percent Fat varies from early adolescence through adolescence into young adulthood in male and female middle distance and distance runners; it is considerably lower than the reference among female runners, whereas % Fat in male runners approximates the male reference at

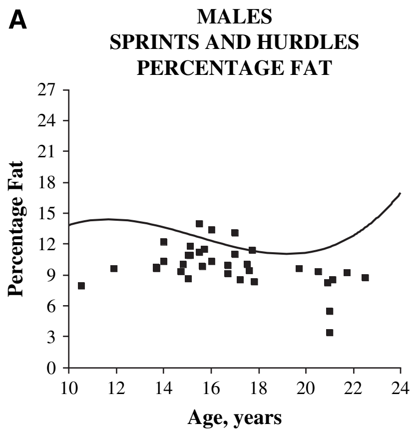

Fig. 2. Estimates of % Fat in samples of adolescent and young adult sprinters and hurdlers. (*A*) Males. (*B*) Females. (See ref. [50] for sources of data. Data for the nonathlete reference from Malina et al [35,39].)

many ages (3). The same general trend is apparent in jumpers and throwers. Percent Fat in female jumpers is well below the female reference, whereas it is quite close to the reference in male jumpers. Percent Fat in female throwers straddles the reference, but is above the reference in male throwers, especially in adolescence. Relative fatness tends to be lower in young adult compared with adolescent male throwers; such variation with age is lacking in female throwers.

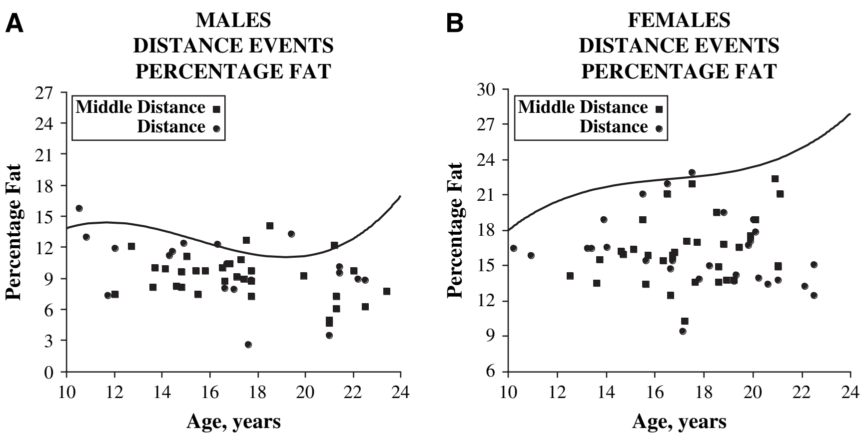

Fig. 3. Estimates of % Fat in samples of adolescent and young adult middle distance and distance runners. (*A*) Males. (*B*) Females. (See ref. [50] for sources of data. Data for the nonathlete reference from Malina et al [35,39].)

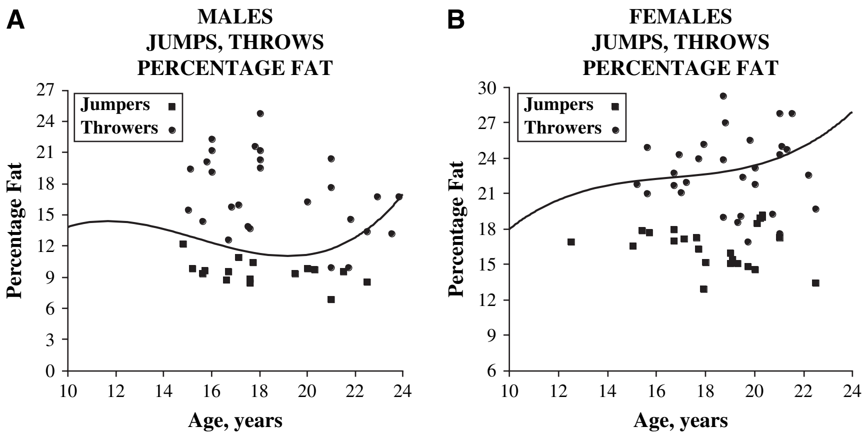

Fig. 4. Estimates of % Fat in samples of adolescent and young adult field athletes in jumping and throwing events. (*A*) Males. (*B*) Females. (See ref. [50] for sources of data. Data for the nonathlete reference from Malina et al [35,39].)

Wrestling

Weight management and specifically weight reduction are concerns in wrestling. Organizations associated with the sport have developed guidelines for minimum weight, defined as the lowest weight that an individual can maintain without comprising health [23]. Wrestling rules of the National Federation of State High School Associations [51] mandates the following:

> Each state association shall develop and use a weight-management program that includes a specific gravity not to exceed 1.025; a body fat assess no lower than seven percent for males/12 percent for females; and a monitored weekly weight loss plan not to exceed 1.5 percent a week.

The American College of Sports Medicine [52] suggests the following for young wrestlers:

> Assess the body composition of each wrestler before the season using valid methods for this population. Males 16 years old and younger with body fat below 7 percent or those over 16 with a body fat below 5 percent need medical clearance before being allowed to compete. Female wrestlers need minimal body fat of 12–14 percent.

The National Collegiate Athletic Association uses 5% Fat as the minimum allowable in weight certification formulas for wrestlers; however, body composition guidelines emphasize that estimates of body composition focus on a range of variation [53].

A key issue in putting the proposed guidelines into action relates to methods of estimating body composition and associated errors. Estimates derived from different methods may not be directly comparable. Some high school associations and school districts specify the type of estimate (DXA, BIA, skinfold measurements) at times with associated costs.

In one of the few detailed studies, body composition was assessed via hydrostatic weighing in the preseason, late season, and postseason in a sample of 9 male wrestlers 15.4 ± 0.3 years old [54,55]. Percent Fat at the three measuring points was 9.9 ± 0.5%, 8.0 ± 0.7% and 12.3 ± 0.8%. Corresponding estimates of FFM were 54.3 ± 3.1 kg, 53.2 ± 3 kg, and 56.2 ± 3.1 kg. The changes are relatively small and need to be viewed in the context of growth and maturation. Although body mass declined from the preseason to late season and increased into the postseason, linear growth, skeletal maturation, and growth-related hormones were not affected.

Among collegiate wrestlers competing at national tournaments (top 5–10% of wrestlers within each division), % Fat based on skinfold measurements was compared from the preseason to the competition [56]. Body mass and % Fat declined from the preseason to the tournament, 74.0 ± 11.1 kg to 71.5 ± 10.4 kg for mass and 12.3 ± 3.4% to 9.5 ± 1.8%. Mean minimal weights established for each wrestler in the preseason did not differ at the tournament.

TRAINING AND BODY COMPOSITION

Body composition is responsive to the demands of systematic training, as is evident in the observations on wrestlers. It is essential to consider separately observations in growing and maturing youth and in mature adults. Of relevance, are changes in body composition associated with training greater than those associated with normal growth and maturation? The increase in FFM (hydrostatic weighing) observed in youth regularly active in sport from 11 to 17 years old would seem to suggest an increase greater than that expected with normal growth and maturation [57,58]. This group of boys was larger in size and advanced in biologic maturation, however, compared with their age peers not engaged in sport. Similarly, among boys 11 to 13 years old undergoing a 5-month endurance training program, larger FFM (^{40}K) were observed in boys advanced in sexual maturation [59], suggesting perhaps that the boys were in their growth spurts [35]. The two studies highlight the difficulties in attempting to partition changes in body composition associated with training from 11 to 17 years old or with a short-term training program from the changes that accompany normal growth and maturation during male adolescence. Much of the variation in body composition in both studies was associated with a reduction in fatness.

Corresponding observations for girls are limited. A program of 30 minutes of high-impact aerobic and strength training activities three times per week for10 months was associated with increases in FFM (2.2 ± 1.1 kg) and FM (0.5 ± 0.8 kg) in 9- to 10-year-old girls [60]. Girls of the same age, body size, composition, and stage of sexual maturity who followed their normal pattern of activity for 10 months also increased in FFM (1.4 ± 1.4 kg) and FM (1.0 ± 0.8 kg). Both groups gained in FFM and FM, and there was, on average, no decrease in fatness. There also was considerable overlap between the trained and normal activity groups. Although the results are suggestive, they indicate difficulties inherent in attempting to partition growth-related from training-related changes in estimated body composition in adolescents [35].

Studies comparing changes in body composition associated with training in young adults generally compare pretraining and post-training means for FFM and % Fat, but duration of training programs and frequency of training vary. In addition, the samples do not comprise athletes. Using data reported by Wilmore [61], differences between pretraining and post-training means in nine studies of males 18 to 23 years old range from −0.2 kg to +1.4 kg for FFM (overall mean +0.8 kg) and −0.4% to −3.0% for relative fatness (overall mean −1.7%). Corresponding differences for 10 studies of females 18 to 22 years old range from −1.7 kg to +1.5 kg for FFM (overall mean +0.3 kg) and −2.1% to +3.1% for relative fatness (overall mean −0.4%). The persistence of changes associated with training are not usually considered; a relevant question is the following: How much training is needed to maintain changes in body composition induced by systematic training?

SEASONAL VARIATION IN BODY COMPOSITION IN ATHLETES

An issue related to the influence of training on body composition is changes in body composition of athletes during the course of a season. Studies commonly compare the body composition of athletes before and at the close of a competitive season [62,63]. Of potential relevance is variation in body composition associated with preseason or early season and in-season training protocols. This variation was considered in a sample of 15 elite university-level female swimmers who had their body composition estimated via densitometry at three points during a competitive season: October, December, and March [64]. Weight training with emphasis on high-repetition and low-resistance activities typically preceded swim training early in the season. Decreases in body mass (−1.3 ± 1.8 kg), FM (−2.4 ± 1.2 kg) and % Fat (−3.8 ± 1.9%) and an increase in FFM (1.1 ± 1.8 kg) characterized the early part of the season between October and December. These changes were generally maintained during the second part of the season, December to March, as the swimmers tapered in preparation for the national championships. Over this interval, changes in body mass (0.8 ± 1.2 kg), FM (0.8 ± 1.5 kg) and % Fat (1.2 ± 2%) were small, and FFM, on average, did not change (0 ± 1.1 kg). The results suggest that changes in body composition over the course of a season were concentrated primarily in the early part of the season. Corresponding changes in estimated body composition using anthropometric indicators have been described for female collegiate distance runners and basketball players [49].

BODY MASS INDEX AND ATHLETES

Many programs monitor the heights and weights of athletes in the form of the BMI. As noted, the BMI is reasonably well correlated with FM and % Fat in large and heterogeneous samples, but correlations between the BMI and FFM and FM are reasonably similar among youth [35]. A question of interest is the association between the BMI and indicators of body composition at the

Table 9
Correlations between the body mass index and estimates of fatness and muscularity in female university athletes and nonathletes grouped by category of body mass index

	Athletes							Nonathletes			
				Estimated Muscle Circumference						Estimated Muscle Circumference	
				Arm		Calf				Arm	Calf
BMI (kg/m^2) Category	*n*	∑8 skf	% Fat	T + B	T only	M + L	M only	*n*	% Fat	T only	M only
<18.5	14	0.68	0.64	0.10	−0.08	0.10	0.05	19	0.61	0.27	0.39
18.5 < 25.0	350	0.39	0.42	0.57	0.50	0.44	0.37	79	0.44	0.34	0.15
≥25.0	23	0.70	0.82	0.88	0.83	0.66	0.52	13	0.88	−0.36	−0.50

∑8 skf, sum of the triceps, biceps, forearm, subscapular, suprailiac, midthigh, medial calf, and lateral calf skinfold thicknesses; % Fat, based on predicted Db using an equation developed on elite female swimmers [20]; T+B, arm circumference corrected for the thickness of the triceps and biceps skinfolds; T only, arm circumference corrected for the thickness of the triceps skinfold only; M + L, calf circumference corrected for the thickness of the medial and lateral calf skinfolds; M only, calf circumference corrected for the thickness of the medial calf skinfold only [30].

Data from Malina RM, Battista RA, Siegel SR. Anthropometry of adult athletes: concepts, methods and applications. In: Driskell JA, Wolinsky I, editors. Nutritional assessment of athletes. Boca Raton (FL): CRC Press; 2002. p. 135–75.

extremes of the BMI distribution. This was addressed in a large sample of female athletes using anthropometric indicators of body composition (Table 9). Although numbers of athletes with low (<18.5 kg/m^2) and high ($\geq$25 kg/m^2) BMI are small, the trends in correlations suggest variable relationships. Among athletes with a BMI in the normal range (18.5 $<$ 25 kg/m^2), correlations between estimates of fatness and muscularity are moderate and reasonably similar, ranging from 0.37 to 0.57. Correlations for % Fat and arm muscle are similar for nonathlete female college students with a BMI in the normal range, 0.44 and 0.34, although that for estimated calf muscle is lower, 0.15. Among those with a low BMI, correlations for fatness are higher and similar in athletes and nonathletes, 0.61 to 0.68. Correlations for estimated limb musculature and the BMI are low in athletes, −0.08 to 0.10, however, and higher in nonathletes, 0.27 and 0.39. Among those with a high BMI, correlations for fatness and estimated limb muscle circumferences are higher in athletes, 0.52 to 0.88, compared with athletes in the other two BMI categories. A similar high correlation, 0.88, is evident for % Fat in nonathletes with a high BMI, but correlations for limb musculature in nonathletes are negative. Overall, the data suggest variation in the association of the BMI and indirect estimates of fatness and muscularity at the extremes of the BMI distribution and indicate a need for further evaluation of the relationship between the BMI and body composition in athletes and nonathletes.

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