CHAPTER

4

Health-Related Physical Fitness Testing and Interpretation

Evidence as outlined in *Chapter 1* now clearly supports the numerous health benefits that result from regular participation in physical activity and structured exercise programs including enhancement of aerobic capacity (*i.e.*, cardiorespiratory fitness [CRF]). The health-related components of physical fitness have a strong relationship with overall health, are characterized by an ability to perform activities of daily living with vigor, and are associated with a lower prevalence of chronic disease and health conditions and their risk factors (29). Measures of health-related physical fitness and CRF are closely allied with disease prevention and health promotion and can be modified through regular participation in physical activity and structured exercise programs. A fundamental goal of primary and secondary prevention and rehabilitative programs should be the promotion of health; therefore, exercise programs should focus on enhancement of the health-related components of physical fitness including CRF. Accordingly, the focus of this chapter is on the health-related components of physical fitness rather than the skill-related components for the general population (46).

PURPOSES OF HEALTH-RELATED PHYSICAL FITNESS TESTING

Measurement of physical fitness is a common and appropriate practice in preventive and rehabilitative exercise programs. The purposes of health/fitness testing in such exercise programs include the following:

- Educating participants about their present health/fitness status relative to health-related standards and age and sex matched norms.
- Providing data that are helpful in development of individualized exercise prescriptions (Ex R_x) to address all health/fitness components.
- Collecting baseline and follow-up data that allow evaluation of progress by exercise program participants.
- Motivating participants by establishing reasonable and attainable health/fitness goals (see *Chapter 11*).

BASIC PRINCIPLES AND GUIDELINES

The information obtained from health-related physical fitness testing, in combination with the individual's health and medical information, is used by the health/fitness and clinical exercise professional to enable an individual to achieve specific health/fitness goals. An ideal health-related physical fitness test is reliable, valid, relatively inexpensive, and easy to administer. The test should yield results that are indicative of the current state of physical fitness, reflect positive changes in health status from participation in a physical activity or exercise intervention, and be directly comparable to normative data.

PRETEST INSTRUCTIONS

All pretest instructions should be provided and adhered to prior to arrival at the testing facility (see *Chapter 3*). Certain steps should be taken to ensure client safety and comfort before administering a health-related physical fitness test. A minimal recommendation is that individuals complete a self-guided questionnaire such as the Physical Activity Readiness Questionnaire (PAR-Q) (see *Figure 2.1*) (89) or the American Heart Association (AHA)/American College of Sports Medicine (ACSM) Health/Fitness Facility Preparticipation Screening Questionnaire (see *Figure 2.2*) (3,102). A listing of preliminary testing instructions for all clients can be found in *Chapter 3* under "Participant Instructions." These instructions may be modified to meet specific needs and circumstances.

TEST ORGANIZATION

The following should be accomplished before the client/patient arrives at the test site:

- Assure all forms, score sheets, tables, graphs, and other testing documents are organized in the client's or patient's file and available for the test's administration.
- Calibrate all equipment (*e.g.*, metronome, cycle ergometer, treadmill, sphygmomanometer, skinfold calipers) at least monthly, or more frequently based on use; certain equipment such as ventilatory expired gas analysis systems should be calibrated prior to each test according to manufacturers' specifications; and document equipment calibration in a designated folder.
- Organize equipment so that tests can follow in sequence without stressing the same muscle group repeatedly.
- Provide an informed consent form and allow time for the individual undergoing assessment to have all questions adequately addressed (see *Figure 3.1*).
- Maintain room temperature between 68° F and 72° F (20° C and 22° C) and humidity of less than 60% with adequate airflow.

When multiple tests are to be administered, the organization of the testing session can be very important, depending on what physical fitness components are to be evaluated. Resting measurements such as heart rate (HR), blood pressure (BP), height, weight, and body composition should be obtained first. Research has not established an optimal testing order for multiple health-related components of fitness (*i.e.*, cardiorespiratory [CR] endurance, muscular fitness, body composition, and flexibility), but sufficient time should be allowed for HR and BP to return to baseline between tests conducted serially. Because certain medications, such as β-blockers which lower HR, will affect some physical fitness test results, use of these medications should be noted (see *Appendix A*).

TEST ENVIRONMENT

The environment is important for test validity and reliability. Test anxiety, emotional problems, room temperature, and ventilation should be controlled as much as possible. To minimize subject anxiety, the test procedures should be explained adequately, and the test environment should be quiet and private. The room should be equipped with a comfortable seat and/or examination table to be used for resting BP and HR and/or electrocardiographic (ECG) recordings. The demeanor of personnel should be one of relaxed confidence to put the subject at ease. Testing procedures should not be rushed, and all procedures must be explained clearly prior to initiating the process.

BODY COMPOSITION

It is well established that excess body fat, particularly when located centrally around the abdomen, is associated with hypertension, metabolic syndrome, Type 2 diabetes mellitus, stroke, cardiovascular disease (CVD), and dyslipidemia (95). Approximately two-thirds of American adults are classified as overweight (body mass index [BMI] $\geq$25 kg · m^{-2}), and about 33% of these are classified as obese (BMI $\geq$30 kg · m^{-2}). Although the prevalence of obesity has steadily risen over the last three decades, recent data indicate a plateau in obesity trends, particularly in women (23,38). Perhaps more troubling are the statistics relating to children that indicate (a) approximately 32% of children aged 2–19 yr are overweight or obese; and (b) over the past three decades, the percentage of children aged 6–11 yr who are considered obese has increased from approximately 4% to more than 17% (95). Moreover, 2006 data indicate race and sex differences in overweight/obesity, with Black and Hispanic women continuing to have the highest prevalence (95). The troubling data on overweight/obesity prevalence among the adult and pediatric populations and its health implications have precipitated an increased awareness in the value of identifying and treating individuals with excess body weight (26,33,64,105).

Basic body composition can be expressed as the relative percentage of body mass that is fat and fat-free tissue using a two-compartment model. Body composition can be estimated with laboratory and field techniques that vary in terms of complexity, cost, and accuracy (34,65). Different assessment techniques are briefly reviewed in this section, but details associated with obtaining measurements and calculating estimates of body fat for all of these techniques are beyond the scope of the *Guidelines*. For more detailed information, see *ACSM's Resource Manual for Guidelines for Exercise Testing and Prescription, Seventh Edition* (101) and elsewhere (48,51,60). Before collecting data for body composition assessment, the technician must be trained, experienced in the techniques, and already have demonstrated reliability in his or her measurements, independent of the technique being used. Experience can be accrued under the direct supervision of a highly qualified mentor in a controlled testing environment.

ANTHROPOMETRIC METHODS

Body Mass Index

BMI or the Quetelet index is used to assess weight relative to height and is calculated by dividing body weight in kilograms by height in meters squared ($kg \cdot m^{-2}$). For most individuals, obesity-related health problems increase beyond a BMI of 25.0 $kg \cdot m^{-2}$. The *Expert Panel on the Identification, Evaluation, and Treatment of Overweight and Obesity in Adults* (35) defines a BMI of 25.0–29.9 $kg \cdot m^{-2}$ as overweight and BMI of ≥30.0 $kg \cdot m^{-2}$ as obese. BMI fails to distinguish between body fat, muscle mass, or bone. Nevertheless, an increased risk of hypertension, sleep apnea, Type 2 diabetes mellitus, certain cancers, CVD, and mortality are associated with a BMI ≥30.0 $kg \cdot m^{-2}$ (*Table 4.1*) (86). Interestingly, there is compelling evidence to indicate patients diagnosed with congestive heart failure (CHF) actually have improved survival when BMI is ≥30.0 $kg \cdot m^{-2}$, a phenomenon known as the "obesity paradox" (79), for reasons that are not clear (4).

Compared to individuals classified as obese, the link between a BMI in the overweight range (25.0–29.9 $kg \cdot m^{-2}$) and higher mortality risk is less clear. However, a BMI of 25.0–29.9 $kg \cdot m^{-2}$, similar to a BMI ≥30.0 $kg \cdot m^{-2}$, is more convincingly linked to an increased risk for other health issues such as Type 2 diabetes mellitus, dyslipidemia, hypertension, and certain cancers (68). A BMI of <18.5 $kg \cdot m^{-2}$

TABLE 4.1. Classification of Disease Risk Based on Body Mass Index (BMI) and Waist Circumference

		Disease Risk[a] Relative to Normal Weight and Waist Circumference	
	BMI ($kg \cdot m^{-2}$)	Men, ≤102 cm Women, ≤88 cm	Men, >102 cm Women, >88 cm
Underweight	<18.5	—	—
Normal	18.5–24.9	—	—
Overweight	25.0–29.9	Increased	High
Obesity, class			
I	30.0–34.9	High	Very high
II	35.0–39.9	Very high	Very high
III	≥40.0	Extremely high	Extremely high

[a]Disease risk for Type 2 diabetes, hypertension, and cardiovascular disease. Dashes (—) indicate that no additional risk at these levels of BMI was assigned. Increased waist circumference can also be a marker for increased risk even in individuals of normal weight.

Modified from (35).

TABLE 4.2. Predicted Body Fat Percentage Based on Body Mass Index (BMI) for African American and White Adults[a]

BMI (kg · m^{-2})	Health Risk	20–39 yr	40–59 yr	60–79 yr
Men				
<18.5	Elevated	<8%	<11%	<13%
18.6–24.9	Average	8%–19%	11%–21%	13%–24%
25.0–29.9	Elevated	20%–24%	22%–27%	25%–29%
>30	High	≥25%	≥28%	≥30%
Women				
<18.5	Elevated	<21%	<23%	<24%
18.6–24.9	Average	21%–32%	23%–33%	24%–35%
25.0–29.9	Elevated	33%–38%	34%–39%	36%–41%
>30	High	≥39%	≥40%	≥42%

[a]Standard error of estimate is ±5% for predicting percent body fat from BMI (based on a four compartment estimate of body fat percentage).

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also increases mortality risk and is responsible for the lower portion of the J-shaped curve when plotting risk on the y-axis and BMI on the x-axis (39). The use of specific BMI values to predict percent body fat and health risk can be found in *Table 4.2* (41). Because of the relatively large standard error of estimating percent body fat from BMI (±5% fat) (34), other methods of body composition assessment should be used to estimate percent body fat during a physical fitness assessment.

Circumferences

The pattern of body fat distribution is recognized as an important indicator of health and prognosis (28,90). Android obesity that is characterized by more fat on the trunk (*i.e.*, abdominal fat) increases the risk of hypertension, metabolic syndrome, Type 2 diabetes mellitus, dyslipidemia, CVD, and premature death compared with individuals who demonstrate gynoid or gynecoid obesity (*i.e.*, fat distributed in the hip and thigh) (85). Moreover, among individuals with increased abdominal fat, higher levels in the visceral compartment confer a higher risk for development of the metabolic syndrome compared to a similar distribution of fat within the subcutaneous compartment (40).

Circumference (or girth) measurements may be used to provide a general representation of body composition, and equations are available for both sexes and a range of age groups (103,104). The accuracy may be within 2.5%–4.0% of the actual body composition if the subject possesses similar characteristics to the original validation population and the girth measurements are precise. A cloth tape measure with a spring-loaded handle (*e.g.*, Gulick tape measure) reduces skin compression and improves consistency of measurement. Duplicate measurements are recommended at each site and should be obtained in a rotational instead of a consecutive order (*i.e.*, take measurements of all sites being assessed and then repeat the sequence). The average of the two measures is used provided they do not differ by more than 5 mm. *Box 4.1* contains a description of the common measurement sites.

The waist-to-hip ratio (WHR) is the circumference of the waist (above the iliac crest) divided by the circumference of the hips (see *Box 4.1* for buttocks/hips

BOX 4.1 Standardized Description of Circumference Sites and Procedures

Abdomen:	With the subject standing upright and relaxed, a horizontal measure taken at the height of the iliac crest, usually at the level of the umbilicus.
Arm:	With the subject standing erect and arms hanging freely at the sides with hands facing the thigh, a horizontal measure midway between the acromion and olecranon processes.
Buttocks/Hips:	With the subject standing erect and feet together, a horizontal measure is taken at the maximal circumference of buttocks. This measure is used for the hip measure in a waist/hip measure.
Calf:	With the subject standing erect (feet apart ~20 cm), a horizontal measure taken at the level of the maximum circumference between the knee and the ankle, perpendicular to the long axis.
Forearm:	With the subject standing, arms hanging downward but slightly away from the trunk and palms facing anteriorly, a measure is taken perpendicular to the long axis at the maximal circumference.
Hips/Thigh:	With the subject standing, legs slightly apart (~10 cm), a horizontal measure is taken at the maximal circumference of the hip/proximal thigh, just below the gluteal fold.
Mid-Thigh	With the subject standing and one foot on a bench so the knee is flexed at 90 degrees, a measure is taken midway between the inguinal crease and the proximal border of the patella, perpendicular to the long axis.
Waist:	With the subject standing, arms at the sides, feet together, and abdomen relaxed, a horizontal measure is taken at the narrowest part of the torso (above the umbilicus and below the xiphoid process). The National Obesity Task Force (NOTF) suggests obtaining a horizontal measure directly above the iliac crest as a method to enhance standardization. Unfortunately, current formulae are not predicated on the NOTF suggested site.

BOX 4.1 Standardized Description of Circumference Sites and Procedures (*Continued*)

Procedures

- All measurements should be made with a flexible yet inelastic tape measure.
- The tape should be placed on the skin surface without compressing the subcutaneous adipose tissue.
- If a Gulick spring-loaded handle is used, the handle should be extended to the same marking with each trial.
- Take duplicate measures at each site and retest if duplicate measurements are not within 5 mm.
- Rotate through measurement sites or allow time for skin to regain normal texture.

Modified from (18).

measure) and has traditionally been used as a simple method for assessing body fat distribution and identifying individuals with higher and more detrimental amounts of abdominal fat (34,85). Health risk increases as WHR increases, and the standards for risk vary with age and sex. For example, health risk is *very high* for young men when WHR is >0.95 and for young women when WHR is >0.86. For individuals aged 60–69 yr, the WHR cutoff values are >1.03 for men and >0.90 for women for the same high-risk classification as young adults (51).

The waist circumference may also be used as an indicator of health risk because abdominal obesity is the primary issue (20,28). The Expert Panel on the Identification, Evaluation, and Treatment of Overweight and Obesity in Adults provides a classification of disease risk based on both BMI and waist circumference as shown in *Table 4.1* (35). Previous research has demonstrated that the waist circumference thresholds shown in *Table 4.1* effectively identify individuals at increased health risk across the different BMI categories (56). Furthermore, a newer risk stratification scheme for adults based on waist circumference has been proposed (see *Table 4.3*) (14). Several methods for waist circumference measurement involving different anatomical sites are available. Evidence indicates that all currently available waist circumference measurement techniques

TABLE 4.3. Risk Criteria for Waist Circumference in Adults

	Waist Circumference cm (in)	
Risk Category	**Women**	**Men**
Very low	<70 cm (<28.5 in)	<80 cm (31.5 in)
Low	70–89 (28.5–35.0)	80–99 (31.5–39.0)
High	90–110 (35.5–43.0)	100–120 (39.5–47.0)
Very high	>110 (>43.5)	>120 (>47.0)

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are equally reliable and effective in identifying individuals at increased health risk (96,108).

Measurement of Waist Circumference

Measurement of waist circumference immediately above the iliac crest, as proposed by National Institutes of Health guidelines, may be the preferable circumference method to assess health risk given the ease by which this anatomical landmark is identified (25).

Skinfold Measurements

Body composition determined from skinfold thickness measurements correlates well (r = 0.70–0.90) with body composition determined by hydrodensitometry (48). The principle behind skinfold measurements is that the amount of subcutaneous fat is proportional to the total amount of body fat. It is assumed that close to one-third of the total fat is located subcutaneously. The exact proportion of subcutaneous to total fat varies with sex, age, and race (94). Therefore, regression equations used to convert sum of skinfolds to percent body fat should consider these variables for greatest accuracy. *Box 4.2* presents a standardized description of skinfold sites and procedures. Refer to *ACSM's Resource Manual for Guidelines for Exercise Testing and Prescription, Seventh Edition* (101) for additional descriptions of skinfold sites. Skinfold assessment of body composition is very dependent on the expertise of the technician, so proper training (*i.e.*, knowledge of anatomical landmarks) and ample practice of the technique is necessary to obtain accurate measurements. The accuracy of predicting percent body fat from skinfolds is approximately ±3.5%, assuming appropriate techniques and equations have been used (51).

Factors that may contribute to measurement error within skinfold assessment include poor technique and/or an inexperienced evaluator, an extremely obese or extremely lean subject, and an improperly calibrated caliper (*i.e.*, tension should be set at $\sim$12 g · mm^{-2}) (49). Various regression equations have been developed to predict body density or percent body fat from skinfold measurements. For example, *Box 4.3* lists generalized equations that allow calculation of body density without a loss in prediction accuracy for a wide range of individuals (49,54). Other equations have been published that are sex, age, race, fat, and sport specific (50). At a minimum, simple anthropometric measurements should be included in the health assessment of all individuals.

Anthropometric Measurements

Although limited in the ability to provide highly precise estimates of percent body fat, anthropometric measurements (*i.e.*, BMI, WHR, waist circumference, and skinfolds) provide valuable information on general health and risk stratification. As such, inclusion of these easily obtainable variables during a comprehensive health/fitness assessment is beneficial.

BOX 4.2 Standardized Description of Skinfold Sites and Procedures

SKINFOLD SITE

Abdominal	Vertical fold; 2 cm to the right side of the umbilicus
Triceps	Vertical fold; on the posterior midline of the upper arm, halfway between the acromion and olecranon processes, with the arm held freely to the side of the body
Biceps	Vertical fold; on the anterior aspect of the arm over the belly of the biceps muscle, 1 cm above the level used to mark the triceps site
Chest/Pectoral	Diagonal fold; one-half the distance between the anterior axillary line and the nipple (men), or one-third of the distance between the anterior axillary line and the nipple (women)
Medial calf	Vertical fold; at the maximum circumference of the calf on the midline of its medial border
Midaxillary	Vertical fold; on the midaxillary line at the level of the xiphoid process of the sternum. An alternate method is a horizontal fold taken at the level of the xiphoid/sternal border in the midaxillary line
Subscapular	Diagonal fold (at a 45-degree angle); 1–2 cm below the inferior angle of the scapula
Suprailiac	Diagonal fold; in line with the natural angle of the iliac crest taken in the anterior axillary line immediately superior to the iliac crest
Thigh	Vertical fold; on the anterior midline of the thigh, midway between the proximal border of the patella and the inguinal crease (hip)

Procedures

- All measurements should be made on the right side of the body with the subject standing upright
- Caliper should be placed directly on the skin surface, 1 cm away from the thumb and finger, perpendicular to the skinfold, and halfway between the crest and the base of the fold
- Pinch should be maintained while reading the caliper
- Wait 1–2 s (not longer) before reading caliper
- Take duplicate measures at each site and retest if duplicate measurements are not within 1–2 mm
- Rotate through measurement sites or allow time for skin to regain normal texture and thickness

BOX 4.3 Generalized Skinfold Equations

MEN

- **Seven-Site Formula** (chest, midaxillary, triceps, subscapular, abdomen, suprailiac, thigh)
  Body density = 1.112 − 0.00043499 (sum of seven skinfolds)
  + 0.00000055 (sum of seven skinfolds)^2
  − 0.00028826 (age) *[SEE 0.008 or ~3.5% fat]*

- **Three-Site Formula** (chest, abdomen, thigh)
  Body density = 1.10938 − 0.0008267 (sum of three skinfolds)
  + 0.0000016 (sum of three skinfolds)^2 − 0.0002574 (age)
  [SEE 0.008 or ~3.4% fat]

- **Three-Site Formula** (chest, triceps, subscapular)
  Body density = 1.1125025 − 0.0013125 (sum of three skinfolds)
  + 0.0000055 (sum of three skinfolds)^2 − 0.000244 (age)
  [SEE 0.008 or ~3.6% fat]

WOMEN

- **Seven-Site Formula** (chest, midaxillary, triceps, subscapular, abdomen, suprailiac, thigh)
  Body density = 1.097 − 0.00046971 (sum of seven skinfolds)
  + 0.00000056 (sum of seven skinfolds)^2 − 0.00012828
  (age) *[SEE 0.008 or ~3.8% fat]*

- **Three-Site Formula** (triceps, suprailiac, thigh)
  Body density = 1.099421 − 0.0009929 (sum of three skinfolds)
  + 0.0000023 (sum of three skinfolds)^2 − 0.0001392 (age)
  [SEE 0.009 or ~3.9% fat]

- **Three-Site Formula** (triceps, suprailiac, abdominal)
  Body density = 1.089733 − 0.0009245 (sum of three skinfolds)
  + 0.0000025 (sum of three skinfolds)^2 − 0.0000979 (age)
  [SEE 0.009 or ~3.9% fat]

SEE, standard error of estimate.
Adapted from (55,87).

DENSITOMETRY

Body composition can be estimated from a measurement of whole-body density using the ratio of body mass to body volume. Densitometry has been used as a reference or criterion standard for assessing body composition for many years. The limiting factor in the measurement of body density is the accuracy of the body volume measurement because body mass is measured simply as body weight. Body volume can be measured by hydrodensitometry (underwater) weighing and by plethysmography.

Hydrodensitometry (Underwater) Weighing

This technique of measuring body composition is based on Archimedes' principle that states when a body is immersed in water, it is buoyed by a counterforce equal to the weight of the water displaced. This loss of weight in water allows for calculation of body volume. Bone and muscle tissue are denser than water, whereas fat tissue is less dense. Therefore, an individual with more fat-free mass (FFM) for the same total body mass weighs more in water and has a higher body density and lower percentage of body fat. Although hydrostatic weighing is a standard method for measuring body volume and hence, body composition, it requires special equipment, the accurate measurement of residual volume, population-specific formulas, and significant cooperation by the subject (44). For a more detailed explanation of the technique, see *ACSM's Resource Manual for Guidelines for Exercise Testing and Prescription, Seventh Edition* (101).

Plethysmography

Body volume also can be measured by air rather than water displacement. One commercial system uses a dual-chamber plethysmograph that measures body volume by changes in pressure in a closed chamber. This technology is now well established and generally reduces the anxiety associated with the technique of hydrodensitometry (31,44,70). For a more detailed explanation of the technique, see *ACSM's Resource Manual for Guidelines for Exercise Testing and Prescription, Seventh Edition* (101).

Conversion of Body Density to Body Composition

Percent body fat can be estimated once body density has been determined. Two of the most common prediction equations used to estimate percent body fat from body density are derived from the two-component model of body composition (15,100):

$$\%\ \text{fat} = \frac{457}{\text{Body Density}} - 414.2$$

$$\%\ \text{fat} = \frac{495}{\text{Body Density}} - 450$$

Each method assumes a slightly different density of fat mass (FM) and FFM. Several population-specific, two-component model conversion formulas are also available (see *Table 4.4*). Currently, three to six component model conversion formulas are available and are increasingly more precise in calculating percent body fat compared to two-component models (34,51).

TABLE 4.4. Population-Specific Formulas for Conversion of Body Density to Percent Body Fat

	Population	Age	Gender	%BF	FFBd[a] (g · cm^{-3})
ETHNICITY	African American	9–17	Women	(5.24 / Db) − 4.82	1.088
		19–45	Men	(4.86 / Db) − 4.39	1.106
		24–79	Women	(4.86 / Db) − 4.39	1.106
	American Indian	18–62	Men	(4.97 / Db) − 4.52	1.099
		18–60	Women	(4.81 / Db) − 4.34	1.108
	Asian Japanese Native	18–48	Men	(4.97 / Db) − 4.52	1.099
			Women	(4.76 / Db) − 4.28	1.111
		61–78	Men	(4.87 / Db) − 4.41	1.105
			Women	(4.95 / Db) − 4.50	1.100
	Singaporean (Chinese, Indian, Malay)		Men	(4.94 / Db) − 4.48	1.102
			Women	(4.84 / Db) − 4.37	1.107
	Caucasian	8–12	Men	(5.27 / Db) − 4.85	1.086
			Women	(5.27 / Db) − 4.85	1.086
		13–17	Men	(5.12 / Db) − 4.69	1.092
			Women	(5.19 / Db) − 4.76	1.090
		18–59	Men	(4.95 / Db) − 4.50	1.100
			Women	(4.96 / Db) − 4.51	1.101
		60–90	Men	(4.97 / Db) − 4.52	1.099
			Women	(5.02 / Db) − 4.57	1.098
	Hispanic		Men	NA	NA
		20–40	Women	(4.87 / Db) − 4.41	1.105
ATHLETES	Resistance trained	24 ± 4	Men	(5.21 / Db) − 4.78	1.089
		35 ± 6	Women	(4.97 / Db) − 4.52	1.099
	Endurance trained	21 ± 2	Men	(5.03 / Db) − 4.59	1.097
		21 ± 4	Women	(4.95 / Db) − 4.50	1.100
	All sports	18–22	Men	(5.12 / Db) − 4.68	1.093
		18–22	Women	(4.97 / Db) − 4.52	1.099
CLINICAL POPULATIONS[b]	Anorexia nervosa	15–44	Women	(4.96 / Db) − 4.51	1.101
	Cirrhosis				
	Childs A			(5.33 / Db) − 4.91	1.084
	Childs B			(5.48 / Db) − 5.08	1.078
	Childs C			(5.69 / Db) − 5.32	1.070
	Obesity	17–62	Women	(4.95 / Db) − 4.50	1.100
	Spinal cord injury (paraplegic/quadriplegic)	18–73	Men	(4.67 / Db) − 4.18	1.116
		18–73	Women	(4.70 / Db) − 4.22	1.114

[a]FFBd, fat-free body density based on average values reported in selected research articles.

[b]There are insufficient multicomponent model data to estimate the average FFBd of the following clinical populations: coronary artery disease, heart/lung transplants, chronic obstructive pulmonary disease, cystic fibrosis, diabetes mellitus, thyroid disease, HIV/AIDS, cancer, kidney failure (dialysis), multiple sclerosis, and muscular dystrophy.

%BF, percentage of body fat; Db, body density; NA, no data available for this population subgroup.

Adapted with permission from (51).

OTHER TECHNIQUES

Additional reliable and accurate body composition assessment techniques include dual-energy X-ray absorptiometry (DEXA) and total body electrical conductivity (TOBEC), but these techniques have limited applicability in routine health/fitness testing because of cost and the need for highly trained personnel (48). Rather, bioelectrical impedance analysis (BIA) and near-infrared interactance are used as assessment techniques in routine health/fitness testing. Generally, the accuracy of BIA is similar to skinfolds, as long as stringent protocol adherence (*e.g.*, assurance of normal hydration status) is followed, and the equations programmed into the analyzer are valid and accurate for the populations being tested (30,47). It should be noted, however, that the ability of BIA to provide an accurate assessment of percent body fat in obese individuals may be limited secondary to differences in body water distribution compared to those who are in the normal weight range (34). Near-infrared interactance requires additional research to substantiate the validity and accuracy for body composition assessment (58,73). Detailed explanations of these techniques are found in *ACSM's Resource Manual for Guidelines for Exercise Testing and Prescription, Seventh Edition* (101).

BODY COMPOSITION NORMS

There are no universally accepted norms for body composition; however, *Tables 4.5* and *4.6*, which are based on selected populations, provide percentile values for percent body fat in men and women, respectively. A consensus opinion for an exact percent body fat value associated with optimal health risk has yet to be defined; however, a range of 10%–22% and 20%–32% for men and women, respectively, has long been viewed as satisfactory for health (70). More recent data support this range although age and race, in addition to sex, impact what may be construed as a healthy percent body fat (41).

CARDIORESPIRATORY FITNESS

CRF is related to the ability to perform large muscle, dynamic, moderate-to-vigorous intensity exercise for prolonged periods of time. Performance of exercise at this level of physical exertion depends on the integrated physiologic and functional state of the respiratory, cardiovascular, and musculoskeletal systems. CRF is considered a health-related component of physical fitness because (a) low levels of CRF have been associated with a markedly increased risk of premature death from all causes and specifically from CVD; (b) increases in CRF are associated with a reduction in death from all causes; and (c) high levels of CRF are associated with higher levels of habitual physical activity, which in turn are associated with many health benefits (10,11,63,98,107). As such, the assessment of CRF is an important part of any primary or secondary prevention and rehabilitative programs.

TABLE 4.5. Fitness Categories for Body Composition (% Body Fat) for Men by Age

		Age (year)					
%		20–29	30–39	40–49	50–59	60–69	70–79
99	Very lean[a]	4.2	7.3	9.5	11.0	11.9	13.6
95		6.4	10.3	12.9	14.8	16.2	15.5
90	Excellent	7.9	12.4	15.0	17.0	18.1	17.5
85		9.1	13.7	16.4	18.3	19.2	19.0
80		10.5	14.9	17.5	19.4	20.2	20.1
75	Good	11.5	15.9	18.5	20.2	21.0	21.0
70		12.6	16.8	19.3	21.0	21.7	21.6
65		13.8	17.7	20.1	21.7	22.4	22.3
60		14.8	18.4	20.8	22.3	23.0	22.9
55	Fair	15.8	19.2	21.4	23.0	23.6	23.7
50		16.6	20.0	22.1	23.6	24.2	24.1
45		17.5	20.7	22.8	24.2	24.9	24.7
40		18.6	21.6	23.5	24.9	25.6	25.3
35	Poor	19.7	22.4	24.2	25.6	26.4	25.8
30		20.7	23.2	24.9	26.3	27.0	26.5
25		22.0	24.1	25.7	27.1	27.9	27.1
20		23.3	25.1	26.6	28.1	28.8	28.4
15	Very poor	24.9	26.4	27.8	29.2	29.8	29.4
10		26.6	27.8	29.2	30.6	31.2	30.7
5		29.2	30.2	31.3	32.7	33.3	32.9
1		33.4	34.4	35.2	36.4	36.8	37.2
***n* =**		1,844	10,099	15,073	9,255	2,851	522

Total *n* = 39,644

[a]Very lean, no less than 3% body fat is recommended for men.

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THE CONCEPT OF MAXIMAL OXYGEN UPTAKE

Maximal oxygen uptake ($\dot{V}O_{2max}$) is accepted as the criterion measure of CRF. This variable is typically expressed clinically in relative ($mL \cdot kg^{-1} \cdot min^{-1}$) as opposed to absolute ($mL \cdot min^{-1}$) terms, allowing for meaningful comparisons between/among individuals with differing body weight. $\dot{V}O_{2max}$ is the product of the maximal cardiac output $\dot{Q}$ ($L\ blood \cdot min^{-1}$) and arterial-venous oxygen difference ($mL\ O_2 \cdot L\ blood^{-1}$). Significant variation in $\dot{V}O_{2max}$ across populations and fitness levels results primarily from differences in $\dot{Q}$ in individuals without pulmonary disease; therefore, $\dot{V}O_{2max}$ is closely related to the functional capacity of the heart. The designation of $\dot{V}O_{2max}$ implies an individual's true physiologic limit has been reached and a plateau in $\dot{V}O_2$ may be observed between the final two work rates of a progressive exercise test. This plateau is rarely observed in individuals with CVD or pulmonary disease. Therefore, peak $\dot{V}O_2$ is commonly used to describe CRF in these and other populations with chronic diseases and health conditions (5).

Open circuit spirometry is used to measure $\dot{V}O_{2max}$. In this procedure, the subject breathes through a low-resistance valve with her or his nose occluded

TABLE 4.6. Fitness Categories for Body Composition (% Body Fat) for Women by Age

		Age (year)					
%		**20–29**	**30–39**	**40–49**	**50–59**	**60–69**	**70–79**
99	Very lean[a]	11.4	11.2	12.1	13.9	13.9	11.7
95		14.0	13.9	15.2	16.9	17.7	16.4
90	Excellent	15.1	15.5	16.8	19.1	20.2	18.3
85		16.1	16.5	18.3	20.8	22.0	21.2
80		16.8	17.5	19.5	22.3	23.3	22.5
75	Good	17.6	18.3	20.6	23.6	24.6	23.7
70		18.4	19.2	21.7	24.8	25.7	24.8
65		19.0	20.1	22.7	25.8	26.7	25.7
60		19.8	21.0	23.7	26.7	27.5	26.6
55	Fair	20.6	22.0	24.6	27.6	28.3	27.6
50		21.5	22.8	25.5	28.4	29.2	28.2
45		22.2	23.7	26.4	29.3	30.1	28.9
40		23.4	24.8	27.5	30.1	30.8	30.5
35	Poor	24.2	25.8	28.4	30.8	31.5	31.0
30		25.5	26.9	29.5	31.8	32.6	31.9
25		26.7	28.1	30.7	32.9	33.3	32.9
20		28.2	29.6	31.9	33.9	34.4	34.0
15	Very poor	30.5	31.5	33.4	35.0	35.6	35.3
10		33.5	33.6	35.1	36.1	36.6	36.4
5		36.6	36.2	37.1	37.6	38.2	38.1
1		38.6	39.0	39.1	39.8	40.3	40.2
***n* =**		1,250	4,130	5,902	4,118	1,450	295

Total *n* = 17,145

[a]Very lean, no less than 10%–13% body fat is recommended for women.

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(or through a nonlatex mask) while pulmonary ventilation and expired fractions of oxygen (O_2) and carbon dioxide (CO_2) are measured. Modern automated systems provide ease of use and a detailed printout of test results that save time and effort (27). However, system calibration is still essential to obtain accurate results (76). Administration of the test and interpretation of results should be reserved for professional personnel with a thorough understanding of exercise science. Because of costs associated with the equipment, space, and personnel needed to carry out these tests, direct measurement of $\dot{V}O_{2max}$ generally is reserved for research or clinical settings.

When direct measurement of $\dot{V}O_{2max}$ is not feasible, a variety of submaximal and maximal exercise tests can be used to estimate $\dot{V}O_{2max}$. These tests have been validated by examining (a) the correlation between directly measured $\dot{V}O_{2max}$ and the $\dot{V}O_{2max}$ estimated from physiologic responses to submaximal exercise (*e.g.*, HR at a specified power output); or (b) the correlation between directly measured $\dot{V}O_{2max}$ and test performance (*e.g.*, time to run 1 or 1.5 mi [1.6 or 2.4 km]), or time to volitional fatigue using a standard graded exercise test protocol. It should be noted that there is the potential for a significant overestimation of directly measured $\dot{V}O_{2max}$ by these types of indirect measurement techniques. Overestimation is more likely to occur when (a) the exercise protocol chosen for testing is too aggressive for a given individual (*i.e.*, Bruce treadmill protocol in patients with CHF); or (b) when treadmill testing is employed and the individual heavily relies on handrail support (5). Every effort should therefore be taken to choose the appropriate exercise protocol given an individual's characteristics and minimize handrail use during testing on a treadmill (76).

MAXIMAL VERSUS SUBMAXIMAL EXERCISE TESTING

The decision to use a maximal or submaximal exercise test depends largely on the reasons for the test, risk level of the client/patient, and availability of appropriate equipment and personnel. $\dot{V}O_{2max}$ can be estimated using conventional exercise test protocols by considering test duration at a given workload on an ergometer and using the prediction equations found in *Chapter 7*. The user should consider the population being tested and standard error of the associated equation. Maximal tests require participants to exercise to the point of volitional fatigue, which might entail the need for medical supervision as detailed in *Chapter 2* and/or emergency equipment (see *Appendix B*). However, maximal exercise testing offers increased sensitivity in the diagnosis of CVD in asymptomatic individuals and provides a better estimate of $\dot{V}O_{2max}$ (see "Indications and Purposes" section in *Chapter 5*). In addition, the use of open circuit spirometry during maximal exercise testing may allow for the accurate assessment of anaerobic/ventilatory threshold and direct measurement of $\dot{V}O_{2max}$ / $\dot{V}O_{2peak}$.

Practitioners commonly rely on submaximal exercise tests to assess CRF because maximal exercise testing is not always feasible in the health/fitness setting. Submaximal exercise testing is also recommended in stable patients 4–7 d post-myocardial infarction (MI) to assess efficacy of medical therapy prior to hospital discharge among other clinical indices (43). In the health/fitness setting, the basic aim of submaximal exercise testing is to determine the HR response to one or more submaximal work rates and use the results to predict $\dot{V}O_{2max}$. Although the primary purpose of the test has traditionally been to predict $\dot{V}O_{2max}$ from the HR workload relationship, it is important to obtain additional indices of the client's response to exercise. The practitioner should use the various submaximal measures of HR, BP, workload, rating of perceived exertion (RPE), and other subjective indices as valuable information regarding one's functional response to exercise. This information can be used to evaluate submaximal exercise responses over time in a controlled environment and appropriately determine the Ex R_x.

The most accurate estimate of $\dot{V}O_{2max}$ is achieved from the HR response to submaximal exercise tests if all of the following assumptions are achieved:

- A steady state HR is obtained for each exercise work rate.
- A linear relationship exists between HR and work rate.
- The difference between actual and predicted maximal HR is minimal.
- Mechanical efficiency (*i.e.*, $\dot{V}O_2$ at a given work rate) is the same for everyone.

- The subject is not on medications, using high quantities of caffeine, under large amounts of stress, ill, or in a high temperature environment, all of which may alter HR.

MODES OF TESTING

Commonly used modes for exercise testing include treadmills, cycle ergometers, steps, and field tests. The mode of exercise testing used is dependent on the setting, equipment available, and training of personnel. Medical supervision is recommended for high-risk individuals as detailed in *Chapter 2* regardless of mode (see *Figure 2.4* and *Table 2.3*).

There are advantages and disadvantages of each exercise testing mode:

- ***Field tests*** consist of walking or running in a predetermined time or distance (*i.e.*, 12-min and 1.5-mi [2.4 km] walk/run tests, and the 1-mi and 6-min walk test). The advantages of field tests are they are easy to administer to large numbers of individuals at one time and little equipment (*e.g.*, a stopwatch) is needed. The disadvantages are some tests can be maximal for some individuals, particularly in individuals with low aerobic fitness, and potentially be unmonitored for BP and HR. An individual's level of motivation and pacing ability also can have a profound impact on test results. These all-out run tests may be inappropriate for sedentary individuals or individuals at increased risk for cardiovascular and/or musculoskeletal complications. Nevertheless, $\dot{V}O_{2max}$ can be estimated from the test results.
- ***Motor-driven treadmills*** can be used for submaximal and maximal testing and are often employed for diagnostic testing in the United States (5). They provide a familiar form of exercise and, if the correct protocol is chosen (*i.e.*, aggressive vs. conservative adjustments in workload), can accommodate the least physically fit to the fittest individuals across the continuum of walking to running speeds. Nevertheless, a practice session might be necessary in some cases to permit habituation and reduce anxiety. On the other hand, treadmills usually are expensive, not easily transportable, and potentially make some measurements (*e.g.*, BP, ECG) more difficult, particularly while an individual is running. Treadmills must be calibrated to ensure the accuracy of the test (76). In addition, holding on to the support rail(s) should be discouraged to ensure accuracy of metabolic work output, particularly when $\dot{V}O_2$ is estimated as opposed to directly measured. Extensive handrail use often leads to significant overestimation of $\dot{V}O_2$ compared to actual values.
- ***Mechanically braked cycle ergometers*** are also a viable test modality for submaximal and maximal testing and are frequently used for diagnostic testing, particularly in European laboratories (76). Advantages of this exercise mode include lower equipment expense, transportability, and greater ease in obtaining BP and ECG (if appropriate) measurements. Cycle ergometers also provide a non–weight-bearing test modality in which work rates are easily adjusted in small increments. The main disadvantage is cycling is a less familiar mode of exercise to individuals in the United States, often resulting

in limiting localized muscle fatigue and an underestimation of $\dot{V}O_2$. The cycle ergometer must be calibrated, and the subject must maintain the proper pedal rate because most tests require HR to be measured at specific work rates (76). Electronic cycle ergometers can deliver the same work rate across a range of pedal rates (*i.e.*, revolutions · min^{-1}, rpm), but calibration might require special equipment not available in some laboratories. Some electronic fitness cycles cannot be calibrated and should not be used for testing.

- ***Step testing*** is an inexpensive modality for predicting CRF by measuring the HR response to stepping at a fixed rate and/or a fixed step height or by measuring postexercise recovery HR. Step tests require little or no equipment, steps are easily transportable, stepping skill requires little practice, the test usually is of short duration, and stepping is advantageous for mass testing (22,72). Postexercise (recovery) HR decreases with improved CRF, and test results are easy to explain to participants (59). Special precautions may be needed for those who have balance problems or are extremely deconditioned. Some single-stage step tests require an energy cost of 7–9 metabolic equivalents (METs), which may exceed the maximal capacity of the participant (6). Therefore, the protocol chosen must be appropriate for the physical fitness level of the client. In addition, inadequate compliance to the step cadence and excessive fatigue in the lead limb may diminish the value of a step test. Most tests do not monitor HR and BP while stepping because of the difficulty of measuring HR and BP.

Field Tests

Two of the most widely used walk/run (based on subject preference) tests for assessing CRF are the Cooper 12-min test and the 1.5-mi (2.4 km) test for time. The objective of the 12-min test is to cover the greatest distance in the allotted time period and for the 1.5-mi (2.4 km) test to run the distance in the shortest period of time. $\dot{V}O_{2max}$ can be estimated from the equations in *Chapter 7*.

The Rockport One-Mile Fitness Walking Test is another well-recognized field test for estimating CRF. In this test, an individual walks 1 mi (1.6 km) as fast as possible, preferably on a track or a level surface, and HR is obtained in the final minute. An alternative is to measure a 10 s HR immediately on completion of the 1 mi (1.6 km) walk, but this may overestimate the $\dot{V}O_{2max}$ compared to when HR is measured during the walk. $\dot{V}O_{2max}$ is estimated from a regression equation found in *Chapter 7* based on weight, age, sex, walk time, and HR (62).

In addition to independently predicting morbidity and mortality (21,97), the 6-min walk test has been used to evaluate CRF in older adults and some clinical patient populations (*e.g.*, individuals with CHF or pulmonary disease). The American Thoracic Society has published guidelines on 6-min walk test procedures and interpretation (8). Even though the test is considered submaximal, it may result in near-maximal performance for those with low physical fitness levels or disease (57). Clients and patients completing less than 300 m (~984 ft) during the 6-min walk demonstrate a poorer short-term survival compared to those surpassing this threshold (16). Several multivariate equations are available to predict $\dot{V}O_{2\ peak}$ from the 6-min walk; however, the following equation requires minimal clinical information (16):

- $\dot{V}O_{2peak} = \dot{V}O_2$ mL · kg^{-1} · min^{-1} = (0.02 × distance [m]) − (0.191 × age [yr]) − (0.07 × weight [kg]) + (0.09 × height [cm]) + (0.26 × RPP [× 10^{-3}]) + 2.45

  Where m = distance in meters; yr = year; kg = kilogram; cm = centimeter; RPP = rate pressure product (HR × systolic BP [SBP] in mm Hg)

- For the aforementioned equation: R^2 = 0.65 and SEE = 2.68 (R^2 = coefficient of determination; SEE = standard error of estimate)

Submaximal Exercise Tests

Single-stage and multistage submaximal exercise tests are available to estimate $\dot{V}O_{2max}$ from simple HR measurements. Accurate measurement of HR is critical for valid testing. Although HR obtained by palpation is commonly used, the accuracy of this method depends on the experience and technique of the evaluator. It is recommended that an ECG, HR monitor, or a stethoscope be used to determine HR. The use of a relatively inexpensive HR monitor can reduce a significant source of error in the test. The submaximal HR response is easily altered by a number of environmental (*e.g.*, heat, humidity, see *Chapter 8*), dietary (*e.g.*, caffeine, time since last meal), and behavioral (*e.g.*, anxiety, smoking, previous physical activity) factors. These variables must be controlled to have a valid estimate that can be used as a reference point in an individual's fitness program. In addition, the test mode (*e.g.*, cycle, treadmill, step) should be consistent with the primary exercise modality used by the participant to address specificity of training issues. Standardized procedures for submaximal testing are presented in *Box 4.4*. Although there are no specific submaximal protocols for treadmill testing, several stages from any of the treadmill protocols found in *Chapter 5* can be used to assess submaximal exercise responses. Preexercise test instructions are presented in *Chapter 3*.

Cycle Ergometer Tests

The Astrand-Ryhming cycle ergometer test is a single-stage test lasting 6 min (7). For the population studied, these researchers observed at 50% $\dot{V}O_{2max}$, the average HR was 128 and 138 beats · min^{-1} for men and women, respectively. If a woman was working at a $\dot{V}O_2$ of 1.5 L · min^{-1} and her HR was 138 beats · min^{-1}, then her $\dot{V}O_{2max}$ was estimated to be 3.0 L · min^{-1}. The suggested work rate is based on sex and an individual's fitness status as follows:

men, unconditioned:	300 or 600 kg · m · min^{-1} (50 or 100 W)
men, conditioned:	600 or 900 kg · m · min^{-1} (100 or 150 W)
women, unconditioned:	300 or 450 kg · m · min^{-1} (50 or 75 W)
women, conditioned:	450 or 600 kg · m · min^{-1} (75 or 100 W)

BOX 4.4 **General Procedures for Submaximal Testing of Cardiorespiratory Fitness**

1. Obtain resting HR and BP immediately prior to exercise in the exercise posture.
2. The client should be familiarized with the ergometer. If using a cycle ergometer, properly position the client on the ergometer (*i.e.*, upright posture, ~25-degree bend in the knee at maximal leg extension, and hands in proper position on handlebars) (81–83).
3. The exercise test should begin with a 2–3 min warm-up to acquaint the client with the cycle ergometer and prepare him or her for the exercise intensity in the first stage of the test.
4. A specific protocol should consist of 2- or 3-min stages with appropriate increments in work rate.
5. HR should be monitored at least two times during each stage, near the end of the second and third minutes of each stage. If HR is >110 beats · min^{-1}, steady state HR (*i.e.*, two HRs within 5 beats · min^{-1}) should be reached before the workload is increased.
6. BP should be monitored in the last minute of each stage and repeated (verified) in the event of a hypotensive or hypertensive response.
7. RPE (using either the Borg category or category-ratio scale [see *Table 4.7*]) and additional rating scales should be monitored near the end of the last minute of each stage.
8. Client's appearance and symptoms should be monitored and recorded regularly.
9. The test should be terminated when the subject reaches 70% heart rate reserve (85% of age-predicted HR_{max}), fails to conform to the exercise test protocol, experiences adverse signs or symptoms, requests to stop, or experiences an emergency situation.
10. An appropriate cool-down/recovery period should be initiated consisting of either
    a. continued exercise at a work rate equivalent to that of the first stage of the exercise test protocol or lower or
    b. a passive cool-down if the subject experiences signs of discomfort or an emergency situation occurs
11. All physiologic observations (*e.g.*, HR, BP, signs and symptoms) should be continued for at least 5 min of recovery unless abnormal responses occur, which would warrant a longer posttest surveillance period. Continue low-level exercise until HR and BP stabilize, but not necessarily until they reach preexercise levels.

BP, blood pressure; HR, heart rate; HR_{max}, maximal heart rate; RPE, rating of perceived exertion.

TABLE 4.7. The Borg Rating of Perceived Exertion Scale

6	No exertion at all
7	
8	Extremely light
9	Very light
10	
11	Light
12	
13	Somewhat hard
14	
15	Hard (heavy)
16	
17	Very hard
18	
19	Extremely hard
20	Maximal exertion

From (13). © Gunnar Borg. Reproduced with permission. The scale with correct instructions can be obtained from Borg Perception, Radisvagen 124, 16573 Hasselby, Sweden. See also the home page: http://www.borgperception.se/index.html.

The pedal rate is set at 50 rpm. The goal is to obtain HR values between 125 and 170 beats · min^{-1}, with HR measured during the fifth and sixth minute of work. The average of the two HRs is then used to estimate $\dot{V}O_{2max}$ from a nomogram (see *Figure 4.1*). This value must then be adjusted for age because HR_{max} decreases with age by multiplying the $\dot{V}O_{2max}$ value by the following correction factors (6):

AGE	CORRECTION FACTOR
15	1.10
25	1.00
35	0.87
40	0.83
45	0.78
50	0.75
55	0.71
60	0.68
65	0.65

In contrast to the Astrand-Ryhming cycle ergometer single-stage test, Maritz et al. (71) measured HR at a series of submaximal work rates and extrapolated the response to the subject's age-predicted HR_{max}. This multistage method is a well-known assessment technique to estimate $\dot{V}O_{2max}$, and the YMCA test is a good example (111). The YMCA protocol uses two to four 3-min stages of continuous exercise (see *Figure 4.2*). The test is designed to raise the steady state HR of the subject to between 110 beats · min^{-1} and 70% heart rate reserve (HRR) (or 85% of the age-predicted HR_{max}) for at least two consecutive stages. It is important to remember that two consecutive HR measurements must be obtained within this HR range to predict $\dot{V}O_{2max}$.

In the YMCA protocol, each work rate is performed for at least 3 min, and HR is recorded during the final 15–30 s of the second and third minutes. The work

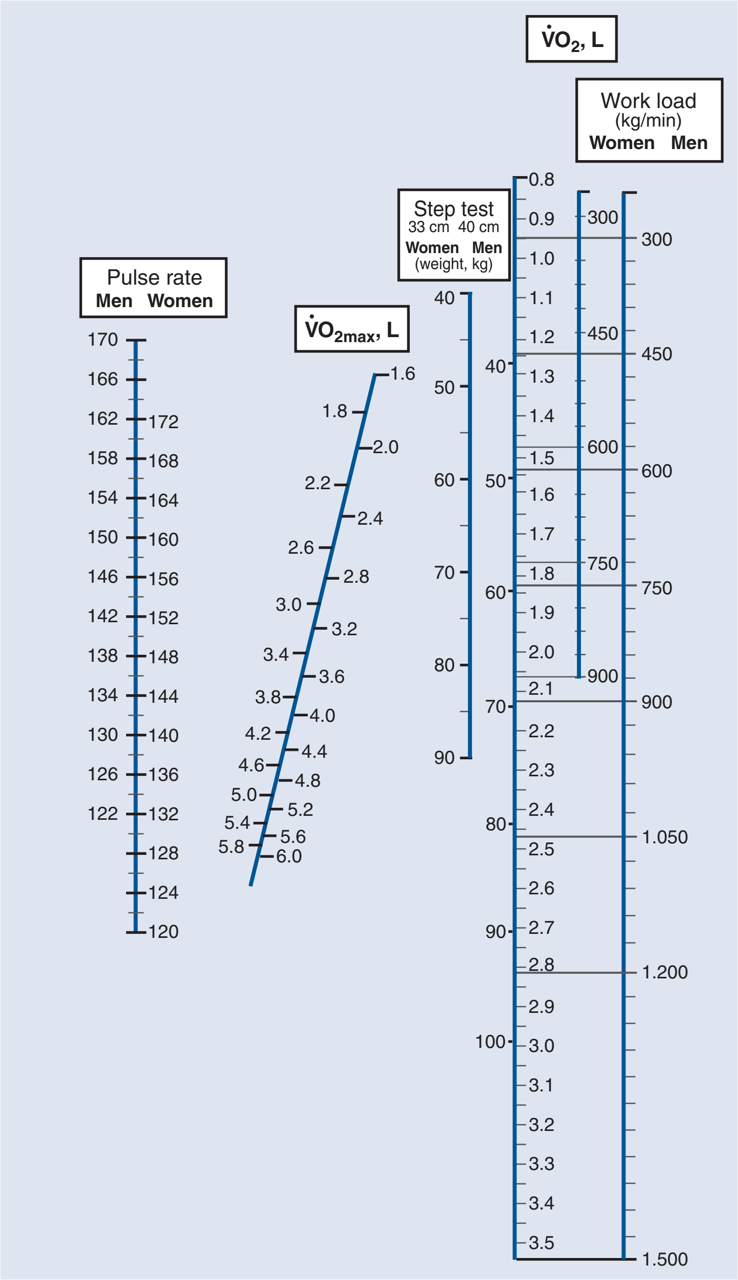


FIGURE 4.1. Modified Astrand-Ryhming nomogram. Used with permission from (7).

1st stage: 150 kgm/min (0.5 kg)

	HR: <80	HR: 80–89	HR: 90–100	HR: >100
2nd stage	750 kgm/min (2.5 kg)*	600 kgm/min (2.0 kg)	450 kgm/min (1.5 kg)	300 kgm/min (1.0 kg)
3rd stage	900 kgm/min (3.0 kg)	750 kgm/min (2.5 kg)	600 kgm/min (2.0 kg)	450 kgm/min (1.5 kg)
4th stage	1050 kgm/min (3.5 kg)	900 kgm/min (3.0 kg)	750 kgm/min (2.5 kg)	600 kgm/min (2.0 kg)

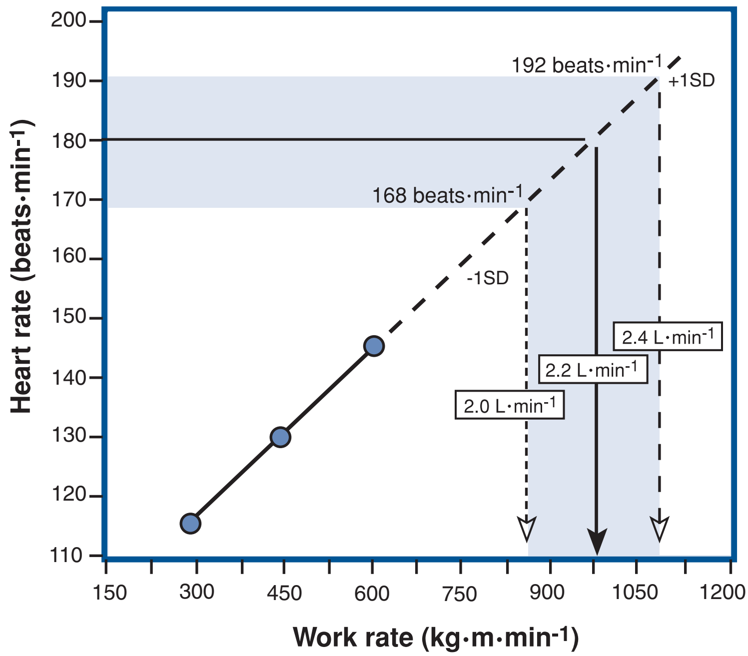
Directions:

1. Set the 1st work rate at 150 kgm/min (0.5 kg at 50 rpm)
2. If the HR in the third minute of the stage is:
   <80, set the 2nd stage at 750 kgm/min (2.5 kg at 50 rpm)
   80-89, set the 2nd stage at 600 kgm/min (2.0 kg at 50 rpm)
   90-100, set the 2nd stage at 450 kgm/min (1.5 kg at 50 rpm)
   >100, set the 2nd stage at 300 kgm/min (1.0 kg at 50 rpm)
3. Set the 3rd and 4th (if required) according to the work rates in the columns below the 2nd loads

FIGURE 4.2. YMCA cycle ergometry protocol. Resistance settings shown here are appropriate for an ergometer with a flywheel of 6 m · rev^{-1} (111).

rate should be maintained for an additional minute if the two HRs vary by more than 5 beats · min^{-1}. The test administrator should recognize the error associated with age-predicted HR_{max} and monitor the subject throughout the test to ensure the test remains submaximal. The HR measured during the last minute of each steady state stage is plotted against work rate. The line generated from the plotted points is then extrapolated to the age-predicted HR_{max} (*e.g.*, 220 − age), and a perpendicular line is dropped to the x-axis to estimate the work rate that would have been achieved if the individual had worked to maximum (see *Figure 4.3*).

The two lines noted as ±1 standard deviation (SD) in *Figure 4.3* show what the estimated $\dot{V}O_{2max}$ would be if the subject's true HR_{max} were 168 or 192 beats · min^{-1}, rather than 180 beats · min^{-1}. Part of the error involved in estimating $\dot{V}O_{2max}$ from submaximal HR responses occurs because the formula "220 − age" has an SD of ±12 beats · min^{-1} and can provide only an estimate of HR_{max} (106). In addition, errors can be attributed to inaccurate pedaling cadence (workload) and imprecise achievement of steady state HR. *Table 4.8* provides normative values for estimated $\dot{V}O_{2max}$ from work rate on the YMCA submax cycle ergometer test with specific reference to age and sex (111). $\dot{V}O_{2max}$ can also be estimated from the work rate using the formula in *Chapter 7* (see *Table 7.3*). This equation is valid to estimate $\dot{V}O_2$ at submaximal steady state workloads



■ **FIGURE 4.3.** Heart rate responses to three submaximal work rates for a sedentary woman 40 yr of age weighing 64 kg. $\dot{V}O_{2max}$ was estimated by extrapolating the heart rate (HR) response to the age-predicted HR_{max} of 180 beats · min^{-1} (based on 220 − age). The work rate that would have been achieved at that HR was determined by dropping a line from that HR value to the x-axis. $\dot{V}O_{2max}$ estimated using the formula in *Chapter 7* and expressed in L · min^{-1} was 2.2 L · min^{-1}. The other two lines estimate what the $\dot{V}O_{2max}$ would have been if the subject's true HR_{max} was ±1 standard deviation (SD) from the 180 beats · min^{-1} value.

(from 300 to 1,200 kg · m · min^{-1}) (49.0 W to 196.1 W); therefore, caution must be used if extrapolating to workloads outside of this range.

Treadmill Tests

The primary exercise modality for submaximal exercise testing traditionally has been the cycle ergometer, although treadmills are used in many settings. The same endpoint (70% HRR or 85% of age-predicted HR_{max}) is used, and the stages of the test should be 3 min or longer to ensure a steady state HR response at each stage. The HR values are extrapolated to age-predicted HR_{max}, and $\dot{V}O_{2max}$ is estimated using the formula in *Chapter 7* from the highest speed and/or grade that would have been achieved if the individual had worked to maximum. Most common treadmill protocols presented in *Chapter 5* can be used, but the duration of each stage should be at least 3 min.

TABLE 4.8. Fitness Categories for Estimated $\dot{V}O_{2max}$ from the YMCA Submaximal Cycle Ergometer Test by Age and Sex

		Norms for Max $\dot{V}O_2$ (mL/kg) — MEN					
		Age (year)					
% Ranking		18–25	26–35	36–45	46–55	56–65	Over 65
100	Excellent	100	95	90	83	65	53
95		75	66	61	55	50	42
90		65	60	55	49	43	38
85	Good	60	55	49	45	40	34
80		56	52	47	43	38	33
75		53	50	45	40	37	32
70	Above average	50	48	43	39	35	31
65		49	45	41	38	34	30
60		48	44	40	36	33	29
55	Average	45	42	38	35	32	28
50		44	40	37	33	31	27
45		43	39	36	32	30	26
40	Below average	42	38	35	31	28	25
35		39	37	33	30	27	24
30		38	34	31	29	26	23
25	Poor	36	33	30	27	25	22
20		35	32	29	26	23	21
15		32	30	27	25	22	20
10	Very poor	30	27	24	24	21	18
5		26	24	21	20	18	16
0		20	15	14	13	12	10
		Norms for Max $\dot{V}O_2$ (mL/kg) — WOMEN					
		Age (year)					
% Ranking		**18–25**	**26–35**	**36–45**	**46–55**	**56–65**	**Over 65**
100	Excellent	95	95	75	72	58	55
95		69	65	56	51	44	48
90		59	58	50	45	40	34
85	Good	56	53	46	41	36	31
80		52	51	44	39	35	30
75		50	48	42	36	33	29
70	Above average	47	45	41	35	32	28
65		45	44	38	34	31	27
60		44	43	37	32	30	26
55	Average	42	41	36	31	28	25
50		40	40	34	30	27	24
45		39	37	33	29	26	23
40	Below average	38	36	32	28	25	22
35		37	35	30	27	24	21
30		35	34	29	26	23	20
25	Poor	33	32	28	25	22	19
20		32	30	26	23	20	18
15		20	28	25	22	19	17
10	Very poor	27	25	24	20	18	16
5		24	22	20	18	15	14
0		15	14	12	11	10	10

Adapted with permission from (111).

Step Tests

Step tests are also used to estimate $\dot{V}O_{2max}$. Astrand and Ryhming (7) used a single-step height of 33 cm (13 in) for women and 40 cm (15.7 in) for men at a rate of 22.5 steps · min^{-1}. These tests require $\dot{V}O_2$ of about 25.8 and 29.5 mL · kg^{-1} · min^{-1}, respectively. HR is measured as described for the cycle test, and $\dot{V}O_{2max}$ is estimated from the nomogram (see *Figure 4.1*). In contrast, Maritz et al. (71) used a single-step height of 12 in (30.5 cm) and four step rates to systematically increase the work rate. A steady state HR is measured for each step rate, and a line formed from these HR values are extrapolated to age-predicted HR_{max}. The maximal work rate is determined as described for the YMCA cycle test. $\dot{V}O_{2max}$ can be estimated from the formula for stepping in *Chapter 7*. Such step tests should be modified to suit the population being tested. The Canadian Home Fitness Test has demonstrated that such testing can be performed on a large scale and at low cost (99).

Instead of estimating $\dot{V}O_{2max}$ from HR responses to several submaximal work rates, a wide variety of step tests have been developed to categorize CRF based on an individual's recovery HR following a standardized step test. The 3-Minute YMCA Step Test is a good example of such a test. This test uses a 12-in (30.5 cm) bench, with a stepping rate of 24 steps · min^{-1} (estimated $\dot{V}O_2$ of 25.8 mL · kg^{-1} · min^{-1}). After stepping is completed, the subject immediately sits down and HR is counted for 1 min. Counting must start within 5 s at the end of exercise. HR values are used to obtain a qualitative rating of fitness from published normative tables (111).

CARDIORESPIRATORY TEST SEQUENCE AND MEASURES

A minimum of HR, BP, and subjective symptoms (*i.e.*, RPE, dyspnea, and angina) should be measured during exercise tests. After the initial screening process, selected baseline measurements should be obtained prior to the start of the exercise test. Taking a resting ECG prior to exercise testing requires that trained personnel are available to interpret the ECG and provide medical guidance. An ECG is not considered necessary when diagnostic testing is not being done. The sequence of measures is listed in *Table 5.2*.

HR can be determined using several techniques including radial pulse palpation, auscultation with a stethoscope, or the use of HR monitors. The pulse palpation technique involves "feeling" the pulse by placing the second and third fingers (*i.e.*, index and middle fingers) most typically over the radial artery, located near the thumb side of the wrist. The pulse is typically counted for 15 s, and then multiplied by 4, to determine the HR for 1 min. For the auscultation method, the bell of the stethoscope should be placed to the left of the sternum just above the level of the nipple. The auscultation method is most accurate when the heart sounds are clearly audible, and the subject's torso is relatively stable. HR telemetry monitors with chest electrodes or radio telemetry have proven to be accurate and reliable, provided there is no outside electrical interference (*e.g.*, emissions from the display consoles of computerized exercise equipment) (66). Many electronic cycles and treadmills have embedded HR telemetry monitoring into the equipment.

BP should be measured at heart level with the subject's arm relaxed and not grasping a handrail (treadmill) or handlebar (cycle ergometer). To help ensure accurate readings, the use of an appropriate-sized BP cuff is important. The rubber bladder of the BP cuff should encircle at least 80% of the subject's upper arm. If the subject's arm is large, a normal size adult cuff will be too small, thus resulting in an erroneous elevated reading; whereas if the cuff is too large for the subject's arm, the resultant reading will be erroneously low. BP measurements should be taken with a recently calibrated aneroid sphygmomanometer. Systolic (SBP) and diastolic (DBP) BP measurements can be used as indicators for stopping an exercise test (see next section of *Chapter 4*). To obtain accurate BP measures during exercise, follow the guidelines in *Chapter 3* (see *Box 3.4*) for resting BP; however, BP will be obtained in the exercise position. If an automated BP system is used during exercise testing, calibration checks with manual BP measurements must be routinely performed to confirm accuracy of the automated readings (76).

RPE can be a valuable indicator for monitoring an individual's exercise tolerance. Although RPEs correlate with exercise HRs and work rates, large interindividual variability in RPE with healthy individuals as well as patient populations mandates caution in the universal application of RPE scales (109). Borg's RPE scale was developed to allow the exerciser to subjectively rate her or his feelings during exercise, taking into account personal physical fitness level and general fatigue levels (77). Ratings can be influenced by psychological factors, mood states, environmental conditions (13), exercise modes, and age reducing its utility (93). Currently, two RPE scales are widely used: (a) the original Borg or category scale, which rates exercise intensity from 6 to 20 (see *Table 4.7*); and (b) the category-ratio scale of 0–10. Both RPE scales are appropriate subjective tools (13,43).

During exercise testing, the RPE can be used as an indication of impending fatigue. Most apparently, healthy subjects reach their subjective limit of fatigue at an RPE of 18–19 (very, very hard) on the category Borg scale, or 9–10 (very, very strong) on the category-ratio scale; therefore, RPE can be used to monitor progress toward maximal exertion during exercise testing (75).

The development of dyspnea and/or angina during exercise is also important to subjectively quantify. In particular, exercise limited by dyspnea as opposed to other subjective symptoms appears to indicate an increased risk for future adverse events (2,12). Four level scales for perceived dyspnea and angina during exercise are available through the current AHA scientific statements on recommendations for clinical exercise laboratories (76).

TEST TERMINATION CRITERIA

Graded exercise test (GXT), whether maximal or submaximal, is a safe procedure when subject screening and testing guidelines as outlined in *Chapter 2* are adhered to. Occasionally, for safety reasons, the test may have to be terminated prior to the subject reaching a measured $\dot{V}O_{2max}$/$\dot{V}O_{2peak}$, volitional fatigue, or a predetermined endpoint (*i.e.*, 50%–70% HRR or 70%–85% age-predicted HR_{max}). Because of the individual variation in HR_{max}, the upper limit of 85% of an estimated HR_{max} may

BOX 4.5 General Indications for Stopping an Exercise Test[a]

- Onset of angina or angina-like symptoms
- Drop in SBP of ≥10 mm Hg with an increase in work rate or if SBP decreases below the value obtained in the same position prior to testing
- Excessive rise in BP: systolic pressure >250 mm Hg and/or diastolic pressure >115 mm Hg
- Shortness of breath, wheezing, leg cramps, or claudication
- Signs of poor perfusion: light-headedness, confusion, ataxia, pallor, cyanosis, nausea, or cold and clammy skin
- Failure of HR to increase with increased exercise intensity
- Noticeable change in heart rhythm by palpation or auscultation
- Subject requests to stop
- Physical or verbal manifestations of severe fatigue
- Failure of the testing equipment

[a]Assumes that testing is nondiagnostic and is being performed without direct physician involvement or ECG monitoring. For clinical testing, *Box 5.2* provides more definitive and specific termination criteria.
BP, blood pressure; ECG, electrocardiogram; HR, heart rate; SBP, systolic blood pressure.

result in a maximal effort for some individuals and submaximal effort in others. General indications — those that do not rely on physician involvement or ECG monitoring — for stopping an exercise test are outlined in *Box 4.5*. More specific termination criteria for clinical or diagnostic testing are provided in *Chapter 5*.

INTERPRETATION OF RESULTS

Table 4.9 provides normative values for $\dot{V}O_{2max}$ (in mL · kg^{-1} · min^{-1}) estimated from treadmill speed and grade with specific reference to age and sex. Research suggests a $\dot{V}O_{2max}$ below the 20th percentile for age and sex, that is often indicative of a sedentary lifestyle, is associated with an increased risk of death from all causes (10). Several regression equations for estimating CRF according to age and sex are also available. These equations produce a single expected aerobic capacity value for comparison to a measured response as opposed to percentiles. Of the available regression equations, research indicates prediction formulas derived from a Veterans Affairs cohort (Predicted METs = 18 − 0.15*age) and the St. James Take Heart project (Predicted METs = 14.7 − 0.13*age) may provide somewhat better prognostic information in men and women, respectively (61).

Although percent predicted aerobic capacity appears to be prognostic (*i.e.*, lower percent predicted = worse prognosis), an individual's age has a significant influence on predictive characteristics in men and women. Specifically, in younger individuals (~40–60 yr), percent predicted aerobic capacity may have to decrease below 60%–70% before indicating poor prognosis, after which the

TABLE 4.9. Fitness Categories for Maximal Aerobic Power for Men and Women by Age

		MEN							
		Age 20–29				Age 30–39			
%		Balke Treadmill (time)	Max $\dot{V}O_2$ (mL/kg/min)	12-Min Run (miles)	1.5-Mi Run (time)	Balke Treadmill (time)	Max $\dot{V}O_2$ (mL/kg/min)	12-Min Run (miles)	1.5-Mi Run (time)
99	Superior	31:30	60.5	2.00	8:29	30:00	58.3	1.94	8:49
95		28:05	55.5	1.86	9:17	27:03	54.1	1.82	9:33
90	Excellent	27:00	54.0	1.81	9:34	25:25	51.7	1.75	10:01
85		25:30	51.8	1.75	10:00	24:13	50.0	1.70	10:24
80		25:00	51.1	1.73	10:09	23:06	48.3	1.66	10:46
75	Good	23:13	48.5	1.66	10:43	22:10	47.0	1.62	11:06
70		22:30	47.5	1.63	10:59	21:30	46.0	1.59	11:22
65		22:00	46.8	1.61	11:10	21:00	45.3	1.57	11:33
60		21:10	45.6	1.58	11:29	20:09	44.1	1.54	11:54
55	Fair	21:40	44.8	1.56	11:41	20:00	43.9	1.53	11:58
50		20:00	43.9	1.53	11:58	19:00	42.4	1.49	12:24
45		19:08	42.6	1.50	12:20	18:07	41.2	1.46	12:50
40		18:30	41.7	1.47	12:38	17:49	40.7	1.44	12:58
35	Poor	18:00	41.0	1.45	12:53	17:00	39.5	1.41	13:24
30		17:17	39.9	1.42	13:15	16:24	38.7	1.39	13:44
25		16:38	39.0	1.40	13:36	15:46	37.8	1.36	14:05
20		15:56	38.0	1.37	14:00	15:00	36.7	1.33	14:34
15	Very poor	15:00	36.7	1.33	14:34	14:02	35.2	1.29	15:13
10		13:37	34.7	1.28	15:30	13:00	33.8	1.25	15:57
5		11:38	31.8	1.20	17:04	11:15	31.2	1.18	17:25
1		8:00	26.5	1.05	20:58	8:00	26.5	1.05	20:58
		n = 2,328				n = 12,730			

Total n = 15,058

		MEN							
		Age 40–49				Age 50–59			
%		Balke Treadmill (time)	Max $\dot{V}O_2$ (mL/kg/min)	12-Min Run (miles)	1.5-Mi Run (time)	Balke Treadmill (time)	Max $\dot{V}O_2$ (mL/kg/min)	12-Min Run (miles)	1.5-Mi Run (time)
99	Superior	28:30	56.1	1.87	9:10	27:00	54.0	1.81	9:34
95		26:00	52.5	1.77	9:51	23:32	49.0	1.68	10:37
90	Excellent	24:00	49.6	1.69	10:28	22:00	46.8	1.61	11:10
85		23:00	48.2	1.65	10:48	20:30	44.6	1.55	11:45
80		21:45	46.4	1.60	11:15	19:37	43.3	1.52	12:08
75	Good	20:42	44.9	1.56	11:40	18:35	41.8	1.48	12:36
70		20:01	43.9	1.53	11:58	18:00	41.0	1.45	12:53
65		19:30	43.1	1.51	12:11	17:08	39.7	1.42	13:20
60		19:00	42.4	1.49	12:24	16:39	39.0	1.40	13:35
55	Fair	18:00	41.0	1.45	12:53	16:00	38.1	1.37	13:58
50		17:22	40.1	1.43	13:12	15:18	37.1	1.34	14:23
45		17:00	39.5	1.41	13:24	15:00	36.7	1.33	14:34
40		16:14	38.4	1.38	13:50	14:12	35.5	1.30	15:06
35	Poor	15:38	37.6	1.36	14:11	13:43	34.8	1.28	15:26
30		15:00	36.7	1.33	14:34	13:00	33.8	1.25	15:58
25		14:30	35.9	1.31	14:53	12:21	32.8	1.23	16:28
20		13:45	34.8	1.28	15:24	11:45	32.0	1.20	16:58
15	Very poor	13:00	33.8	1.25	15:58	11:00	30.9	1.17	17:38
10		12:00	32.3	1.21	16:46	10:00	29.4	1.13	18:37
5		10:01	29.4	1.13	18:48	8:15	26.9	1.06	20:38
1		7:00	25.1	1.01	22:22	5:25	22.8	0.95	25:00
			n = 18,104				*n* = 10,627		

Total *n* = 28,731

(continued)

TABLE 4.9. Fitness Categories for Maximal Aerobic Power for Men and Women by Age (*Continued*)

		MEN							
		Age 60–69				Age 70–79			
%		Balke Treadmill (time)	Max $\dot{V}O_2$ (mL/kg/min)	12-Min Run (miles)	1.5-Mi Run (time)	Balke Treadmill (time)	Max $\dot{V}O_2$ (mL/kg/min)	12-Min Run (miles)	1.5-Mi Run (time)
99	Superior	25:00	51.1	1.73	10:09	24:00	49.6	1.69	10:28
95		21:18	45.7	1.59	11:26	20:00	43.9	1.53	11:58
90	Excellent	19:10	42.7	1.50	12:20	17:00	39.5	1.41	13:24
85		18:01	41.0	1.45	12:53	16:00	38.1	1.37	13:58
80		17:01	39.6	1.41	13:23	15:00	36.7	1.33	14:34
75	Good	16:09	38.3	1.38	13:52	14:01	35.2	1.29	15:14
70		15:30	37.4	1.35	14:16	13:05	33.9	1.26	15:54
65		15:00	36.7	1.33	14:34	12:32	33.1	1.23	16:19
60		14:15	35.6	1.30	15:04	12:03	32.4	1.21	16:43
55	Fair	13:47	34.9	1.28	15:23	11:29	31.6	1.19	17:12
50		13:02	33.8	1.25	15:56	11:00	30.9	1.17	17:38
45		12:30	33.0	1.23	16:21	10:26	30.1	1.15	18:11
40		12:00	32.3	1.21	16:46	10:00	29.4	1.13	18:38
35	Poor	11:30	31.6	1.19	17:11	9:17	28.4	1.10	19:24
30		10:57	30.8	1.17	17:41	9:00	28.0	1.09	19:43
25		10:04	29.5	1.13	18:33	8:17	26.9	1.06	20:36
20		9:30	28.7	1.11	19:10	7:24	25.7	1.03	21:47
15	Very poor	8:30	27.3	1.07	20:19	6:40	24.6	1.00	22:52
10		7:21	25.6	1.03	21:51	5:31	23.0	0.95	24:49
5		5:57	23.6	0.97	24:03	4:00	20.8	0.89	27:58
1		3:16	19.7	0.86	29:47	2:15	18.2	0.82	32:46
		n = 2,971				n = 417			

Total n = 3,388

		WOMEN							
		Age 20–29				Age 30–39			
%		Balke Treadmill (time)	Max $\dot{V}O_2$ (mL/kg/min)	12-Min Run (miles)	1.5-Mi Run (time)	Balke Treadmill (time)	Max $\dot{V}O_2$ (mL/kg/min)	12-Min Run (miles)	1.5-Mi Run (time)
99	Superior	27:23	54.5	1.83	9:30	25:37	52.0	1.76	9:58
95		24:00	49.6	1.69	10:28	22:26	47.4	1.63	11:00
90		22:00	46.8	1.61	11:10	21:00	45.3	1.57	11:33
85	Excellent	21:00	45.3	1.57	11:33	20:00	43.9	1.53	11:58
80		20:01	43.9	1.53	11:58	19:00	42.4	1.49	12:24
75		19:00	42.4	1.49	12:24	18:02	41.0	1.45	12:53
70	Good	18:04	41.1	1.46	12:51	17:01	39.6	1.41	13:24
65		18:00	41.0	1.45	12:53	16:18	38.5	1.38	13:47
60		17:00	39.5	1.41	13:24	15:43	37.7	1.36	14:08
55		16:17	38.5	1.38	13:48	15:10	36.9	1.34	14:28
50	Fair	15:50	37.8	1.37	14:04	15:00	36.7	1.33	14:34
45		15:00	36.7	1.33	14:34	14:00	35.2	1.29	15:14
40		14:36	36.1	1.32	14:50	13:20	34.2	1.27	15:43
35		14:00	35.2	1.29	15:14	13:00	33.8	1.25	15:58
30	Poor	13:15	34.1	1.26	15:46	12:03	32.4	1.21	16:42
25		12:30	33.0	1.23	16:21	11:47	32.0	1.20	16:56
20		12:00	32.3	1.21	16:46	11:00	30.9	1.17	17:38
15		11:01	30.9	1.17	17:38	10:00	29.4	1.13	18:37
10	Very poor	10:04	29.5	1.13	18:33	9:00	28.0	1.09	19:43
5		8:43	27.6	1.08	20:03	7:33	25.9	1.03	21:34
1		6:00	23.7	0.97	23:58	5:27	22.9	0.95	24:56
			n = 1,280				*n* = 4,257		

Total *n* = 5,537

(continued)

TABLE 4.9. Fitness Categories for Maximal Aerobic Power for Men and Women by Age (*Continued*)

		WOMEN							
		Age 40–49				Age 50–59			
%		Balke Treadmill (time)	Max $\dot{V}O_2$ (mL/kg/min)	12-Min Run (miles)	1.5-Mi Run (time)	Balke Treadmill (time)	Max $\dot{V}O_2$ (mL/kg/min)	12-Min Run (miles)	1.5-Mi Run (time)
99	Superior	25:00	51.1	1.73	10:09	21:31	46.1	1.59	11:20
95		21:00	45.3	1.57	11:33	18:01	41.0	1.45	12:53
90	Excellent	19:30	43.1	1.51	12:11	16:30	38.8	1.39	13:40
85		18:02	41.0	1.45	12:53	15:16	37.0	1.34	14:24
80		17:02	39.6	1.41	13:23	15:00	36.7	1.33	14:34
75	Good	16:22	38.6	1.39	13:45	14:02	35.2	1.29	15:13
70		16:00	38.1	1.37	13:58	13:20	34.2	1.27	15:43
65		15:01	36.7	1.33	14:34	12:40	33.3	1.24	16:13
60		14:30	35.9	1.31	14:53	12:13	32.6	1.22	16:35
55	Fair	14:01	35.2	1.29	15:13	12:00	32.3	1.21	16:46
50		13:32	34.5	1.27	15:34	11:21	31.4	1.19	17:19
45		13:00	33.8	1.25	15:58	11:00	30.9	1.17	17:38
40		12:18	32.8	1.22	16:31	10:19	29.9	1.14	18:18
35	Poor	12:00	32.3	1.21	16:46	10:00	29.4	1.13	18:37
30		11:10	31.1	1.18	17:29	9:30	28.7	1.11	19:10
25		10:32	30.2	1.15	18:05	9:00	28.0	1.09	19:43
20		10:00	29.4	1.13	18:37	8:10	26.8	1.06	20:44
15	Very poor	9:07	28.2	1.10	19:35	7:30	25.8	1.03	21:38
10		8:04	26.6	1.05	20:52	6:40	24.6	1.00	22:52
5		7:00	25.1	1.01	22:22	5:33	23.0	0.95	24:46
1		5:00	22.2	0.93	25:49	3:31	20.1	0.87	29:09
		n = 5,908				n = 3,923			

Total n = 9,831

		WOMEN							
		Age 60–69				Age 70–79			
%		Balke Treadmill (time)	Max $\dot{V}O_2$ (mL/kg/min)	12-Min Run (miles)	1.5-Mi Run (time)	Balke Treadmill (time)	Max $\dot{V}O_2$ (mL/kg/min)	12-Min Run (miles)	1.5-Mi Run (time)
99	Superior	19:00	42.4	1.49	12:24	19:00	42.4	1.49	12:24
95		15:46	37.8	1.36	14:05	15:21	37.2	1.35	14:21
90	Excellent	14:30	35.9	1.31	14:53	12:06	32.5	1.22	16:40
85		13:17	34.2	1.26	15:45	12:00	32.3	1.21	16:46
80		12:15	32.7	1.22	16:33	10:47	30.6	1.16	17:51
75	Good	12:00	32.3	1.21	16:46	10:16	29.8	1.14	18:21
70		11:09	31.1	1.18	17:30	10:01	29.4	1.13	18:37
65		11:00	30.9	1.17	17:38	10:00	29.4	1.13	18:37
60		10:10	29.7	1.14	18:27	9:06	28.1	1.10	19:36
55	Fair	10:00	29.4	1.13	18:37	9:00	28.0	1.09	19:43
50		9:35	28.8	1.12	19:04	8:44	27.6	1.08	20:02
45		9:07	28.2	1.10	19:35	8:05	26.7	1.05	20:52
40		8:33	27.3	1.07	20:16	7:35	25.9	1.03	21:31
35	Poor	8:04	26.6	1.05	20:52	7:07	25.3	1.02	22:07
30		7:32	25.9	1.03	21:36	6:44	24.7	1.00	22:46
25		7:01	25.1	1.01	22:21	6:23	24.2	0.99	23:20
20		6:39	24.6	1.00	22:52	5:55	23.5	0.97	24:06
15	Very poor	6:12	23.9	0.98	23:37	5:00	22.2	0.93	25:49
10		5:32	23.0	0.95	24:48	4:30	21.5	0.91	26:51
5		4:45	21.8	0.92	26:19	3:12	19.6	0.86	30:00
1		3:07	19.5	0.86	30:12	1:17	16.8	0.78	36:13
		n = 1,131				n = 155			

Total n = 1,286

Adapted with permission from *Physical Fitness Assessments and Norms for Adults and Law Enforcement*. The Cooper Institute, Dallas, Texas. 2009.
For more information: www.cooperinstitute.org

increase in mortality risk becomes rather steep. In older individuals (>60 yr), there appears to be a more linear relationship between percent predicted aerobic capacity and mortality risk across the range of potential values as opposed to a single threshold. In a comparison of the physical fitness status of any one individual to published norms, the accuracy of the classification is dependent on the similarities between the populations and methodology (*e.g.*, estimated vs. measured $\dot{V}O_{2max}$, maximal vs. submaximal).

Although submaximal exercise testing is not as precise as maximal exercise testing, it provides a general reflection of an individual's physical fitness at a lower cost, potentially reduced risk for adverse events, and requires less time and effort on the part of the subject. Some of the assumptions inherent in a submaximal test are more easily met (*e.g.*, steady state HR can be verified), whereas others (*e.g.*, estimated HR_{max}) introduce unknown errors into the prediction of $\dot{V}O_{2max}$. When an individual is given repeated submaximal exercise tests over a period of weeks or months and the HR response to a fixed work rate decreases over time, it is likely that the individual's CRF has improved, independent of the accuracy of the $\dot{V}O_{2max}$ prediction. Despite differences in test accuracy and methodology, virtually all evaluations can establish a baseline and be used to track relative progress.

MUSCULAR STRENGTH AND MUSCULAR ENDURANCE

Muscular strength and endurance are health-related fitness components that may improve or maintain the following (110):

- Bone mass, which is related to osteoporosis.
- Glucose tolerance, which is pertinent in both the prediabetic and diabetic state.
- Musculotendinous integrity, which is related to a lower risk of injury including low back pain.
- The ability to carry out the activities of daily living, which is related to perceived quality of life and self-efficacy among other indicators of mental health.
- The FFM and resting metabolic rate, which are related to weight management.

The ACSM has melded the terms muscular strength, endurance, and power into a category termed "muscular fitness" and included it as an integral portion of total health-related fitness in the position stand on the quantity and quality of exercise for developing and maintaining fitness (42). Muscular strength refers to *the muscle's ability to exert force*, muscular endurance is *the muscle's ability to continue to perform successive exertions or many repetitions*, and muscular power is *the muscle's ability to exert force per unit of time* (*i.e.*, rate) (29). Traditionally, tests allowing few (<3) repetitions of a task prior to reaching momentary muscular fatigue have been considered strength measures, whereas those in which numerous repetitions (>12) are performed prior to momentary muscular fatigue were considered measures of muscular endurance. However, the performance of a maximal repetition range (*i.e.*, 4, 6, or 8 repetitions at a given resistance) also can be used to assess strength.

RATIONALE

Physical fitness tests of muscular strength and muscular endurance before commencing exercise training or as part of a health/fitness screening evaluation can provide valuable information on a client's baseline physical fitness level. For example, muscular fitness test results can be compared to established standards and can be helpful in identifying weaknesses in certain muscle groups or muscle imbalances that could be targeted in exercise training programs. The information obtained during baseline muscular fitness assessments can also serve as a basis for designing individualized exercise training programs. An equally useful application of physical fitness testing is to show a client's progressive improvements over time as a result of the training program, and thus provide feedback that is often beneficial in promoting long-term exercise adherence.

PRINCIPLES

Muscle function tests are very specific to the muscle group tested, the type of muscle action, velocity of muscle movement, type of equipment, and joint range of motion (ROM). Results of any one test are specific to the procedures used, and no single test exists for evaluating total body muscular endurance or strength. Individuals should participate in familiarization/practice sessions with test equipment and adhere to a specific protocol including a predetermined repetition duration and ROM in order to obtain a reliable score that can be used to track true physiologic adaptations over time. Moreover, warm-up consisting of 5–10 min of light intensity, aerobic exercise (*i.e.*, treadmill or cycle ergometer), static stretching, and several light intensity repetitions of the specific testing exercise should precede muscular fitness testing. These warm-up activities increase muscle temperature and localized blood flow and promotes appropriate cardiovascular responses to exercise. A summary of standardized conditions include the following:

- Strict posture.
- Consistent repetition duration (movement speed).
- Full ROM.
- Use of spotters (when necessary).
- Equipment familiarization.
- Warm-up.

Change in muscular fitness over time can be based on the absolute value of the external load or resistance (*e.g.*, newtons, kilograms [kg], or pounds [lb]), but when comparisons are made between individuals, the values should be expressed as relative values (per kilogram of body weight [$kg \cdot kg^{-1}$]). In both cases, caution must be used in the interpretation of the scores because the norms may not include a representative sample of the individual being measured, a standardized protocol may be absent, or the exact test being used (*e.g.*, free weight vs. machine weight) may differ. In addition, the biomechanics for a given resistance exercise may differ significantly when using equipment from different manufactures, further impacting *generalizability*.

MUSCULAR STRENGTH

Although muscular strength refers to the external force (properly expressed in newtons, although kilograms and pounds are commonly used as well) that can be generated by a specific muscle or muscle group, it is commonly expressed in terms of resistance met or overcome. Strength can be assessed either statically (*i.e.*, no overt muscular movement at a given joint or group of joints) or dynamically (*i.e.*, movement of an external load or body part in which the muscle changes length). Static or isometric strength can be measured conveniently using a variety of devices including cable tensiometers and handgrip dynamometers. In certain instances, measures of static strength are specific to the muscle group and joint angle involved in testing; therefore, their utility in describing overall muscular strength may be limited. Peak force development in such tests is commonly referred to as the maximum voluntary contraction (MVC).

Traditionally, the one repetition maximum (1-RM), the greatest resistance that can be moved through the full ROM in a controlled manner with good posture, has been the standard for dynamic strength assessment. With appropriate testing familiarization, 1-RM is a reliable indicator of muscle strength (67,84). A multiple RM, such as 4- or 8-RM, can be used as a measure of muscular strength. For example, if one were training with 6- to 8-RM, the performance of a 6-RM to momentary muscular fatigue would provide an index of strength changes over time, independent of the true 1-RM. Reynolds et al. (91) have demonstrated multiple repetition tests in the 4- to 8-RM range provide a reasonably accurate estimate of 1-RM.

In addition, a conservative approach to assessing maximal muscle strength should be considered in patients at high risk for or with known CVD, pulmonary, and metabolic diseases and health conditions. For these groups, assessment of 10- to 15-RM that approximates training recommendations may be prudent (110). Valid measures of general upper body strength include the 1-RM values for bench press or shoulder press. Corresponding indices of lower body strength include 1-RM values for the leg press or leg extension. Norms based on resistance lifted divided by body mass for the bench press and leg press are provided in *Tables 4.10* and *4.11*, respectively. The following represents the basic steps in 1-RM (or any multiple RM) testing following familiarization/practice sessions (69):

1. The subject should warm up by completing a number of submaximal repetitions of the specific exercise that will be used to determine the 1-RM.
2. Determine the 1-RM (or any multiple of 1-RM) within four trials with rest periods of 3–5 min between trials.
3. Select an initial weight that is within the subject's perceived capacity (~50%–70% of capacity).
4. Resistance is progressively increased by 2.5–20.0 kg (5.5–44.0 lb) until the subject cannot complete the selected repetition(s); all repetitions should be performed at the same speed of movement and ROM to instill consistency between trials.
5. The final weight lifted successfully is recorded as the absolute 1-RM or multiple RM.

TABLE 4.10. Fitness Categories for Upper Body Strength[a] for Men and Women by Age

$$\text{Bench Press Weight Ratio} = \frac{\text{weight pushed in lbs}}{\text{body weight in lbs}}$$

MEN							
		Age					
%		<20	20–29	30–39	40–49	50–59	60+
99	Superior	>1.76	>1.63	>1.35	>1.20	>1.05	>0.94
95		1.76	1.63	1.35	1.20	1.05	0.94
90	Excellent	1.46	1.48	1.24	1.10	0.97	0.89
85		1.38	1.37	1.17	1.04	0.93	0.84
80		1.34	1.32	1.12	1.00	0.90	0.82
75	Good	1.29	1.26	1.08	0.96	0.87	0.79
70		1.24	1.22	1.04	0.93	0.84	0.77
65		1.23	1.18	1.01	0.90	0.81	0.74
60		1.19	1.14	0.98	0.88	0.79	0.72
55	Fair	1.16	1.10	0.96	0.86	0.77	0.70
50		1.13	1.06	0.93	0.84	0.75	0.68
45		1.10	1.03	0.90	0.82	0.73	0.67
40		1.06	0.99	0.88	0.80	0.71	0.66
35	Poor	1.01	0.96	0.86	0.78	0.70	0.65
30		0.96	0.93	0.83	0.76	0.68	0.63
25		0.93	0.90	0.81	0.74	0.66	0.60
20		0.89	0.88	0.78	0.72	0.63	0.57
15	Very poor	0.86	0.84	0.75	0.69	0.60	0.56
10		0.81	0.80	0.71	0.65	0.57	0.53
5		0.76	0.72	0.65	0.59	0.53	0.49
1		<0.76	<0.72	<0.65	<0.59	<0.53	<0.49
n		60	425	1,909	2,090	1,279	343

Total *n* = 6,106

WOMEN							
99	Superior	>0.88	>1.01	>0.82	>0.77	>0.68	>0.72
95		0.88	1.01	0.82	0.77	0.68	0.72
90	Excellent	0.83	0.90	0.76	0.71	0.61	0.64
85		0.81	0.83	0.72	0.66	0.57	0.59
80		0.77	0.80	0.70	0.62	0.55	0.54
75	Good	0.76	0.77	0.65	0.60	0.53	0.53
70		0.74	0.74	0.63	0.57	0.52	0.51
65		0.70	0.72	0.62	0.55	0.50	0.48
60		0.65	0.70	0.60	0.54	0.48	0.47
55	Fair	0.64	0.68	0.58	0.53	0.47	0.46
50		0.63	0.65	0.57	0.52	0.46	0.45
45		0.60	0.63	0.55	0.51	0.45	0.44
40		0.58	0.59	0.53	0.50	0.44	0.43
35	Poor	0.57	0.58	0.52	0.48	0.43	0.41
30		0.56	0.56	0.51	0.47	0.42	0.40
25		0.55	0.53	0.49	0.45	0.41	0.39
20		0.53	0.51	0.47	0.43	0.39	0.38

(*continued*)

TABLE 4.10. Fitness Categories for Upper Body Strength[a] for Men and Women by Age (*Continued*)

$$\text{Bench Press Weight Ratio} = \frac{\text{weight pushed in lbs}}{\text{body weight in lbs}}$$

WOMEN							
		Age					
%		<20	20–29	30–39	40–49	50–59	60+
15	Very poor	0.52	0.50	0.45	0.42	0.38	0.36
10		0.50	0.48	0.42	0.38	0.37	0.33
5		0.41	0.44	0.39	0.35	0.31	0.26
1		<0.41	<0.44	<0.39	<0.35	<0.31	<0.26
n		20	191	379	333	189	42

Total *n* = 1,154

[a]One repetition maximum bench press, with bench press weight ratio = weight pushed in pounds per body weight in pounds.

Adapted with permission from *Physical Fitness Assessments and Norms for Adults and Law Enforcement*. The Cooper Institute, Dallas, Texas. 2009. For more information: www.cooperinstitute.org

TABLE 4.11. Fitness Categories for Leg Strength by Age and Sex[a]

		Age (year)				
Percentile		20–29	30–39	40–49	50–59	60+
Men						
90	Well above average	2.27	2.07	1.92	1.80	1.73
80	Above average	2.13	1.93	1.82	1.71	1.62
70		2.05	1.85	1.74	1.64	1.56
60	Average	1.97	1.77	1.68	1.58	1.49
50		1.91	1.71	1.62	1.52	1.43
40	Below average	1.83	1.65	1.57	1.46	1.38
30		1.74	1.59	1.51	1.39	1.30
20	Well below average	1.63	1.52	1.44	1.32	1.25
10		1.51	1.43	1.35	1.22	1.16
Women						
90	Well above average	1.82	1.61	1.48	1.37	1.32
80	Above average	1.68	1.47	1.37	1.25	1.18
70		1.58	1.39	1.29	1.17	1.13
60	Average	1.50	1.33	1.23	1.10	1.04
50		1.44	1.27	1.18	1.05	0.99
40	Below average	1.37	1.21	1.13	0.99	0.93
30		1.27	1.15	1.08	0.95	0.88
20	Well below average	1.22	1.09	1.02	0.88	0.85
10		1.14	1.00	0.94	0.78	0.72

[a]One repetition maximum leg press with leg press weight ratio = weight pushed per body weight.

Adapted from Institute for Aerobics Research, Dallas, 1994. Study population for the data set was predominantly white and college educated. A Universal Dynamic Variable Resistance (DVR) machine was used to measure the 1-repetition maximum (RM).

Isokinetic testing involves the assessment of maximal muscle tension throughout a ROM set at a constant angular velocity (*e.g.*, 60 angles · s^{-1}). Equipment that allows control of the speed of joint rotation (degrees · s^{-1}) as well as the ability to test movement around various joints (*e.g.*, knee, hip, shoulder, elbow) is available from commercial sources. Such devices measure peak rotational force or torque, but an important drawback is that this equipment is substantially more expensive compared to other strength testing modalities (45).

MUSCULAR ENDURANCE

Muscular endurance is the ability of a muscle group to execute repeated muscle actions over a period of time sufficient to cause muscular fatigue or to maintain a specific percentage of the 1-RM for a prolonged period of time. If the total number of repetitions at a given amount of resistance is measured, the result is termed absolute muscular endurance. If the number of repetitions performed at a percentage of the 1-RM (*e.g.*, 70%) is used pretesting and posttesting, the result is termed relative muscular endurance. Simple field tests such as a curl-up (crunch) test (19,45) or the maximum number of push-ups that can be performed without rest (19) may be used to evaluate the endurance of the abdominal muscle groups and upper body muscles, respectively. Procedures for conducting the push-up and curl-up (crunch) muscular endurance tests are given in *Box 4.6*, and physical fitness categories are provided in *Tables 4.12* and *4.13*, respectively.

Resistance training equipment also can be adapted to measure muscular endurance by selecting an appropriate submaximal level of resistance and measuring the number of repetitions or the duration of static muscle action before fatigue. For example, the YMCA bench press test involves performing standardized repetitions at a rate of 30 lifts or reps · min^{-1}. Men are tested using a 36.3-kg (80 lb) barbell and women using a 15.9-kg (35 lb) barbell. Subjects are scored by the number of successful repetitions completed (111). The YMCA test is an excellent example of a test that attempts to control for repetition duration and posture alignment, thus possessing high reliability. Normative data for the YMCA bench press test are presented in *Table 4.14*.

SPECIAL CONSIDERATIONS IN MUSCULAR FITNESS

Older Adults

The number of older adults in the United States is expected to increase exponentially over the next several decades as described in *Chapter 8*. As individuals are living longer, it is becoming increasingly more important to find ways to extend active and independent life expectancy. Assessing muscular strength and endurance, neuromotor fitness, and other aspects of health-related physical fitness among older adults can aid in detecting physical limitations and yield important information used to design exercise programs that improve muscular fitness before serious functional limitations or injuries occur. The Senior Fitness Test (SFT) was developed in response to a need for improved health/fitness

BOX 4.6 Push-up and Curl-up (Crunch) Test Procedures for Measurement of Muscular Endurance

PUSH-UP

1. The push-up test is administered with men starting in the standard "down" position (hands pointing forward and under the shoulder, back straight, head up, using the toes as the pivotal point) and women in the modified "knee push-up" position (legs together, lower leg in contact with mat with ankles plantar-flexed, back straight, hands shoulder width apart, head up, using the knees as the pivotal point).
2. The client/patient must raise the body by straightening the elbows and return to the "down" position, until the chin touches the mat. The stomach should not touch the mat.
3. For both men and women, the subject's back must be straight at all times and the subject must push up to a straight arm position.
4. The maximal number of push-ups performed consecutively without rest is counted as the score.
5. The test is stopped when the client strains forcibly or unable to maintain the appropriate technique within two repetitions.

CURL-UP (CRUNCH)[†]

1. Two strips of masking tape are to be placed on a mat on the floor at a distance of 12 cm apart (for clients/patients <45 yr) or 8 cm apart (for clients/patients ≥45 yr).
2. Subjects are to lie in a supine position across the tape, knees bent at 90° with feet on the floor and arms extended to their sides, such that their fingertips touch the nearest strip. This is the bottom position. To reach the top position, subjects are to flex their spines to 30°, reaching their hands forward until their fingers touch the second strip of tape.
3. A metronome is to be set at 40 beats · min^{-1}. At the first beep, the subject begins the curl-up, reaching the top position at the second beep, returning to the starting position at the third, top position at the fourth, etc.
4. Repetitions are counted each time the subject reaches the bottom position. The test is concluded either when the subject reaches 75 curl-ups, or the cadence is broken.
5. Every subject will be allowed several practice repetitions prior to the start of the test.

[†]Alternatives include: 1) having the hands held across the chest with the head activating a counter when the trunk reaches a 30° position (32) and placing the hands on the thighs and curling up until the hands reach the knee caps (37). Elevation of the trunk to 30° is the important aspect of the movement.
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TABLE 4.12. Fitness Categories for the Push-Up by Age and Sex

	Age (year)									
Category	**20–29**		**30–39**		**40–49**		**50–59**		**60–69**	
Sex	**M**	**W**	**M**	**W**	**M**	**W**	**M**	**W**	**M**	**W**
Excellent	36	30	30	27	25	24	21	21	18	17
Very good	35	29	29	26	24	23	20	20	17	16
	29	21	22	20	17	15	13	11	11	12
Good	28	20	21	19	16	14	12	10	10	11
	22	15	17	13	13	11	10	7	8	5
Fair	21	14	16	12	12	10	9	6	7	4
	17	10	12	8	10	5	7	2	5	2
Needs improvement	16	9	11	7	9	4	6	1	4	1

M, men; W, women.

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assessment tools for older individuals (92). The test was designed to assess the key physiologic parameters (*e.g.*, strength, endurance, agility, balance) needed to perform common everyday physical activities that are often difficult to perform in later years. One aspect of the SFT is the 30-s chair stand test. This test, and others of the SFT, meets scientific standards for reliability and validity, is simple and easy to administer in the "field" setting, and has accompanying performance norms for older men and women 60–94 yr based on a study of over 7,000 older Americans (92). This test has been shown to correlate well with other muscular fitness tests such as the 1-RM. Two specific tests included in the SFT — the 30-s chair stand and single-arm curl — can be used by the health/fitness and clinical exercise professionals to safely and effectively assess muscular strength and endurance in most older adults.

TABLE 4.13. Fitness Categories for the Partial Curl-Up by Age and Sex

		Age (year)									
Percentile		**20–29**		**30–39**		**40–49**		**50–59**		**60–69**	
Gender		**M**	**W**	**M**	**W**	**M**	**W**	**M**	**W**	**M**	**W**
90	Well above average	75	70	75	55	75	55	74	48	53	50
80	Above average	56	45	69	43	75	42	60	30	33	30
70		41	37	46	34	67	33	45	23	26	24
60	Average	31	32	36	28	51	28	35	16	19	19
50		27	27	31	21	39	25	27	9	16	13
40	Below average	24	21	26	15	31	20	23	2	9	9
30		20	17	19	12	26	14	19	0	6	3
20	Well below average	13	12	13	0	21	5	13	0	0	0
10		4	5	0	0	13	0	0	0	0	0

M, men; W, women.

Adapted from (37).

TABLE 4.14. Fitness Categories for the YMCA Bench Press Test (Total Lifts) by Age and Sex

	Age (year)											
Category	**18–25**		**26–35**		**36–45**		**46–55**		**56–65**		**>65**	
Sex	**M**	**W**	**M**	**W**	**M**	**W**	**M**	**W**	**M**	**W**	**M**	**W**
Excellent	64	66	61	62	55	57	47	50	41	42	36	30
	44	42	41	40	36	33	28	29	24	24	20	18
Good	41	38	37	34	32	30	25	24	21	21	16	16
	34	30	30	29	26	26	21	20	17	17	12	12
Above average	33	28	29	28	25	24	20	18	14	14	10	10
	29	25	26	24	22	21	16	14	12	12	9	8
Average	28	22	24	22	21	20	14	13	11	10	8	7
	24	20	21	18	18	16	12	10	9	8	7	5
Below average	22	18	20	17	17	14	11	9	8	6	6	4
	20	16	17	14	14	12	9	7	5	5	4	3
Poor	17	13	16	13	12	10	8	6	4	4	3	2
	13	9	12	9	9	6	5	2	2	2	2	0
Very poor	<10	6	9	6	6	4	2	1	1	1	1	0

M, men; W, women.

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Coronary Prone Clients

Moderate intensity resistance training performed 2–3 d • wk^{-1} is effective for improving muscular fitness, preventing and managing a variety of chronic medical conditions, modifying CVD risk factors, and enhancing psychosocial well-being for individuals with and without CVD. Consequently, authoritative professional health organizations including the ACSM and AHA support the inclusion of resistance training as an adjunct to aerobic exercise in their current recommendations and guidelines on exercise for individuals with CVD (see *Chapter 9*) (110).

The absence of anginal symptoms, ischemic ST-segment changes on the ECG, abnormal hemodynamics, and complex ventricular dysrhythmias suggests moderate intensity (*e.g.*, performance of 10–15 repetitions) resistance testing and training can be performed safely by patients with CVD deemed "low risk" (*e.g.*, individuals without resting or exercise-induced evidence of myocardial ischemia, severe left ventricular dysfunction, or complex ventricular dysrhythmias, and with normal or near normal CRF [see *Chapter 2*]). Moreover, despite concerns that resistance exercise elicits abnormal cardiovascular "pressor responses" in patients with CVD and/or controlled hypertension, studies have found strength testing and resistance training in these patients elicit HR and BP responses that appear to fall within clinically acceptable limits (110). Resistance training in moderate-to-high risk patients with CVD may be deemed appropriate following a thorough clinical assessment by an experienced health care professional. Furthermore, moderate-to-high risk patients with CVD who do participate in a resistance training program should be closely monitored (110). Absolute and relative contraindications to resistance testing and training are provided in *Box 4.7*.

BOX 4.7 Absolute and Relative Contraindications to Resistance Training and Testing

ABSOLUTE

- Unstable CHD
- Decompensated HF
- Uncontrolled arrhythmias
- Severe pulmonary hypertension (mean pulmonary arterial pressure >55 mm Hg)
- Severe and symptomatic aortic stenosis
- Acute myocarditis, endocarditis, or pericarditis
- Uncontrolled hypertension (>180/110 mm Hg)
- Aortic dissection
- Marfan syndrome
- High intensity RT (80% to 100% of 1-RM) in patients with active proliferative retinopathy or moderate or worse nonproliferative diabetic retinopathy

RELATIVE (SHOULD CONSULT A PHYSICIAN BEFORE PARTICIPATION)

- Major risk factors for CHD
- Diabetes at any age
- Uncontrolled hypertension (>160/100 mm Hg)
- Low functional capacity (<4 METs)
- Musculoskeletal limitations
- Individuals who have implanted pacemakers or defibrillators

CHD, Coronary heart disease; HF, Heart failure; METs, Metabolic equivalents; RM, Repetition maximum; RT, Resistance training.

Children and Adolescents

Along with CRF, flexibility, and body composition, muscular fitness is recognized as an important component of health-related fitness in children and adolescents (see *Chapter 8*) (9,36). The benefits of enhancing muscular strength and endurance in youth include developing proper posture, reducing the risk of injury, improving body composition, enhancing motor performance skills such as sprinting and jumping, and enhancing self-confidence and self-esteem. As a general guide, children who are ready to begin participation in sport activities (~7–8 yr) may also be ready to initiate a resistance training program (36).

Assessing muscular strength and endurance with the push-up and abdominal curl-up is common practice in most physical education programs, YMCA/YWCA recreation programs, and youth sport centers. Use of resistance training equipment commonly available in fitness facilities is also appropriate for the assessment of muscle strength and endurance. When properly administered, different muscular fitness measures can be used to assess a child's strengths and weaknesses, develop a personalized fitness program, track progress, and motivate participants. Conversely, unsupervised or poorly administered muscular fitness assessments may not only discourage youth from participating in fitness activities, but may also result in injury. Qualified health/fitness and clinical exercise professionals should demonstrate proper performance of each skill, provide an opportunity for each child to practice a few repetitions of each skill, and offer guidance and instruction when necessary. In addition, it is important and usually required to obtain informed consent from the parent or legal guardian prior to initiating muscular testing. The informed consent includes information on potential benefits and risks, the right to withdraw at any time, and issues regarding confidentiality. General guidelines for resistance training in children and adolescents are listed in *Box 4.8* (see *Chapter 8*).

BOX 4.8 Guidelines for Resistance Training in Children and Adolescents

- Ensure appropriate training for individual providing training instruction and supervision
- Provide a safe exercise environment
- Start training session with a 5- to 10-min dynamic warm-up
- Initiate training program two to three times per week on nonconsecutive days, with light resistance, and ensure exercise technique is correct
- General training session guidelines: one to three sets of 6–15 repetitions with combination of upper and lower body exercise
- Incorporate exercises specifically focusing on trunk
- Training program should induce symmetrical and balanced muscular development
- Individualized exercise progression based on goals and skill
- Gradual increase (~5%–10%) in training resistance as gains are made
- Use calisthenics and/or stretching postresistance training session
- Be aware of individual needs/concerns during each session
- Consider use of an individualized exercise log
- Continually alter training program to maintain interest and avoid training plateaus
- Ensure proper nutrition, hydration, and sleep
- Instructor and parents should be supportive and encouraging to help maintain interest

Adapted from (36).

FLEXIBILITY

Flexibility is the ability to move a joint through its complete ROM. It is important in athletic performance (*e.g.*, ballet, gymnastics) and in the ability to carry out activities of daily living. Consequently, maintaining flexibility of all joints facilitates movement; in contrast, when an activity moves the structures of a joint beyond its full ROM, tissue damage can occur.

Flexibility depends on a number of specific variables including distensibility of the joint capsule, adequate warm-up, and muscle viscosity. In addition, compliance (*i.e.*, tightness) of various other tissues such as ligaments and tendons affects the ROM. Just as muscular strength and endurance is specific to the muscles involved, flexibility is joint specific; therefore, no single flexibility test can be used to evaluate total body flexibility. Laboratory tests usually quantify flexibility in terms of ROM expressed in degrees. Common devices for this purpose include goniometers, electrogoniometers, the Leighton flexometer, inclinometers, and tape measures. Comprehensive instructions are available for the evaluation of flexibility of most anatomic joints (24,80). Visual estimates of ROM can be useful in fitness screening but are inaccurate relative to directly measured ROM. These estimates can include neck and trunk flexibility, hip flexibility, lower extremity flexibility, shoulder flexibility, and postural assessment.

A more precise measurement of joint ROM can be assessed at most anatomic joints following strict procedures (24,80) and the proper use of a goniometer. Accurate measurements require in-depth knowledge of bone, muscle, and joint anatomy as well as experience in administering the evaluation. *Table 4.15*

TABLE 4.15. Range of Motion of Select Single Joint Movements in Degrees

	Degrees		Degrees
Shoulder Girdle Movement			
Flexion	90–120	Extension	20–60
Abduction	80–100		
Horizontal abduction	30–45	Horizontal adduction	90–135
Medial rotation	70–90	Lateral rotation	70–90
Elbow Movement			
Flexion	135–160		
Supination	75–90	Pronation	75–90
Trunk Movement			
Flexion	120–150	Extension	20–45
Lateral flexion	10–35	Rotation	20–40
Hip Movement			
Flexion	90–135	Extension	10–30
Abduction	30–50	Adduction	10–30
Medial rotation	30–45	Lateral rotation	45–60
Knee Movement			
Flexion	130–140	Extension	5–10
Ankle Movement			
Dorsiflexion	15–20	Plantarflexion	30–50
Inversion	10–30	Eversion	10–20

Adapted from (78).

provides normative ROM values for select anatomic joints. Additional information can be found in the *ACSM's Resource Manual for Guidelines for Exercise Testing and Prescription, Seventh Edition* (101).

The sit-and-reach test has been used commonly to assess low back and hamstring flexibility; however, its relationship to predict the incidence of low back pain is limited (54). The sit-and-reach test is suggested to be a better measure of hamstring flexibility than low back flexibility (53). The relative importance of hamstring flexibility to activities of daily living and sports performance, therefore, supports the inclusion of the sit-and-reach test for health-related fitness testing until a criterion measure evaluation of low back flexibility is available. Although limb and torso length disparity may impact sit-and-reach scoring, modified testing that establishes an individual zero point for each participant has not enhanced the predictive index for low back flexibility or low back pain (17,52,74).

Poor lower back and hip flexibility, in conjunction with poor abdominal strength and endurance or other causative factors, may contribute to development of muscular low back pain; however, this hypothesis remains to be substantiated (88). Methods for administering the sit-and-reach test are presented in *Box 4.9*. Normative data for two sit-and-reach tests are presented in *Tables 4.16* and *4.17*.

BOX 4.9 Trunk Flexion (Sit-and-Reach) Test Procedures

Pretest: Clients/Patients should perform a short warm-up prior to this test and include some stretches (*e.g.*, modified hurdler's stretch). It is also recommended that the participant refrain from fast, jerky movements, which may increase the possibility of an injury. The participant's shoes should be removed.

1. For the Canadian Trunk Forward Flexion test, the client sits without shoes and the soles of the feet flat against the flexometer (sit-and-reach box) at the 26 cm mark. Inner edges of the soles are placed within 2 cm of the measuring scale. For the YMCA sit-and-reach test, a yardstick is placed on the floor and tape is placed across it at a right angle to the 15 in mark. The client/patient sits with the yardstick between the legs, with legs extended at right angles to the taped line on the floor. Heels of the feet should touch the edge of the taped line and be about 10 to 12 in apart. (Note the zero point at the foot/box interface and use the appropriate norms.)
2. The client/patient should slowly reach forward with both hands as far as possible, holding this position approximately 2 s. Be sure that the participant keeps the hands parallel and does not lead with one hand. Fingertips can be overlapped and should be in contact with the measuring portion or yardstick of the sit-and-reach box.

BOX 4.9 Trunk Flexion (Sit-and-Reach) Test Procedures (*Continued*)

3. The score is the most distant point (cm or in) reached with the fingertips. The best of two trials should be recorded. To assist with the best attempt, the client/patient should exhale and drop the head between the arms when reaching. Testers should ensure that the knees of the participant stay extended; however, the participant's knees should not be pressed down. The client/patient should breathe normally during the test and should not hold her/his breath at any time. Norms for the Canadian test are presented in *Table 4.16*. Note that these norms use a sit-and-reach box in which the "zero" point is set at the 26 cm mark. If a box is used in which the zero point is set at 23 cm (*e.g.*, Fitnessgram), subtract 3 cm from each value in this table. The norms for the YMCA test are presented in *Table 4.17*.

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A COMPREHENSIVE HEALTH FITNESS EVALUATION

A comprehensive health/fitness assessment includes the following:

- Prescreening/risk classification.
- Resting HR, BP, height, weight, BMI, and ECG (if appropriate).
- Body composition.
    - Waist circumference.
    - Skinfold assessment.

TABLE 4.16. Fitness Categories for Trunk Forward Flexion Using a Sit-and-Reach Box (cm)[a] by Age and Sex

	Age (year)									
Category	**20–29**		**30–39**		**40–49**		**50–59**		**60–69**	
Sex	**M**	**W**	**M**	**W**	**M**	**W**	**M**	**W**	**M**	**W**
Excellent	40	41	38	41	35	38	35	39	33	35
Very good	39	40	37	40	34	37	34	38	32	34
	34	37	33	36	29	34	28	33	25	31
Good	33	36	32	35	28	33	27	32	24	30
	30	33	28	32	24	30	24	30	20	27
Fair	29	32	27	31	23	29	23	29	19	26
	25	28	23	27	18	25	16	25	15	23
Needs improvement	24	27	22	26	17	24	15	24	14	22

[a]These norms are based on a sit-and-reach box in which the "zero" point is set at 26 cm. When using a box in which the zero point is set at 23 cm, subtract 3 cm from each value in this table.

M, men; W, women.

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TABLE 4.17. Fitness Categories for the YMCA Sit-and-Reach Test (in) by Age and Sex

		Age (year)											
Percentile		18–25		26–35		36–45		46–55		56–65		>65	
Gender		M	W	M	W	M	W	M	W	M	W	M	W
90	Well above average	22	24	21	23	21	22	19	21	17	20	17	20
80	Above average	20	22	19	21	19	21	17	20	15	19	15	18
70		19	21	17	20	17	19	15	18	13	17	13	17
60	Average	18	20	17	20	16	18	14	17	13	16	12	17
50		17	19	15	19	15	17	13	16	11	15	10	15
40	Below average	15	18	14	17	13	16	11	14	9	14	9	14
30		14	17	13	16	13	15	10	14	9	13	8	13
20	Well below average	13	16	11	15	11	14	9	12	7	11	7	11
10		11	14	9	13	7	12	6	10	5	9	4	9

M, men; W, women.

Adapted with permission from (111).

- Cardiorespiratory fitness.
  - Submaximal or maximal test typically on a cycle ergometer or treadmill.
- Muscular strength.
  - 1- to multiple-RM upper body (bench press) and lower body (leg press).
- Muscular endurance.
  - Curl-up test.
  - Push-up test.
  - Specific motion using appropriate equipment to fatigue (*i.e.*, bench press).
- Flexibility.
  - Sit-and-reach test or goniometric measures of isolated anatomic joints.

Additional evaluations may be administered; however, the components of a health/fitness evaluation listed earlier represent a comprehensive assessment that can be performed within 1 d. The data accrued from the evaluation should be interpreted by a competent health/fitness or clinical exercise professional and conveyed to the client/patient. This information is central to the development of a client's/patient's short- and long-term goals as well as forming the basis for the initial Ex R_x and subsequent evaluations to monitor progress.

THE BOTTOM LINE

The ACSM Health-Related Fitness Testing and Interpretation Summary Statements.

- Health/fitness assessments provide a wealth of information regarding an individual's health and functional status. A comprehensive assessment includes an evaluation of body composition, CRF, muscle strength/endurance, and flexibility.

- Each component of the assessment can be performed through several approaches to accommodate availability of equipment, the facility, training of personnel, and health/fitness status of the individual undergoing testing.
- Adherence to the recommendations for the health/fitness assessments provided in *Chapter 4* allows for an individualized and safe approach.
- When available, results from each component of the health/fitness assessment should be compared to normative data provided in *Chapter 4*.

Online Resources

ACSM Exercise is Medicine:
http://exerciseismedicine.org

American Heart Association:
http://www.americanheart.org

Clinical Guidelines on the Identification, Evaluation, and Treatment of Overweight and Obesity in Adults: The Evidence Report:
http://www.nhlbi.nih.gov/guidelines/obesity/ob_gdlns.htm

The Cooper Institute:
http://www.cooperinstitute.org

National Heart, Lung, and Blood Institute Health Information for Professionals:
http://www.nhlbi.nih.gov/health/indexpro.htm

2008 Physical Activity Guidelines for Americans (1):
http://www.health.gov/PAguidelines

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