Science of Strength and Conditioning Series

NSCA's Guide to TESTS AND ASSESSMENTS

NSCA™
National Strength and Conditioning Association

Todd Miller
EDITOR

NSCA's Guide to Tests and Assessments

National Strength and Conditioning Association

NSCA

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Heart Rate and Blood Pressure

Daniel G. Drury, DPE, FACSM

Heart rate and blood pressure are two circulatory factors that ensure the proper distribution of blood throughout the body. As physiological demands change, each factor is adjusted to help perfuse the tissues with the right amount of blood. Changes in position, exercise intensity, mode of exercise, and state of arousal may result in an adjustment of heart rate and blood pressure. Although both factors can be altered independently, they are systemically interrelated so that an adjustment in one is often accompanied by an adjustment in the other.

Because active heart rate is an indirect indicator of exercise intensity, it is often used for monitoring, adjusting, and individualizing training programs. Heart rate monitors have become more accurate and readily available in recent years. Consequently, coaches and trainers have been able to help athletes fine-tune their training by making the intensity of workouts relative to their own physiological capabilities. Furthermore, chronic training adaptations can also be monitored by examining changes in the resting heart rate as well as during exercise at any given exercise intensity.

The pressure in the arteries is in a constant state of flux and is continually being adjusted and readjusted. The circulatory system provides just the right amount of blood pressure to meet the demands of a wide variety of activities. Although blood pressure is not commonly used as an indicator of fitness, it is important for trainers to understand blood pressure norms and the circumstances that may lead to rapid increases or decreases in blood pressure. Fluctuations in pressure enable athletes to circulate more blood to more tissues when needed. Because each activity requires a unique blood pressure response, trainers need to understand the mechanics of this dynamic system.

Heart Rate Control

Heart rate (HR) is a simple yet valuable indicator of cardiorespiratory function. At rest, the heart typically beats between 60 and 80 times per minute. However, in highly conditioned athletes, the physiological adaptations of endurance training can result in a resting HR as low as 28 beats per minute (Wilmore, Costill, and Kenney 2008). This decrease is thought to be a result of an increase in the stroke volume of the heart in combination with an increase in the parasympathetic influence of the nervous system. Conversely, a high resting heart rate could be a sign of poor cardiorespiratory function, overtraining, increases in stress, and a host of other factors that may be counterproductive to clients.

Heart rate measurements must be taken under certain physiological conditions. First, experts recommend that resting heart rate (RHR) be taken early in the morning on an empty stomach. During sleep and times of relaxation, the sympathetic nervous system has less drive, which allows the heart rate to better reflect the parasympathetic influence. The subject should be seated or recumbent and in an environment free of distraction. If RHR is being tracked over time, the measurement should be taken under similar circumstances each time.

During exercise, HR is a good indicator of relative exercise intensity and is used widely to monitor cardiorespiratory function in both health and disease (Ehrman et al. 2009). The heart muscle is one of the few tissues capable of generating its own impulse, and it does this at the sinoatrial (SA) node, which is located on the right ventricle (Marieb and Hoehn 2010). The SA node is considered the pacemaker of the heart. It is innervated by sympathetic and parasympathetic nerve fibers that emanate from the medulla oblongata and the cardiorespiratory control centers within the central nervous system (see figure 3.1). Both sets of nerve fibers innervate the SA node; the atrioventricular (AV) node provides a tonic influence that can be either enhanced or depressed. The sympathetic nerve fibers increase heart rate, whereas parasympathetic nerve fibers slow it down. At rest, parasympathetic influence usually dominates control of the HR by reducing the heart's natural, or inherent, rate of about 100 beats per minute (bpm) to somewhere between 60 and 80 bpm (Wilmore, Costill, and Kenney 2008). At the initiation of exercise, the removal of parasympathetic influence initially allows the heart rate to increase to about 100 bpm, followed by an increase in sympathetic activity that further accelerates HR based on circulatory demands (Wilmore, Costill, and Kenney 2008).

Exercise Intensity and Heart Rate

HR can be used as an indirect and noninvasive measure of exercise intensity because of its strong correlation with exercise intensity and oxygen

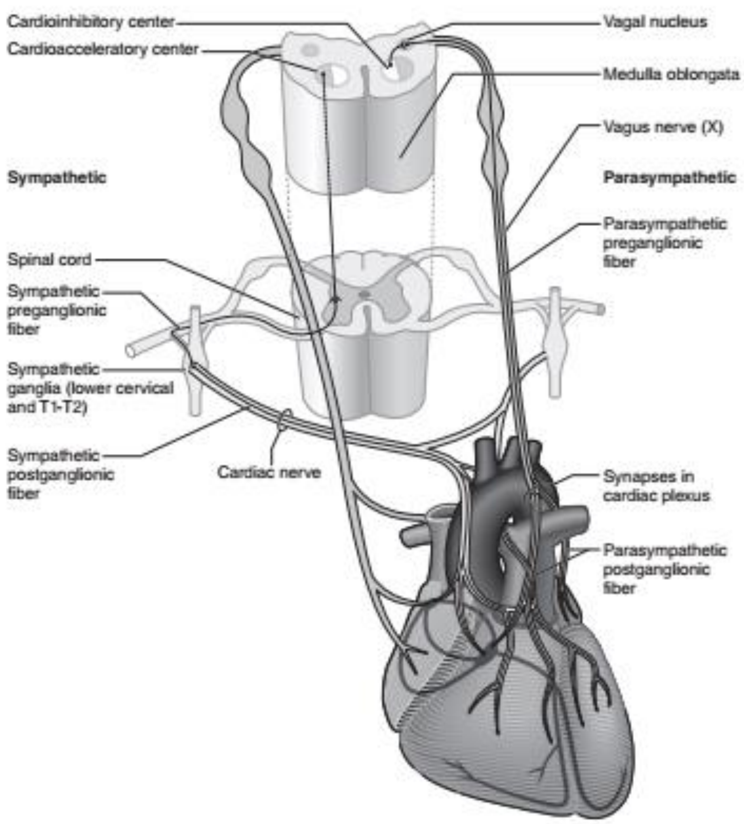

FIGURE 3.1 Sympathetic and parasympathetic nerve innervations of the heart.

consumption (Adams and Beam 2008). Numerous cardiorespiratory fitness tests use exercise HR to estimate or predict oxygen consumption by assessing a steady state HR (SSHR) at a given workload (Franklin 2000). SSHR is indicated when the circulatory demands of the current activity have been met by the circulatory system, and no further increases in HR are necessary (Wilmore, Costill, and Kenney 2008). At this point, because HR neither increases nor decreases substantially, it can be used to indicate the demands of that specific workload.

SSHR that occurs at any given absolute workload can vary significantly based on the person's fitness level. For example, if a sedentary person and a highly trained person of similar size and stature were walking together at 4 miles per hour (6.5 km/h), the sedentary person would likely have a much higher HR than the trained person, despite similar levels of oxygen consumption. This disparity in efficiency is also reflected in the way HR is adjusted between workloads. In short, an inefficient cardiorespiratory system relies on increases in HR more dramatically to meet the demands of an increased workload. Eventually, as exercise intensity increases, the sedentary person would approach maximal HR at a much lower workload compared to the trained person. Furthermore, after exercise has stopped, the trained person's HR would return to normal much more rapidly than that of the sedentary person, providing yet another way HR can be used to predict cardiorespiratory efficiency (Adams and Beam 2008). Given the relative ease of measuring HR, combined with the many ways HR can be used to predict cardiorespiratory efficiency, it is obvious why HR has been so widely used in the health and fitness industry.

Maximal Heart Rate

Maximal heart rate (MHR) is the greatest number of heart beats per unit of time that can be attained during an all-out effort to exhaustion. This number does not seem to be altered substantially by increases in cardiorespiratory efficiency or cardiorespiratory training. Rather, MHR seems to decline with age and is often predicted by subtracting one's age from 220 (Karvonen and Vuorimaa 1988). This value is appropriately called an age-predicted maximal heart rate (APMHR). For example, a 40-year-old male would estimate his APMHR as follows: 220 – 40 (age) = 180. Although this method of estimating maximal HR can vary considerably among people and is only an estimate, it is still used widely as a field method to establish the upper limits of HR, without exposing people to the maximal effort needed to measure a true maximal HR (Franklin 2000).

Heart Rate Reserve

Once APMHR has been calculated, this information can be used to establish exercise intensity guidelines based on heart rate reserve (HRR) (Franklin 2000). This prediction formula includes one variable that is affected by age (APMHR or maximal HR) and one factor that is affected by the state of fitness (RHR). Determining RHR and APMHR permits the calculation of the number of beats the person can potentially use to meet the demands of exercise (i.e., beats held in reserve). Heart rate reserve is found by subtracting RHR from APMHR.

Once the number of beats in reserve has been determined, a percentage of this reserve can be calculated by simply multiplying this number by the desired exercise intensity expressed as a percentage. By adding a percentage of the beats held in reserve onto RHR, a target HR can be determined to provide some objective criteria for monitoring training intensity. Both a minimum and a maximum training HR can be determined so that a desired training zone adaptation can be established. Athletes can train at a much higher percentage (70 to 85%) of their HRR as compared to sedentary or recreational athletes (55 to 70%). Often referred to as the Karvonen formula, this technique is based on research Dr. M. Karvonen conducted in the 1950s (Karvonen and Vuorimaa 1988). This formula is often used by having athletes maintain a certain HR intensity as they complete their cardiorespiratory training.

Here's an example of how to calculate training intensity using the heart rate reserve method. Begin by first determining the age-predicted maximal heart rate by subtracting the person's age from 220 (APMHR = 220 – 22 [age] = 198 bpm). Next, subtract the resting heart rate from this number to determine the number of beats that are held in reserve (198 [APMHR] – 72 [RHR] = 126 bpm [HRR]). In this case, the athlete literally needs a minimum of 72 beats per minute to meet the body's demands at rest and 198 beats to exercise at maximal intensity. Therefore, 126 beats are held in reserve. These beats can be added to the resting heart rate to increase the circulation of blood as needed. For a person wanting to train at approximately 70% of HRR, the calculation would look like this:

$$126\ (\text{HRR}) \times 0.70\ (\%) = 88.2 \text{ beats per minute}$$
$$\text{Target training HR} = 72\ (\text{RHR}) + 88.2 = 160 \text{ bpm } (70\% \text{ of HRR})$$

What truly makes this formula unique is the fact that a trained athlete with a low resting heart rate will increase this reserve by meeting the resting demands with fewer beats. This ultimately increases the heart rate reserve. At the same time, the natural decrease in maximal heart rate is also considered in the formula. Ultimately, the following formula can be used:

$$\text{Target heart rate} = [\text{fractional intensity (maximal HR} - \text{resting HR)}] + \text{RHR}$$

Sport Performance and Heart Rate

The intensity of training can be closely monitored to control and hopefully optimize the training regimen and adaptations (Franklin 2000). For example, if an athlete has a low degree of cardiorespiratory fitness, it might be appropriate to have her maintain a pace high enough to challenge her current cardiorespiratory efficiency, but not so high that she cannot sustain the exercise. As her fitness improves over time, the relative intensity of exercise that is reflected by HR can be increased so that she is constantly pushing herself to improve. The Karvonen method of maintaining exercise intensity provides a customized upper and lower HR limit that can be used to help the athlete remain motivated and focused on maintaining a specific relative intensity. If used religiously, monitoring HR can be a great way to quantify the difficulty of workouts over time, giving the coach or trainer some additional objective insight as to how the athlete is feeling.

Many practitioners establish target heart rate by simply calculating a percentage of the age-predicted maximal heart rate, although this method is not as robust as the Karvonen method. At first glance, this method appears rudimentary and generic because the formula does not consider anything but age. However, the exercise intensity established using this method is indeed specific to the person because each person requires a unique amount of work to reach any given target heart rate. Therefore, a sedentary 20-year-old and an athletic 20-year-old may have the same predicted values, but the exercise intensity needed to reach these values would be considerably different.

Figure 3.2 demonstrates the exercise heart rate range for a 35-year-old who wants to improve fitness (green zone). Because this person is not fit enough to handle the intensity required to increase performance (red zone), he should probably ease off on the intensity and choose a level more appropriate for his current state of fitness. Over time, the level can be adjusted, but it is probably best to be conservative when prescribing intensity so that the client remains motivated and develops a base of fitness to build on.

An athlete may use these target heart rates to cycle the intensity of training in a given workout or throughout the training season. Consider a soccer midfielder who has the physiological challenge of executing anaerobic bursts of speed throughout a game that lasts well over an hour. The training program for this athlete should most likely involve days focused on endurance as well as days that include high-intensity interval training.

Heart rate can be used in both of these situations. For long endurance training, the athlete may want to maintain a certain moderate intensity by monitoring his heart rate over the course of a long run. As cardiorespiratory improvements are gained over time, his heart rate will decrease at any given speed providing evidence that a faster pace may be needed to initiate additional improvements in fitness. Conversely, when the athlete engages in anaerobic interval training, heart rate can still be a valuable tool. Although heart rate is not an indicator of performance during sprinting activities, it can be an indicator of recovery between sprints. As the season approaches, the trainer can adjust the recovery interval to provide a customized challenge for the athlete or to slowly introduce a gamelike physiological challenge that will translate into improved performance.

Heart Rate Measurement

There are numerous ways to measure HR including palpation, auscultation, Doppler ultrasonic monitoring, and electrical monitoring. Although electrocardiography is considered the gold standard for HR measurement, other methods can be used with varying degrees of accuracy. The following sections provide brief descriptions of the techniques most often used in nonclinical settings.

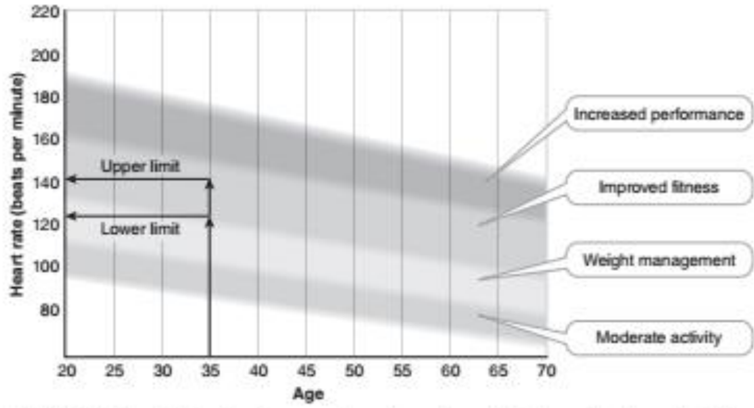

FIGURE 3.2 Target heart rate zones based on age-predicted maximal heart rate for males and females.

PALPATION

Palpation is the process of determining heart rate by feeling the distension of the arteries as a bolus of blood passes through the vessel. Numerous large arteries run close to the surface of the skin making them ideal for palpation. Two of the most commonly used locations for HR palpation are the radial artery on the palm side of the wrist (figure 3.3*a*) and the carotid arteries (figure 3.3*b*).

Deeper arteries and those surrounded by excessive adipose tissue can make palpating the pulse difficult. Also, exercises such as walking and running during measurement can confound the ability to count a pulse because the rhythmic body movements make distinguishing pulse waves difficult. Furthermore, it is important not to occlude (pinch) the artery with the pressure of the fingers. This is especially important when taking a pulse using the carotid artery; occluding the artery can hamper blood flow to the brain leading to syncope (dizziness) and possibly injury. The technique is to locate a relatively large artery, place the fingertips over it, and count the number of beats that occur in a given period of time.

PROCEDURE

1. The procedure begins by counting the first pulsation detected as zero and then counting the number of completed beats for the predetermined period of time.
2. Because HR is usually expressed in beats per minute (bpm), the amount of time a pulse is monitored is conveniently divisible into 60

seconds. For example, a pulse taken for 10 seconds can be multiplied by 6 to estimate bpm. Time increments of 15 seconds × 4) and 30 seconds (× 2) are also commonly used. It is important to note that smaller increments of monitoring time can amplify uncounted partial beats resulting in counting errors (Adams and Beam 2008).

3. Another palpation method for measuring HR involves determining the amount of time required for the heart to complete 30 beats and then dividing this time period into the constant of 1,800. This technique is based on the fact that 30 beats, or any given number of beats, will occur in a shorter period of time as the heart rate increases. The constant 1,800 is used so that smaller increments of one tenth of a second can be used for a 30-beat period to determine HR (Adams and Beam 2008). This test is simplified further by using a chart with the calculations already completed. This technique is often considered more accurate than time interval techniques because only completed cardiac intervals are counted. With the time interval techniques, a small error in counting or estimating partial beats can result in a large error when multiplied.

Example 1: 30 beats in 15.0 seconds
1,800 / 15 seconds = 120 bpm

Example 2: 30 beats in 10.0 seconds
1,800 / 10 = 180 bpm

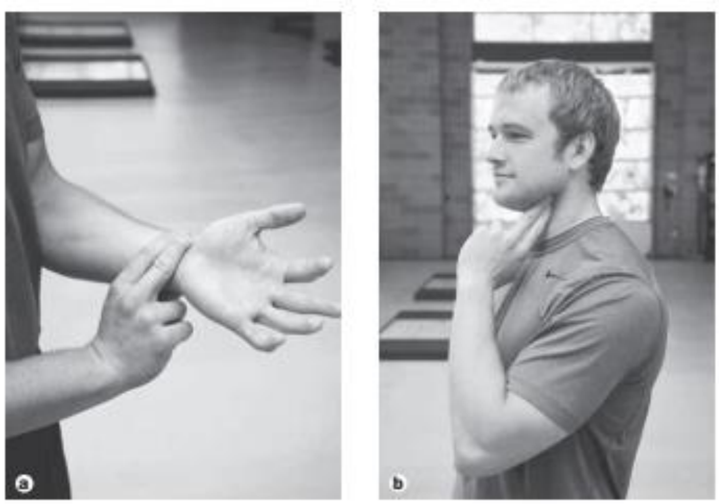

FIGURE 3.3 Common palpation locations.

AUSCULTATION

The counting techniques used for monitoring HR are very similar for auscultation and palpation. However, with auscultation the pulse waves that are felt are replaced by the sounds of the myocardium, large arteries, or both. A stethoscope facilitates hearing and counting the sounds associated with heart contractions.

PROCEDURE

1. The diaphragm of the stethoscope should be placed directly onto the subject with the entire diaphragm of the stethoscope flush with the surface of the skin. The diaphragm should be placed over the apical (apex) region of the heart or over the base of the heart between the second and third ribs just below the proximal end of the clavicle (Adams and Beam 2008). Slight pressure on the diaphragm may improve the quality of the heart sounds.
2. Once the stethoscope is in place, similar procedures to those of palpation can be used to count or time the beats of the heart. Both the palpation and the auscultatory methods are easier to conduct during exercise than at rest. Although the beats are occurring at a much faster pace during exercise, the strength of the pulse waves and of the contraction of the heart make the pulse easier to feel and hear.

ELECTROCARDIOGRAPHY

Although electrocardiography (ECG) is often reserved for clinical and research settings, calculating HR using this tool is not difficult and does not require extensive training. The ECG wave form is created by a unified moving wave of ions flowing through the heart as the signal to contract is passed from the SA node to the AV node and down the bundle branches (Guyton 1991). The normal electrocardiogram is composed of a P wave (atrial depolarization), a QRS complex (ventricular depolarization), and a T wave (ventricular repolarization). The specialized electrogenic system found in the heart conducts the rhythmic electrical impulse. Because cardiac tissue transmits electrical signals rapidly, the heart can contract in a coordinated and unified manner, which creates a detectable electrical impulse. A basic representation of the wave form associated with one cardiac cycle is depicted in figure 3.4. Note that the wave with the highest amplitude (R wave) is associated with the contraction of the ventricles. This wave is most often used to calculate HR in healthy people.

ECG strips are useful in a clinical setting because abnormalities in the timing (seconds) and amplitude (millivolts) of the basic wave form can be predictive of various forms of myocardial pathology. However, ECG analysis can also be used to establish an exact HR under resting and exercise conditions (Goldberg and Goldberg 1994).

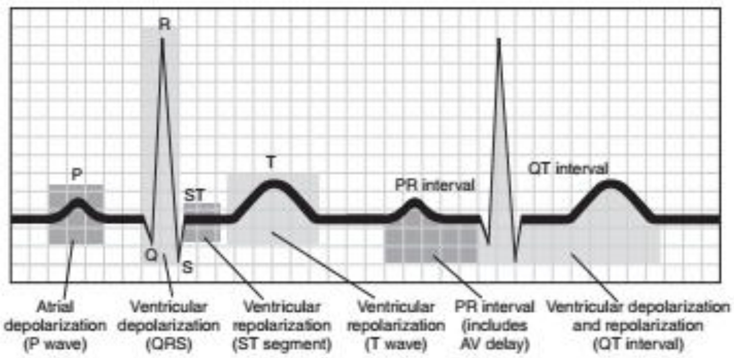

FIGURE 3.4 The phases of the resting electrocardiogram.

Reprinted, by permission, from W.L. Kenney, J. Wilmore, and D. Costill, 2011, *Physiology of sport and exercise*, 5th ed. (Champaign, IL: Human Kinetics), 147.

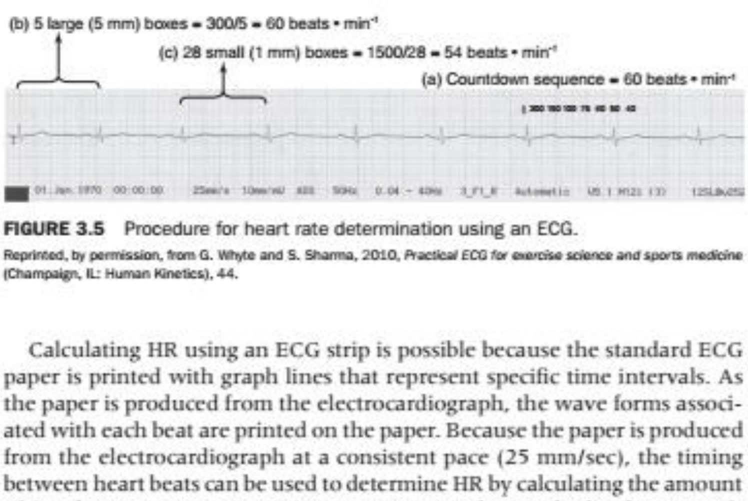

FIGURE 3.5 Procedure for heart rate determination using an ECG.

Reprinted, by permission, from G. Whyte and S. Sharma, 2010, *Practical ECG for exercise science and sports medicine* (Champaign, IL: Human Kinetics), 44.

Calculating HR using an ECG strip is possible because the standard ECG paper is printed with graph lines that represent specific time intervals. As the paper is produced from the electrocardiograph, the wave forms associated with each beat are printed on the paper. Because the paper is produced from the electrocardiograph at a consistent pace (25 mm/sec), the timing between heart beats can be used to determine HR by calculating the amount of time between two consecutive R waves using the standardized ECG graph paper (Goldberg and Goldberg 1994).

PROCEDURE FOR CALCULATING HEART RATE USING AN ECG STRIP

1. Indentify two consecutive R waves.
2. Count the number of small boxes (mm) on the graph paper between the R waves.
3. Divide the number of small boxes (mm) into 1,500 to obtain HR.
   - Example: 1,500 / 20 (ECG squares) = 75 (see figure 3.5)

HEART RATE MONITORS

In recent years, the technology of personal HR monitoring devices has improved significantly (Boudet and Chaumoux 2001). These devices function using the same principles as ECG machines, but are made to detect only HR using small electrodes impregnated into a reusable chest strap. The electrical impulse generated by the heart is monitored by these electrodes, which are then sent, via telemetry, to a digital display worn on the wrist. A mean HR is reestablished and updated about every five seconds giving a valuable and objective way to determine relative exercise intensity. More advanced HR monitors interface with computer tracking programs that can display training HR over time. HR monitors are a useful addition to a comprehensive approach to monitoring an exercise regimen.

Monitoring HR can be valuable for gaining insight into this important cardiorespiratory variable both at rest and during exercise. Developing the skills for monitoring HR should be high on the list of any exercise professional, and these skills should be practiced frequently.

Blood Pressure

Blood pressure (BP) is the force that the blood exerts on the walls of all the vessels within the cardiovascular system (Venes 2009). Although the term *blood pressure* seems to refer to a singular factor, blood pressure is actually established and maintained by the working of numerous variables simultaneously to ensure the pressure necessary for blood circulation under a variety of conditions (Guyton 1991). Among other things, these factors include the elasticity of the vessels, the resistance to flow before and after the capillaries, and the forceful contraction of the left ventricle, as well as blood volume and viscosity (Smith and Kampine 1984). BP fluctuates throughout the day based on metabolic demands, body position, arousal, diet, and many other factors (Wilmore, Costill, and Kenney 2008). Furthermore, numerous hormonal, hemodynamic, and anatomical factors working together ultimately ensure the pressure needed for adequate circulation of the blood (Perloff et al. 1993).

Understanding the basic physiology of BP control and assessment is of critical importance to those involved in health promotion and health care. As one of the basic vital signs used to evaluate health, BP needs to be maintained within a certain range. At rest, normal systolic blood pressure is maintained between 100 and 120 mmHg, whereas diastolic blood pressure is maintained between 75 and 85 mmHg. BP that is chronically elevated (i.e., hypertension) can contribute to the development of cardiovascular disease. If BP drops too low (i.e., hypotension), blood delivery can be compromised, which may eventually lead to circulatory shock. During exercise and other strenuous activities, BP must be altered to deliver larger and larger amounts of blood and oxygen to the tissues. This section provides a basic summary of the factors associated with the physiological control and measurement of BP.

Hypertension

Hypertension is one of the most prevalent cardiovascular risk factors among Americans (Pickering et al. 2005b). This insidious disease is relatively easy to diagnose, but goes undetected primarily because symptoms are not readily apparent to the average person. The cause of primary hypertension remains elusive, yet the diagnosis and treatment of this condition are relatively inexpensive. Therefore, regular monitoring of BP can be an effective screening tool to help those at risk recognize this potentially life-threatening condition prior to a major coronary event. Although the etiology and physiology of hypertension are far beyond the scope of this chapter, table 3.1, from the American Medical Association, has been included indicating the various hypertension classifications for adults. Although the diagnosis of hypertension should be reserved for a medical professional, the day-to-day monitoring of BP can be self-performed at home or performed by another trusted health and wellness professional; proper procedures need to be followed (Pickering et al. 2005a).

Because BP tends to fluctuate throughout the day, hypertension may be incorrectly diagnosed or even undetected, based on the time and circumstances in which it has been measured. To ensure an accurate diagnosis, people need to monitor BP at different times during the day, preferably under the circumstances of natural daily living. This can now be performed with a 24-hour BP monitor (Clement et al. 2003), which can be worn under-

TABLE 3.1 Classification of Hypertension

	JNC 7		WHO/ISH		ESH/ESC	
Classification	SBP*	DBP*	SBP*	DBP*	SBP*	DBP*
Optimal	—	—	—	—	<120	<80
Normal	<120	<80	—	—	120-129	80–84
Prehypertension/ high normal	120–139	80–89	—	—	130-139	85–89
Stage 1/grade 1	140–159	90–99	140–159	90–99	140–159	90–99
Stage 2/grade 2	≤160	≤100	160–179	100–109	160–179	100–109
Grade 3	—	—	≤180	≤110	≤180	≤110
Isolated systolic hypertension	—	—	—	—	≤140	≤90

*Pressure measured in mmHg.

JNC 7 = *Seventh Report of the Joint National Committee on Prevention, Detection, Evaluation, and Treatment of High Blood Pressure*; WHO/ISH = World Health Organization/International Society of Hypertension; ESH/ESC = European Society of Hypertension/European Society of Cardiology.

Adapted from Chobanian et al. 2003; Mancia et al. 2007; and Whitworth et al. 2003.

neath clothing to work, around the house, and even during exercise. The primary advantage of these machines is that they permit people to monitor BP during real-life circumstances rather than only in a physician's office or other clinical setting. This may be helpful in preventing what is called white coat syndrome—that is, an artificially high BP due to the nervousness caused by visiting a physician's office.

Hypotension

Hypotension is experienced when the pressure in the system is compromised or insufficient to maintain the circulatory demand. A systolic pressure of less than 90 mmHg, a diastolic pressure of less than 60 mmHg, or both, generally indicate hypotension. This lack of pressure can leave the heart, brain, and muscles with an insufficient blood flow. Hypotension can occur from dehydration related to heat illness as well as other pathological conditions. Although much less common than hypertension, hypotension can be a very serious medical condition. The diagnosis of hypotension is highly individualized but is characterized by a significant drop in pressure from normal. What may be too low for one person, however, may be fine for another (www.ncbi.nlm.nih.gov/pubmedhealth/PMH0004536/).

Typically, signs of hypotension are dizziness, disorientation, or confusion. Other signs are blurry vision, fainting, and weakness. Hypotension may occur acutely with an orthostatic challenge (change in position) and may be caused by alcohol, certain medications, and a variety of medical conditions. People who experience hypotension on a regular basis should strive to identify the specific trigger and seek medical attention if necessary. Preventive measures include ensuring proper hydration, avoiding alcohol, and avoiding long periods of standing in one place. (www.ncbi.nlm.nih.gov/pubmedhealth/PMH0004536/).

Pressure Gradients and Blood Pressure

The movement of blood through the circulatory system depends on the development of pressure gradients (PG) (Venes 2009; Wilmore, Costill, and Kenney 2008). When blood is put under pressure, it automatically seeks an area of lower pressure in all directions. When an area of lower pressure is introduced, the blood flows in that direction based on how large the difference is between the pressure of the current compartment, the pressure of the new environment, and the resistance to flow within the vessel. Within the arteries, capillaries, and veins, PGs must be created to facilitate the movement of blood (Smith and Kampine 1984) . Blood moves from the heart into the circulation based on the PG created by the forceful contraction of the heart in relation to the pressure in the aorta. Initially, the blood that leaves the left ventricle of the heart and enters circulation is under relatively high pressure as the heart rhythmically contracts and relaxes

(Marieb and Hoehn 2010). As the heart beats, every cardiac cycle is composed of a low-pressure filling phase (diastole), followed by a higher-pressure ejection phase (systole) (Smith and Kampine 1984). Therefore, the volume of blood as well as the pressure of the blood that enters the aorta are constantly changing according to the cardiac cycle and the rhythmic creation of PGs (Powers and Howley 2007).

As the aorta and other large arteries receive this blood, they expand and store some potential energy in the elastic fibers in the walls of the arteries and arterioles (Tanaka, DeSouza, and Seals 1998). After systole has concluded and the aortic valve closes, these vessels recoil and squeeze the blood, creating yet another PG that moves the blood to vessels downstream. In each case, the blood moves down its PG seeking an area of lesser pressure while moving closer to the capillaries where the exchange of gasses and nutrients can take place (figure 3.6).

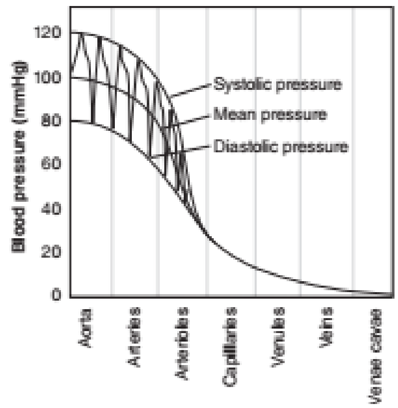

FIGURE 3.6 Blood pressure throughout the vascular system.

Adapted, by permission, from D.L. Smith and B. Fernhall, 2010, *Advanced cardiovascular exercise physiology* (Champaign, IL: Human Kinetics), 8.

Once the blood has entered the capillaries, the majority of the pressure created from the heart itself has been dissipated, and the blood entering the venous side of the circulatory loop is under very low pressure as it travels back to the heart (Smith and Kampine 1984; Wilmore, Costill, and Kenney 2008). To facilitate this flow in an environment of very low pressure, the venous circulation is supported by three mechanisms that also create PGs. The first mechanism lies in the anatomical configuration of one-way valves located within the veins. These valves are arranged to promote unidirectional flow to combat the pull of gravity on the blood as it travels back to the heart. These structures allow blood to travel in only one direction, preventing backflow and venous pooling.

The skeletal muscles work in conjunction with the one-way valves by increasing intramuscular pressure within the active muscles. These contractions help create a PG by squeezing the blood in the veins of the muscles. Finally, the respiratory system facilitates venous blood movement by creating a cyclic pressure difference within the thorax that corresponds to the rising and falling of the diaphragm. Both the skeletal muscle and respiratory pumps help "milk" the blood through the veins so that it returns to the heart under the influence of almost no pressure. PGs are essential for the movement of blood through the circulatory system. Anatomically, the human body is designed to circulate blood by creating PGs to facilitate blood movement (Marieb and Hoehn 2010).

Arterial Blood Pressure

BP varies considerably in different parts of the cardiovascular loop. The term *blood pressure* is often used generically to refer to arterial blood pressure (ABP), which is expressed in millimeters of mercury (mmHg) (Adams and Beam 2008). The arterial portion of the cardiovascular loop begins at the aorta and ends at the arterioles, just prior to the capillaries. Because of their elastic nature, these vessels can accommodate the dynamic pressure changes during systole and diastole. ABP is not a static pressure within the system, but a dynamic relationship between the upper and lower values achieved between beats and over time. It is also important to note that ABP is not representative of the pressure throughout all of the arteries, but is more of a reflection of the pressure in the large arteries that are subject to the greatest degree of pressure fluctuation. Therefore, ABP is expressed as two pressures. The highest pressure created in the vessels during left ventricular contraction is referred to as the systolic blood pressure (SBP) (Pickering et al. 2005b). Conversely, the lowest pressure occurs during the relaxation phase of the cardiac cycle and is called the diastolic blood pressure (DBP) (Pickering et al. 2005c). It is important to note that these pressures represent only the extremes of pressure at any given time and that ABP is truly in constant flux between these two pressure measurements.

The mathematical difference between SBP and DBP is termed pulse pressure (PP). At rest, an elevated PP may be used as an indicator of arterial compliance (Adams and Beam 2008). During exercise and other vigorous activities, one would expect the PP to increase as the need for additional flow is increased. Theoretically, SBP is an indicator of the pressure of blood entering the arterial circulation, whereas DBP represents the resistance of blood to leaving. Therefore, if the difference between these pressures increases during exercise, more blood must be both entering and leaving the arterial circulation indicating a greater flow through the tissues.

Mean arterial pressure (MAP) can be calculated using SBP and DBP. Although ABP is always in transition within the arterial system, MAP represents the average pressure in the arteries at any given time. At rest, the pressure generated during systole represents approximately one third of the entire cardiac cycle, whereas the diastolic phase is approximately twice as long (Adams and Beam 2008). Therefore, the formula for calculating resting MAP must account for the fact that the heart is in the diastolic relaxation phase for a longer period of time as compared to the contraction phase. The formula for calculating MAP at rest is as follows:

$$\text{Resting MAP} = 2/3\ \text{DBP} + 1/3\ \text{SBP}$$

Example: 120/80 (120 systolic and 80 diastolic)

$$80\ \text{DBP} \times 0.666 = 53\ \text{mmHg}$$
$$120\ \text{SBP} \times 0.333 = 40\ \text{mmHg}$$
$$\text{MAP} = 53.28 + 39.96 = 93\ \text{mmHg}$$

During exercise, the diastolic phase of the cardiac cycle is reduced as the heart rate increases making the systolic and diastolic phases approximately equal. Consequently, the formula for MAP changes slightly to account for this change:

$$\text{Exercise MAP} = 1/2\ \text{DBP} + 1/2\ \text{SBP}$$

Example: 140/80 (140 systolic and 80 diastolic)

$$80\ \text{DBP} \times 0.50 = 40\ \text{mmHg}$$
$$140\ \text{SBP} \times 0.50 = 70\ \text{mmHg}$$
$$\text{MAP} = 40 + 70 = 110\ \text{mmHg}$$

Arterial Blood Pressure Regulation

Under resting conditions, the volume of blood on the arterial side of the circulatory loop is relatively small (13%) compared with the volume contained in the capacitance vessels of the venous circulation (64%) (Wilmore, Costill, and Kenney 2008). At rest, this distribution of blood is sufficient to meet the pressure and circulatory demands of the body. However, when an increase in ABP is needed, it can be achieved by mobilizing the blood from the venous side of the loop and redistributing it over to the arterial side (Powers and Howley 2007). Arterial blood pressure is dynamically altered by manipulating the factors that control the volume of blood within the system. Arterial blood volume can be changed by increasing or decreasing cardiac output ($\dot{Q}$), increasing or decreasing total peripheral resistance (TPR), or changing both factors simultaneously.

Cardiac output is the total amount of blood that leaves the left ventricle each minute. It is calculated by considering the stroke volume multiplied by the number of cardiac cycles (HR) completed in one minute. Total peripheral resistance represents the resistance the blood encounters while flowing from the arterial side of the cardiovascular loop over to the venous side. The interplay between the amount of blood entering the arterial circulation and the amount of blood allowed to leave ultimately determines whether ABP increases, decreases, or stays the same (Smith and Kampine 1984).

Acute Arterial Blood Pressure Regulation

The cardiovascular system is equipped with a negative feedback system that detects ABP changes and reports them to the central nervous system, which responds with adjustments to blood pressure. These reports are sent to the central nervous system by specific pressure or stretch receptors called baroreceptors (Smith and Kampine 1984; Marieb and Hoehn 2010). Strategically located in the aortic arch and carotid arteries, baroreceptors provide a tonic flow of information to cardiovascular centers within the medulla (Marieb and Hoehn 2010). Under low-pressure circumstances, afferent input to the brain is decreased, and the brain responds by increasing and decreasing sympathetic and parasympathetic drive, respectively (Marieb and Hoehn 2010; Wilmore, Costill, and Kenney 2008). Consequently, heart rate (HR) and stroke volume (SV) increase leading to increases in blood volume in arterial circulation. A concurrent increase in TPR prevents too much blood from exiting the arterial circuit, which ultimately expands arterial blood volume and pressure. Under higher nonexertion-based pressure situations, adjustments are made in exactly the opposite manner (Marieb and Hoehn 2010).

Exercise and Arterial Blood Pressure Regulation

As the result of an acute bout of aerobic exercise, SBP will typically increase to meet the metabolic demands of the tissues. DBP will most likely stay the same, leading to an expansion of both MAP and PP (Wilmore, Costill, and Kenney 2008). A release of the sympathetic neurotransmitters epinephrine (EPI) and norepinephrine (N-EPI) causes an increase in both HR and SV contributing to an expansion in arterial blood volume and ultimately ABP. At the same time, this sympathetic response causes a temporary vasoconstriction of the peripheral vessels allowing relatively less blood to exit the arterial circulation in comparison to the amount flowing in from the increase in $\dot{Q}$. Together, these variables temporarily expand arterial blood volume, increase ABP, and promote a greater distribution of the blood to active tissues.

Consider the blood pressure requirements of cycling on a flat surface and of cycling up a 5-mile (8 km) hill. While a person is cycling on flat ground, a slight increase in blood pressure will easily provide the leg muscles with the additional pressure needed to supply the active tissues with more blood. However, when the intensity of exercise increases while cycling up a hill, more blood flow will be needed to supply the oxygen requirements of the leg muscles. More of the leg muscles will be active, and more blood will be delivered. But this cannot be achieved without an increase in ABP.

Prolonged, vigorous activity resulting in excessive sweating leads to a decrease in plasma volume resulting in dehydration, an increase in hemoconcentration, and a decrease in blood pressure. Under these conditions, antidiuretic hormone (ADH) is produced and then secreted by the hypothalamus. Also known as vasopressin, ADH acts on the kidneys to help retain water in an effort to dilute the hemoconcentration (Wilmore, Costill, and Kenney 2008).

During acute bouts of intense anaerobic activity (e.g., weight training), SBP is likely to increase substantially along with a concomitant increase in DBP. Pressures as high as 480/350 mmHg have been recorded during maximal lifts (MacDougall et al. 1985). For this reason, weight training has historically been contraindicated for many people with cardiovascular disease. However, the American Heart Association has recently acknowledged the safety and potential value of strength training as a mode of therapeutic exercise if contemporary recommendations are followed (Thompson et al. 2007).

The degree to which both SBP and DBP will be elevated seems to be linked to the relative intensity of the exercise. In this context, *relative intensity* refers to the amount of weight being lifted in comparison to the person's maximal capabilities (MacDougall et al. 1992). During maximal or near-maximal lifting efforts, people often hold their breath, initiating the Valsalva maneuver (VM) (Venes 2009). Although this tends to stabilize the core, it can also cause spikes in SBP and DBP (Sale et al. 1994; Sjøgaard and Saltin 1982). For this reason, people at risk for cardiovascular disease should avoid it.

Long-Term Regulation of Arterial Blood Pressure

Arterial blood pressure is largely regulated by the kidneys and several key hormones. Recall that the kidneys filter the blood continuously and help balance the extracellular fluids within the body (Robergs and Roberts 1987). When the body becomes dehydrated, the kidneys conserve water to maintain fluid balance. Conversely, when the body has an excess amount of water, the kidneys determine how much to excrete (Kapit, Macey, and Meisami 1987). The process of fluid balance becomes very important to the understanding of blood pressure because excess fluid held in the blood can contribute to hypertension (Robergs and Roberts 1987). Furthermore, excessive fluid loss from the blood can also be extremely dangerous. Because arterial blood volume ultimately dictates arterial blood pressure, fluid balance within the extracellular fluid and blood can be of critical importance for regulating blood pressure.

When the body loses excessive amounts of fluid, the kidneys secrete the enzyme renin, which activates the plasma protein angiotensinogen. After several enzymatic conversions, angiotensinogen is converted into angiotensin I, which is converted to angiotensin II in the lungs; angiotensin II has two primary effects that can elevate blood pressure. First, it is an extremely powerful vasoconstrictor that increases TPR. Second, it decreases the excretion of Na+, which ultimately increases extracellular fluid. Furthermore, this process triggers the minerlocorticoid aldosterone, which promotes sodium reabsorption enabling the body to retain fluids as they pass through the kidney. Therefore, the renin-angiotensin-aldosterone mechanism helps to maintain blood pressure by increasing TPR while simultaneously attempting to balance the extracellular fluid that in turn affects blood volume.

ARTERIAL BLOOD PRESSURE MEASUREMENT

Early methods for measuring ABP used water columns to measure pressure, but these systems were very large and were subject to significant fluctuations on a beat-by-beat basis (Adams and Beam 2008). Eventually, mercury columns were created resulting in a much more compact and manageable fluid column. Today, ABP is universally reported in millimeters of mercury (mmHg) regardless of the apparatus used for measuring (Pickering et al. 2005a). Despite their accuracy, sphygmomanometers that use mercury are susceptible to breaking and exposing the mercury, which is a toxic substance that is very dangerous to humans. For this reason, many health professionals have switched to automated BP cuffs or to aneroid devices. These devices can be highly accurate if calibrated regularly (Canzanello, Jensen, and Schwartz 2001; Clement et al. 2003; Pickering et al. 2005a).

Although ABP can be measured using indwelling catheters inserted into arterial vessels, this is a very invasive form of measuring ABP and is reserved for the clinical setting (Pickering 2002). A much more common technique using a sphygmomanometer can measure ABP at rest and during vigorous exercise (O'Brien, Beevers, and Lip 2001). Often referred to as the cuff method, this technique uses an inflatable tourniquet to temporarily occlude blood flow through the brachial artery. As the pressure is bled from the cuff, the technician listens to the artery below the cuff through a stethoscope and auscultates the various Korotkoff sounds.

Arterial blood pressure can be measured using Korotkoff sounds based on how the blood flows through the brachial artery. Initially, the cuff is inflated to a pressure that literally prevents any blood flow through the artery. Because no blood is passing through the artery, no sounds or vibrations are detected beyond the cuff by the stethoscope. As the air pressure in the cuff is slowly released, the technician listens for the initial bolus of blood to pass through the previously occluded artery. This first Korotkoff sound is indicative of systolic blood pressure (SBP) because the pressure in the artery must be higher than the pressure in the cuff if the blood in the artery has the PG needed to flow forward past the cuff through the semiconstricted artery (Franklin 2000).

As the cuff continues to be deflated, greater amounts of blood pass through the artery and the cuff during the systolic phase of each heartbeat. The classic lub-dub sound is heard while auscultating the heart directly. However, the sounds heard during blood pressure measurement are created by the blood that passes through the cuff when the pressure in the system exceeds the pressure in the bladder of the cuff. Because the cuff is still impeding *some* of the flow that would naturally pass through the brachial artery, vibrations can still be auscultated during this phase. Eventually, as the pressure in the cuff continues to fall, normal blood flow is restored. The pressure at which the restoration of normal blood flow and the concurrent disappearance of sound heard through the stethoscope occur is the diastolic blood pressure (DBP).

PROCEDURE

1. Have paper and pencil available to record SBP and DBP.
2. The subject should be seated in a quiet environment with the arm resting on a table approximately at heart level.
3. Apply the appropriate-sized cuff around the midpoint of the upper arm centering the bladder over the brachial artery approximately 2 centimeters above the antecubital fossa. The aneroid gauge should be at eye level for visual inspection.
4. Place the stethoscope ear pieces in the ear canals so that they are angled forward. Be sure that the bell of the stethoscope is rotated to the low-frequency position by lightly tapping on the diaphragm.
5. Place the head of the stethoscope over the brachial artery below the cuff and medial to the antecubital fossa. Press the head of the stethoscope so that the entire circumference of the diaphragm is in contact with the skin.
6. Inflate the bladder rapidly by squeezing the bulb to a pressure that is approximately 30 mmHg above the suspected or previously recorded systolic pressure.
7. Open the release valve on the bulb and slowly (3 to 5 mm/sec) deflate the air from the bladder listening for the initial appearance of the Korotkoff sounds (see table 3.2 for Korotkoff sounds).
8. Continue to reduce the pressure listening for the sound to become muffled (fourth phase of DBP) and finally disappear (fifth phase of DBP). Normally, the fifth phase is recorded as DBP.
9. Once the sounds disappear, continue to slowly deflate the cuff for another 10 mmHg to ensure that no further sounds are audible; then release all of the air from the bladder and wait a minimum of 30 seconds before repeating these procedures.
10. Average the two trials together and record these values for future reference.

Modified from Perloff et al. 1993.

TABLE 3.2 Korotkoff Sounds

Phase I	First appearance of clear, repetitive, tapping sounds. This coincides approximately with the reappearance of a palpable pulse.
Phase II	Sounds are softer and longer, with the quality of an intermittent murmur.
Phase III	Sounds again become crisper and louder.
Phase IV	Sounds are muffled, less distinct, and softer.
Phase V	Sounds disappear completely.

Reprinted, by permission, from D. Perloff et al., 1993, "Human blood pressure determination by sphygmomanometry," Circulation 88(5): 2460-2470.

The measurement of ABP is a relatively easy procedure that can be performed accurately without extensive medical training if standardized procedures are followed closely. Although the procedural steps are relatively easy to understand, it often takes years of experience to learn how to take blood pressure accurately and reliably (Canzanello, Jensen, and Schwartz 2001). Methods and procedures for taking blood pressure have been published by the American Heart Association (Pickering et al. 2005a).

Professional Applications

As described earlier in the chapter, resting heart rate can be used as a measure of fitness. Typically, a lower resting heart rate is indicative of better cardiovascular health. Although this adaptation is common among those who have achieved a high level of cardiorespiratory efficiency, it is possible that a highly trained athlete will maintain a normal resting heart rate (60 to 80 bpm). Furthermore, untrained people can also have relatively low heart rates that are not the result of cardiorespiratory training. The important factor here is that the fitness professional have a baseline measurement that can be used for future comparison. Both increases and decreases in resting heart rate can be important.

It is also important to note that a variety of external factors can affect resting heart rate. Stress, caffeinated drinks, various medications, and overtraining are all factors that can elevate resting heart rate. Fitness professionals must recognize why someone might have an elevated resting heart rate and consider ways to help the person reduce this number. A chronically elevated resting heart rate (100+ beats per minute) may require medical attention. Teaching athletes to monitor their own resting heart rates during periods of intense training may be helpful in determining a potential problem.

The use of heart rate as a training tool is a skill that all fitness professionals should master. This relatively simple skill is easy to execute and can be of great value to both the client and the trainer. The primary reason this technique is so widely used is that heart rate is a reflection of how the body is responding to the current physiological challenge. People can report verbally how they are feeling, but this is of limited value when they are influenced by other nonphysiological factors. For example, an ex-athlete may wish to appear strong and tough during a vigorous workout that actually exceeds his current physical condition. His verbal response may be that he is feeling fine when in reality he is on the edge of exhaustion. This may also happen in a group exercise class in which a client does not want to be identified or perceived as the weakest link. The social pressure to keep up with the group may cause people to overextend themselves. A simple measurement of heart rate can provide some objective feedback that may tell the trainer and the client what's really going on. Consequently, the intensity of the workout can be altered so that the client can continue to exercise rather than having to quit once undeniable fatigue has set in. This is a safer approach for everyone involved.

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Finally, it is important to acknowledge the relatively new technology related to heart rate monitors. Not only has the price of these devices come down, but also the usability and technical programming have also improved. One particular feature that can be very useful is the pacing feature in which an audible beeping sound is triggered when the person reaches a predetermined target heart rate zone. Heart rate monitors can give audible feedback when the exercise intensity is too high or too low. This is a great feature for distance athletes as well as for people who want to monitor their pace closely. Once the workout is complete, many new systems allow users to download results for tracking purposes. This is an affordable and accurate way to provide some objective data and analysis to what has traditionally been a subjective process.

SUMMARY

- Resting heart rate can be used as a measure of cardiovascular health.
- Maximal heart rate can be estimated by subtracting the person's age from 220.
- Training intensity can be monitored using heart rate because of the correlations among oxygen consumption, workload, and heart rate.
- Training intensity can be established using exercise heart rate. The Karvonen method is a valuable formula for determining the minimal and maximal heart rate that should be achieved during a workout.
- Measuring heart rate is an easy, inexpensive, and valuable skill to learn for fitness professionals.
- Arterial blood pressure is the pressure that the blood exerts against the arterial walls.
- Although the arterial blood pressure is in constant flux, it is typically reported by writing the systolic pressure over the diastolic pressure.
- Systolic pressure is the pressure in the system while the heart is pumping, whereas diastolic pressure is the pressure in the arterial system between heartbeats.
- Arterial blood pressure can be either too high (hypertension) or too low (hypotension). Fitness professionals should be familiar with both extremes.

In fact, one coach or assistant should be assigned to each athlete for consistent and accurate data acquisition. For example, with skinfold analysis two practitioners' techniques may be slightly different yielding two different values for the athlete. In this case, the body fat difference is due to tester error rather than physiological changes.

Calibration sessions for single athletes can be helpful. In such sessions, multiple testers perform the skinfold analysis on the same athlete, and the results are compared. Consistent results from staff members confirm data consistency. However, because athletes with more body fat have more variation, calibration sessions are most productive when small, medium, and large athletes are examined. This gives good practice to those learning proper technique. Thus, multiple athletes can be used as subjects, but the results must be compared among the same individual athletes. That is, athletes A, B, and C are tested, but testers compare results for A to calibrate technique, then compare results for B, and subsequently compare results for C. If the data vary glaringly, the staff must alter the technique to produce greater consistency.

With girth measurements, a slight variation in the location of the tape measure or a difference in tension applied to the tape measure can yield variable results. Body weight measurements, on the other hand, are standard provided the scale is functioning properly.

The head strength and conditioning coach must ensure that the staff uses consistent techniques. The most accurate system is to assign certain staff members to certain athletes. This standardizes the procedures per athlete and provides more accurate measurements of body composition over time.

SUMMARY

- Excess body fat is detrimental to health and performance, so measurement of body composition is of great importance for health professionals, fitness practitioners, athletes, and coaches.
- Several methods exist to indirectly measure body composition. Simple methods such as girth measurements, BMI, and skinfolds can be performed with little equipment and at low cost, and are fast and easy to perform, which is advantageous when testing large numbers of people over time.
- BIA is another simple body composition tool that can be attractive for use with athletic populations. However, equipment is more costly than that for skinfold and girth measurements, and BIA is prone to error.
- Advanced body composition estimates (hydrodensitometry, ADP, DXA, CT, and MRI) can be made when specific information is needed, equipment is available, and trained technicians perform the procedures. These methods are less practical for many athletes, but show greater accuracy, reliability, and validity than simpler methods.