Exercise is an essential factor in fitness conditioning, injury prevention, and injury rehabilitation. An athletic trainer working with an athletic population in secondary schools, in colleges and universities, or at the professional level is well aware that to compete successfully at a high level, the athlete must be fit. An athlete who is not fit is more likely to sustain an injury. The athletic trainer should recognize that improper conditioning is one of the primary contributing factors to sports injuries. It is essential that the athlete engage in *conditioning exercises* that can minimize the possibility of injury while maximizing performance.[55]

Lack of physical fitness is one of the primary causes of sports injury.

The basic principles of conditioning exercises also apply to techniques of therapeutic, rehabilitative, or reconditioning exercises that are specifically concerned with restoring normal body function following injury. Athletic trainers providing patient care in a clinic or hospital are more likely to apply these principles to reconditioning or rehabilitation of an injured patient. The term *therapeutic exercise* is perhaps most widely used to indicate exercises that are used in a rehabilitation program.

Regardless of whether the primary focus is making certain an athlete is fit or reconditioning an injured patient, the athletic trainer must understand the basic principles for improving cardiorespiratory endurance, muscle strength and endurance, and flexibility.

THE RELATIONSHIP BETWEEN ATHLETIC TRAINERS AND STRENGTH AND CONDITIONING COACHES

The responsibility for making certain that an athlete is fit for competition depends on the personnel who are available to oversee this aspect of the athletic program. At the professional level and at most colleges and universities, a full-time strength and conditioning coach is employed to conduct both team and individual training sessions. Many, but not all, strength coaches are certified by the National Strength and Conditioning Association. If a strength coach is involved, it is essential that both the athletic trainers and the team coaches communicate freely and work in close cooperation with the strength coach to ensure that the athletes achieve an optimal level of fitness.

The specific role of the athletic trainer is to critically review the training and conditioning program designed by the strength and conditioning coach and to be extremely familiar with what is expected of the athletes on a daily basis. The athletic trainer should feel free to offer suggestions and make recommendations that are in the best interest of the athletes' health and well-being. If it becomes apparent that a particular exercise or a specific training session seems to be causing an inordinate number of injuries, the athletic trainer should inform the strength and conditioning coach of the problem, so that some alternative exercise can be substituted.

If an athlete is injured and is undergoing a rehabilitation program, it should be the athletic trainer's responsibility to communicate to the strength and conditioning coach how the conditioning program should be limited and/or modified. The athletic trainer must respect the role of the strength and conditioning coach in getting the athlete fit. However, the responsibility for rehabilitating an injured patient should belong to the athletic trainer.

In the majority of secondary-school settings, if a strength and conditioning coach is not available, the responsibility for ensuring that the athlete gets fit lies with the athletic trainer and the team coaches. In this situation, the athletic trainer very often assumes the role of a strength and conditioning coach in addition to his or her athletic training responsibilities. The athletic trainer frequently finds it necessary not only to design training and conditioning programs but also to oversee the weight room and to educate young, inexperienced athletes about getting themselves fit to compete. The athletic trainer must demand the cooperation of the team coaches in supervising the training and conditioning program.

PRINCIPLES OF CONDITIONING

The following principles should be applied in all conditioning programs to minimize the likelihood of injury:

1. *Safety.* Make the conditioning environment safe. Take time to educate individuals regarding proper techniques, how they should feel during the workout, and when they should push harder or back off.[41]
2. *Warm-up/cool-down.* Take time to do an appropriate warm-up before engaging in any activity. Do not neglect the cool-down period after a training bout.
3. *Motivation.* Athletes are generally highly motivated to work hard because they want to be successful in their sport. Varying the training program and incorporating techniques of periodization can keep the program enjoyable rather than routine and boring. (See the discussion of periodization at the end of this chapter.)
4. *Overload.* To improve in any physiological component, the individual must work harder than he or she is accustomed to working. Logan and Wallis identified

the **SAID principle,** which directly relates to the principle of overload.[62] SAID is an acronym for specific adaptation to imposed demands. The SAID principle states that, *when the body is subjected to stresses and overloads of varying intensities, it will gradually adapt over time to overcome whatever demands are placed on it.* For example, in weight training, as you progressively add more weight, the muscle tends to adapt to this increase in resistance by increasing in size and efficiency. Although overload is a critical factor in conditioning, the stress must not be great enough to produce damage or injury before the body has had a chance to adjust specifically to the increased demands.

5. *Consistency.* An individual must engage in a conditioning program on a regularly scheduled basis if it is to be effective.
6. *Progression.* Increase the intensity of the conditioning program gradually and within the individual's ability to adapt to increasing workloads.
7. *Intensity.* Stress the intensity of the work rather than the quantity. Coaches and athletic trainers too often confuse working hard with working for long periods of time. They make the mistake of prolonging the workout rather than increasing tempo or workload. The tired athlete is prone to injury.
8. *Specificity.* Identify specific goals for the conditioning program. The program must be designed to address specific components of fitness (i.e., strength, flexibility, cardiorespiratory endurance) relative to the activity in which the individual is participating.
9. *Individuality.* The needs of different individuals vary considerably. The successful coach is one who recognizes these individual differences and adjusts or alters the conditioning program accordingly to best accommodate the individual.
10. *Minimal stress.* Expect that athletes will train as close to their physiological limits as they can. Push the athletes as far as possible, but consider other stressful aspects of their lives and allow them time to be away from the conditioning demands of their sport.

WARM-UP AND COOL-DOWN

Warm-Up

It is generally accepted that a period of warm-up exercises should take place before a training session begins, although a systematic review of the evidence-based literature reveals that there is insufficient evidence to endorse or discontinue a warm-up prior to exercise to prevent injuries, although the weight of the evidence favors a decreased risk of injury.[39] Nevertheless, most athletic trainers would agree empirically that a warm-up period is a precaution against unnecessary musculoskeletal injuries and possible muscle soreness.[28] Some evidence suggests that a good dynamic warm-up may also improve certain aspects of performance.[3,40,97]

The function of the warm-up is to prepare the body physiologically for some upcoming physical work.[27] The purpose is to gradually stimulate the cardiorespiratory system to a moderate degree to increase the blood flow to working skeletal muscles and increase muscle temperature.[103]

Moderate activity speeds up the metabolic processes that produce an increase in core body temperature. An increase in the temperature of skeletal muscle alters the mechanical properties of the muscle. The elasticity of the muscle (the length to which the muscle can be stretched) is increased, and the viscosity (the rate at which the muscle can change shape) is decreased, which means that the muscle changes in shape more rapidly.

A good warm-up routine should begin with 2 or 3 minutes of slow walking, light jogging, or cycling to increase metabolism and warm up the muscles. Breaking into a light sweat is a good indication that muscle temperature has increased. Although research has indicated that increasing core temperature is effective in reducing injuries, there is moderate to strong evidence that stretching during the warm-up does not reduce injury.[90] Empirically, many professionals feel that stretching should be a part of the warm-up, and they continue to recommend that flexibility exercises be included. Six to twelve minutes of dynamic stretching is recommended to improve flexibility.[83] Passive stretching, although not harmful, may not improve performance.[82]

Dynamic Warm-Up For many years, the accepted technique was to perform a light jog followed by some static stretching. A more contemporary approach to the warm-up is to use an active, or "dynamic," warm-up to prepare for physical activity. A dynamic warm-up involves continuous movement using hopping, skipping, and bounding activities with several different footwork drills and patterns. It enhances coordination and motor ability as it revs up the nervous system. It prepares the muscles and joints in a more activity-specific manner than static stretching. The dynamic warm-up forces individuals to focus and concentrate. It should include exercises that address all the major muscle groups. The entire dynamic warm-up can be done in as little as 5 minutes or as long as 20 minutes, depending on the goals, age, and fitness level of the group. *Focus Box 4–1:* "Dynamic warm-up routine" lists a series of activities that can be included in a dynamic warm-up. Activity should begin immediately following the warm-up routine.

Warming up involves general body warming and warming specific body areas for the demands of the sport.

The individual should not wait longer than 15 minutes to begin the main sports activity after the warm-up, although the effects may last up to about 45 minutes.[77]

FOCUS 4–1 Focus on Therapeutic Intervention

Dynamic warm-up routine

Two sets of cones are spaced 10 to 20 yards apart. The individual performs the following dynamic exercises between the cones, then jogs back to the start.

1. Jog forward
2. Jog backward
3. Walking calf stretch
4. Walking hamstring stretch
5. Hand-assisted knee stretch to chest
6. Hand-assisted knee stretch to opposite shoulder
7. Hand-assisted walking adductor stretch
8. Lateral shuffle moving to the right followed by the left
9. Walking lateral lunge to the right followed by the left
10. Skipping with low knees
11. Walking lunge, arms extended overhead
12. Walking lunge with rotation to each side
13. Walking quadriceps stretch
14. Jogging butt kicks
15. Open the gate exercise
16. Close the gate exercise
17. Carioca to the right followed by the left
18. Power high knees skipping
19. Prancing
20. High knees running
21. Back pedaling butt kicks
22. Forward sprint

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Cool-Down

Following a workout or training session, a cool-down period may be beneficial. The cool-down period enables the body to cool and return to a resting state. Such a period should last about 5 to 10 minutes. An example of a cool-down activity would be to have the individual jog and progressively decrease the pace to a walk to allow the metabolism to return to resting levels. This would be followed by stretching activities.

Although the warm-up period is common, the importance of a cool-down period afterward is often ignored. Again, experience and observation indicate that persons who stretch during the cool-down period tend to have fewer problems with muscle soreness after strenuous activity.[79]

4–1 Clinical Application Exercise

A marathon runner comes into the sports medicine clinic, complaining of feeling tightness in her lower extremity during workouts. She states that she has a difficult time during her warm-up and cannot seem to "get loose" until her workout is almost complete. She feels that she is always on the verge of pulling a muscle.

? What should the athletic trainer recommend as a specific warm-up routine that this patient should consistently do before beginning her workout?

CARDIORESPIRATORY ENDURANCE

Cardiorespiratory endurance is the ability to perform whole-body, large-muscle activities for extended periods of time. The cardiorespiratory system provides a means by which oxygen is supplied to the various tissues of the body.[44] For anyone who engages in exercise, cardiorespiratory endurance is critical both for performance and for preventing undue fatigue that may predispose the person to injury.

Transport and Utilization of Oxygen

Basically, transport of oxygen throughout the body involves the coordinated function of four components: heart, lungs, blood vessels, and blood. The improvement of cardiorespiratory endurance through training occurs because of the increased capability of each of these four elements collectively to provide necessary oxygen to the working tissues. The greatest rate at which oxygen can be taken in and used during exercise is referred to as *maximum aerobic capacity* ($\dot{V}O_2max$).[34] The performance of

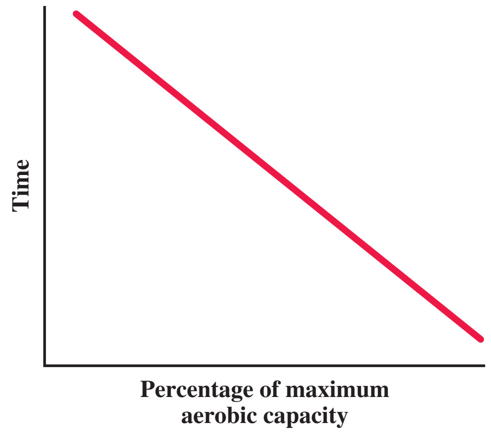

FIGURE 4–1 The greater the percentage of maximum aerobic capacity required during an activity, the less time the activity may be performed.

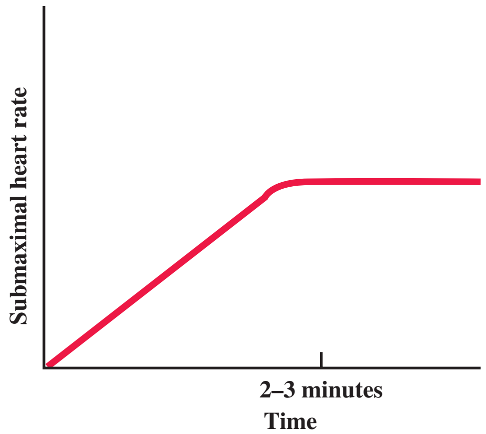

FIGURE 4–2 Two to three minutes are required for heart rate to plateau at a given workload.

any activity requires a certain rate of oxygen consumption that is about the same for all persons, depending on the level of fitness. Generally, the greater the rate or intensity of the performance of an activity, the greater the oxygen consumption. Each person has his or her own maximal rate of oxygen consumption. That person's ability to perform an activity or to fatigue is closely related to the amount of oxygen required by that activity and is limited by the person's maximal rate of oxygen consumption. The greater the percentage of maximum oxygen consumption required during an activity, the less time the activity may be sustained (Figure 4–1).[69]

The maximal rate at which oxygen can be used is a genetically determined characteristic; a person inherits a certain range of maximum aerobic capacity, and the more active that person is, the higher the existing maximum aerobic capacity will be in that range.[31] A conditioning program allows an individual to increase maximum aerobic capacity to its highest limit within that person's range. Maximum aerobic capacity is most often presented in terms of the volume of oxygen used relative to body weight per unit of time (ml/kg/min). A normal maximum aerobic capacity for most college-age athletes would fall in the range of 45 to 60 ml/kg/min.[92] A world-class male or female marathon runner may have a maximum aerobic capacity in the 70 to 80 ml/kg/min range.

Three factors determine the maximal rate at which oxygen can be used: external respiration involving the ventilatory process or pulmonary function; gas transport, which is accomplished by the cardiovascular system (i.e., the heart, blood vessels, and blood); and internal respiration, which involves the use of oxygen by the cells to produce energy. Of these three factors, the most limiting is generally the ability to transport oxygen through the system; thus, the cardiovascular system limits the overall rate of oxygen consumption. A high maximum aerobic capacity within an individual's inherited range indicates that all three systems are working well.

Effects on the Heart

The heart is the main pumping mechanism, circulating oxygenated blood throughout the body to the working tissues. As the body begins to exercise, the muscles use oxygen at a much higher rate, and the heart must pump more oxygenated blood to meet this increased demand. The heart is capable of adapting to this increased demand through several mechanisms. Heart rate shows a gradual adaptation to an increased workload by becoming more efficient and increasing proportionally to the intensity of the exercise. Heart rate will plateau at a given level after about 2 to 3 minutes (Figure 4–2). At rest, the heart beats about 70 times per minute. The maximal heart rate is different in everybody, but it can be estimated by multiplying the person's age in years by .70 and subtracting it from 208.

Monitoring heart rate is an indirect method of estimating oxygen consumption. In general, heart rate and oxygen consumption have a linear relationship, although at very low intensities and at high intensities this linear relationship breaks down (Figure 4–3).[36] During higher-intensity activities, maximal heart rate may be achieved before maximal oxygen consumption, which will continue to rise.[59] The greater the intensity of the exercise, the higher the heart rate. Because of these existing relationships, it should become apparent that the rate of oxygen consumption can be estimated by taking heart rate.[17]

A second mechanism by which the heart is able to adapt to increased demands during exercise is to increase the *stroke volume*—the volume of blood being pumped out with each beat.[17] The heart pumps out approximately 70 ml of blood per beat. Stroke volume can continue to increase only to the point at which there is simply not enough time between beats for the heart to

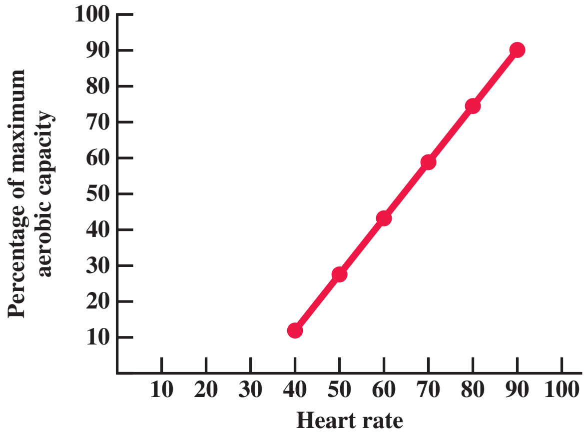

FIGURE 4–3 Maximal heart rate is achieved at about the same time as maximum aerobic capacity.

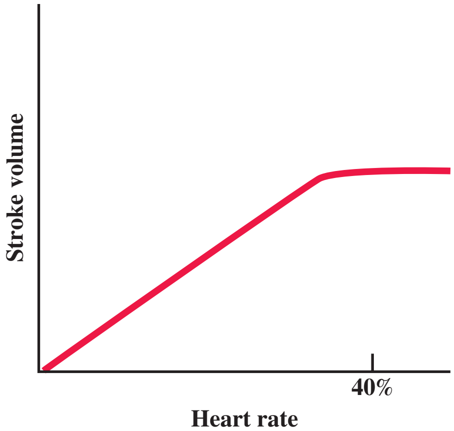

FIGURE 4–4 Stroke volume plateaus at 40 percent of maximal heart rate.

fill up. This point occurs at about 40 percent of maximal heart rate, and above this level increases in the volume of blood being pumped out per unit of time must be caused entirely by increases in heart rate (Figure 4–4).[66]

Stroke volume and heart rate together determine the volume of blood being pumped through the heart in a given unit of time. This is referred to as the *cardiac output,* which indicates how much blood the heart is capable of pumping in exactly 1 minute.[66] Approximately 5 L of blood are pumped through the heart during each minute at rest. Thus, cardiac output is the primary determinant of the maximal rate of oxygen consumption possible (Figure 4–5). During exercise, cardiac output increases to approximately four times that experienced during rest in the normal individual and may increase as much as six times in the elite endurance athlete.

A **training effect** occurs with regard to cardiac output of the heart—the stroke volume increases while exercise heart rate is reduced at a given standard exercise load. The heart becomes more efficient because it is capable of pumping more blood with each stroke. Because the heart

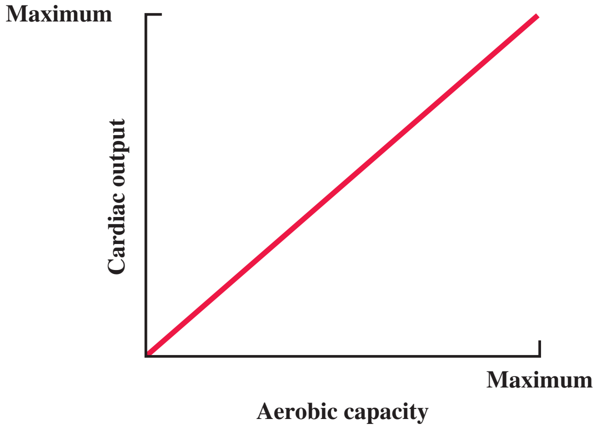

FIGURE 4–5 Cardiac output limits maximum aerobic capacity.

is a muscle, it will hypertrophy to some extent, but this hypertrophy is in no way a negative effect of training.

$$\text{Cardiac output} = \text{Increased stroke volume} \times \text{Decreased heart rate}$$

Effects on Work Ability

Cardiorespiratory endurance plays a critical role in an individual's ability to resist fatigue. Fatigue is closely related to the percentage of maximum aerobic capacity that a particular workload demands.[17] Without sufficient oxygen, glycogen stores are quickly depleted. For example, Figure 4–6 presents two individuals, A and B. A has a maximum aerobic capacity of 50 ml/kg/min, whereas B has a maximum aerobic capacity of only 40 ml/kg/min. If A and B are both exercising at the same intensity, A will be working at a much lower percentage of maximum aerobic capacity than B. Consequently, A should be able to sustain his or her activity over a much longer period of time. Performance may be impaired if the ability to use oxygen efficiently is

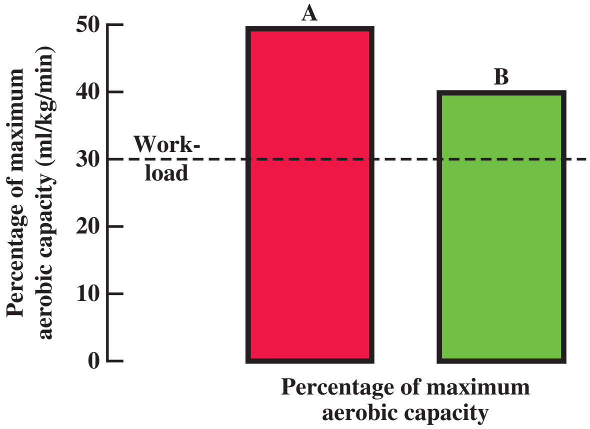

FIGURE 4–6 Person A should be able to work longer than Person B as a result of lower utilization of maximum aerobic capacity.

impaired. Thus, improvement of cardiorespiratory endurance should be an essential component of any conditioning program.

The Energy Systems

Various sports activities involve specific demands for energy. For example, sprinting and jumping are high-energy activities, requiring a relatively large production of energy for a short time. Long-distance running and swimming, on the other hand, are mostly low-energy activities per unit of time, requiring energy production for a prolonged time. Other physical activities demand a blend of both high- and low-energy output. These various energy demands can be met by the different processes in which energy can be supplied to the skeletal muscles.

ATP: The Immediate Energy Source Energy is produced from the breakdown of nutrient foodstuffs.[66] This energy is used to produce *adenosine triphosphate (ATP),* which is the ultimate usable form of energy for muscular activity. ATP is produced in the muscle tissue from blood glucose or glycogen. Glucose is derived from the breakdown of dietary carbohydrates. Glucose not needed immediately is stored as glycogen in the resting muscle and liver. Stored glycogen in the liver can later be converted back to glucose and transferred to the blood to meet the body's energy needs. Fats and proteins can also be metabolized to generate ATP.

Once much of the muscle and liver glycogen is depleted, the body relies more heavily on fats stored in adipose tissue to meet its energy needs. The longer the duration and the lower the intensity of an activity, the greater the amount of fat that is used, especially during the later stages of endurance events. During rest and submaximal exertion, both fat and carbohydrates are used as an energy substrate in approximately a 60 percent to 40 percent ratio.[66]

Regardless of the nutrient source that produces ATP, it is always available in the cell as an immediate energy source. When all available sources of ATP are depleted, more must be regenerated for muscular contraction to continue.

4–2 Clinical Application Exercise

A professional football player sustained a grade 2 hamstring strain during the sixth week of the season. Just before the playoffs, he reinjured the muscle while doing some slow-speed cutting drills. Unfortunately, he was forced to remain on the injured reserve list for the duration of the season despite his best efforts to return. He has lost a great deal of cardiorespiratory fitness because he has been unable to run, and he exhibits weakness in lower-extremity muscular strength because lifting has been difficult.

? Given that he will be required to attend two minicamps during the spring and early summer and that preseason practice officially begins in July, what should his conditioning plan be during the postseason and the off-season?

Aerobic versus Anaerobic Metabolism Three energy-generating systems function in muscle tissue to produce ATP: the ATP, glycolytic, and oxidative systems. During sudden outbursts of activity in intensive, short-term exercise, ATP can be rapidly metabolized to meet energy needs. However, after a few seconds of intensive exercise, the small stores of ATP are used up. The body then turns to stored glycogen as an energy source. Glycogen is broken down to supply glucose, which is then metabolized within the muscle cells to generate ATP for muscle contractions without the need for oxygen. This breakdown also produces a by-product called lactic acid that immediately dissociates to *lactate,* which seeps out of the muscle cells into the blood to be used elsewhere. This energy system is referred to as *anaerobic metabolism.*[85]

As exercise continues, the body has to rely on a more complex form of carbohydrate and fat metabolism to generate ATP. This energy system requires oxygen and is therefore referred to as *aerobic metabolism.* The aerobic system burns the lactate using oxygen, thus removing it and creating far more ATP than the anaerobic system. Normally, it takes about 20 minutes to clear the lactate from the system. Training to improve endurance helps an individual get rid of the lactic acid before it can build to the point where it contributes to muscle fatigue.[5]

In most activities, both aerobic and anaerobic systems function simultaneously.[66] The degree to which the two are involved is determined by the intensity and duration of the activity. If the intensity of the activity is such that sufficient oxygen can be supplied to meet the demands of working tissues, the activity is considered to be aerobic. Conversely, if the activity is of high enough intensity or the duration is such that there is insufficient oxygen available to meet energy demands, the activity becomes anaerobic. Consequently, an oxygen debt is incurred, which must be paid back during the recovery period. For example, short bursts of muscle contraction, as in running or swimming sprints, use predominantly the anaerobic system. However, endurance events depend a great deal on the aerobic system. Most activities use a combination of anaerobic and aerobic metabolism and all activities will initially utilize the anaerobic energy system (Table 4–1).

Training Techniques for Improving Cardiorespiratory Endurance

Cardiorespiratory endurance may be improved through several different training techniques.[68] Largely, the amount of improvement possible will be determined by an individual's initial levels of cardiorespiratory endurance.

Continuous Training Continuous training involves four considerations:

- *Frequency* of the activity
- *Intensity* of the activity
- *Type* of activity
- *Time* of the activity

TABLE 4–1 **Comparison of Aerobic versus Anaerobic Activities**

	Mode	Relative Intensity	Performance	Frequency	Duration	Miscellaneous
Aerobic activities	Continuous, long-duration, sustained activities	Less intense	50% to 85% of maximum range	At least three but not more than six times per week	20 to 60 min	Less risk to sedentary or older individuals
Anaerobic activities	Explosive, short-duration, burst-type activities	More intense	85% to 100% of maximum range	Three to four times per week	10 sec to 2 min	Used in sport and team activities

Frequency To see at least minimal improvement in cardiorespiratory endurance, it is necessary for the average person to engage in no fewer than three sessions per week.[5] If possible, an individual should aim for four or five sessions per week. A competitive athlete should be prepared to train as often as six times per week. Everyone should take at least one day per week off to allow for both psychological and physiological rest.

4–3 Clinical Application Exercise

A female soccer player has a grade 1 ankle sprain that is likely to keep her out of practice for about a week. She has worked extremely hard on her fitness levels and is concerned that not being able to run for an entire week will hurt her cardiorespiratory fitness.

? What types of activity should the athletic trainer recommend during her rehabilitation period that can help her maintain her existing level of cardiorespiratory endurance?

Intensity of Activity The intensity of the exercise is also a critical factor, although recommendations regarding training intensities vary. This is particularly true in the early stages of training, when the body is forced to make a lot of adjustments to increased workload demands.

Determining Exercise Intensity by Monitoring Heart Rate The objective of aerobic exercise is to elevate heart rate to a specified target rate and maintain it at that level during the entire workout. Because heart rate is directly related to the intensity of the exercise and to the rate of oxygen utilization, it becomes a relatively simple process to identify a specific workload (pace) that will make the heart rate plateau at the desired level.[35] By monitoring heart rate, athletes know whether the pace is too fast or too slow to get the heart rate into a target range.[85]

Heart rate can be increased or decreased by speeding up or slowing down the pace. As mentioned, heart rate increases proportionately with the intensity of the workload and will plateau after 2 to 3 minutes of activity. Thus, the athlete should be actively engaged in the workout for 2 to 3 minutes before measuring his or her pulse.

Several formulas allow you to identify a training *target heart rate*.[44,54] To calculate a specific target heart rate, you must first determine your maximum heart rate (MHR). Exact determination of MHR involves exercising an individual at a maximal level and monitoring the heart rate (HR) using an electrocardiogram. This is a difficult process outside of a laboratory. Maximum heart rate is related to age, and, as you get older, your MHR decreases. An approximate estimate of MHR for individuals of both genders would be:

$$HR_{max} = 208 - 0.7 \times \text{Age}$$

For a 20-year-old individual, maximum heart rate would be about 194 beats per minute ($208 - 0.7 \times 20$).

Heart rate reserve is used to determine upper and lower limits of the target heart rate range. Heart rate reserve (HRR) is the difference between resting heart rate (HR_{rest})* and maximum heart rate (HR_{max}).*

$$HRR = HR_{max} - HR_{rest}$$

The greater the difference, the larger your heart rate reserve and the greater your range of potential training heart rate intensities. The *Karvonen equation* is used to calculate target heart rate at a given percentage of training intensity.[53]

To use the Karvonen equation, you need to know your HRR.

$$\text{Target HR} = HR_{rest} + \%\text{ of target intensity} \times HRR$$

When using estimated HR_{max} or/and HR_{rest}, the values are always predictions. So, in a 20-year-old with a calculated HR_{max} of 194 and an HR_{rest} of 70 beats per minute, the heart rate reserve is (124 ($194 - 70 = 124$)). For moderate-intensity activity, the heart should work in a range between the lower limit and an upper limit. The lower limit is calculated by taking 70 percent of the heart rate reserve and adding the resting heart rate, which would be 157 beats per minute ($(124 \times 0.7) + 70 = 157$). The upper limit is calculated by taking 79 percent of the heart rate reserve and adding the resting heart rate ($(124 \times 0.79) + 70 = 168$).

The American College of Sports Medicine (ACSM) recommends that young healthy individuals train at either

*True resting heart rate should be monitored with the subject lying down.

moderate intensity (70 to 79 percent of maximum heart rate) or vigorous intensity (greater than 80 percent of maximum heart rate) levels to improve cardiorespiratory endurance and reduce the risk for chronic disease.[5] Individuals who are less fit, have led a previously sedentary lifestyle, are overweight, have a history of risk factors for heart disease, are elderly, have arthritis, and who have special instructions from a physician should engage initially in low-intensity workouts. For those individuals, the important thing is for them to become active; if they are persistent they should gradually be able to increase the intensity of the activity.[5]

Determining Exercise Intensity through Rating of Perceived Exertion *Rating of perceived exertion (RPE)* can be used in addition to heart rate monitoring to indicate exercise intensity.[35] During exercise, individuals are asked to rate subjectively on a numerical scale from 6 to 20 exactly how they feel relative to their level of exertion (Table 4–2). More intense exercise that requires a higher level of oxygen consumption and energy expenditure is directly related to higher subjective ratings of perceived exertion. Over time, individuals can be taught to exercise at a specific RPE that relates directly to more objective measures of exercise intensity.

Type of Activity The type of activity used in continuous training must be aerobic.[17] Aerobic activities are those that elevate the heart rate and maintain it at that level for an extended time. Aerobic activities generally involve repetitive, whole-body, large-muscle movements performed over an extended time. Examples of aerobic activities are running, jogging, walking, cycling, swimming, rope skipping, stair-climbing, and cross-country skiing. The advantage of these aerobic activities as opposed to more intermittent activities, such as racquetball, squash, basketball, or tennis, is that aerobic activities are easy to regulate by either speeding up or slowing down the pace. Because the given intensity of the workload elicits a given heart rate, these aerobic activities allow athletes to maintain heart rate at a specified or target level. Intermittent activities involve variable speeds and intensities that cause the heart rate to fluctuate considerably. Although these intermittent activities improve cardiorespiratory endurance, their intensity is much more difficult to monitor.

Time (Duration) of Activity For minimal improvement to occur, the ACSM recommends 20 to 60 minutes of workout/activity with the heart rate elevated to training levels.[5] Generally, the greater the duration of the workout, the greater the improvement in cardiorespiratory endurance. The competitive athlete should train for at least 45 minutes per session.

High-Intensity Interval Training Unlike continuous training, **high-intensity interval training** involves activities that are more intermittent. Interval training consists of alternating periods of relatively intense work and active recovery.[19] It allows for performance of much more work at a more intense workload over a longer period than does working continuously.[19] In continuous training, the athlete strives to work at an intensity of about 60 to 85 percent of maximum heart rate. Obviously, sustaining activity at the higher intensity over a 20-minute period is extremely difficult. The advantage of high-intensity interval training is that it allows work at the 80 percent or higher level for a short period followed by an active period of recovery during which the athlete may be working at only 30 to 45 percent of maximum heart rate. Thus, the intensity of the workout and its duration can be greater than with continuous training. High-intensity interval training has also been shown to improve cardiorespiratory fitness ($VO2_{max}$) in as little as 2 weeks.[94]

Most sports are intermittent, involving short bursts of intense activity followed by a sort of active recovery period (e.g., football, basketball, soccer, or tennis).[42] Training with the high-intensity interval training technique allows the athlete to be more sport specific during the workout. With high-intensity interval training, the overload principle is applied by making the training period much more intense. There are several important considerations in high-intensity interval training. The *training period* is the amount of time that continuous activity is actually being performed, and the *recovery period* is the time between training periods. A *set* is a group of combined training and recovery periods, and a *repetition* is the number of training/recovery periods per set. *Training time* or *distance* refers to the rate or distance of the training period. The training/recovery ratio indicates a time ratio for training versus recovery.

An example of high-intensity interval training is a soccer player running sprints. An interval workout would involve running ten 120-yard sprints in under 20 seconds each, with a 1-minute walking recovery period between each sprint. During this training session, the soccer player's heart rate will probably increase to 85 to 90 percent of maximum level during the sprint and will probably fall to the 35 to 45 percent level during the recovery period.

TABLE 4–2 Rating of Perceived Exertion

Scale	Verbal Rating
6	
7	Very, very light
8	
9	Very light
10	
11	Fairly light
12	
13	Somewhat hard
14	
15	Hard
16	
17	Very hard
18	
19	Very, very hard
20	

Fartlek Training *Fartlek,* a training technique that is a type of cross-country running originated in Sweden. Fartlek literally means "speed play." It is similar to interval training in that the athlete must run for a specified period; however, specific pace and speed are not identified. The course for a fartlek workout should be a varied terrain with some level running, some uphill and downhill running, and some running through obstacles such as trees or rocks. The object is to put surges into a running workout, varying the length of the surges according to individual purposes. One big advantage of fartlek training is that because the pace and terrain are always changing, the training session is less regimented and allows for an effective alternative in the training routine. Most people who jog or walk around the community are really engaging in a fartlek-type workout.

Again, if fartlek training is going to improve cardiorespiratory endurance, it must elevate the heart rate to at least minimal training levels (60 to 85 percent). Fartlek may best be used as an off-season conditioning activity or as a change-of-pace activity to counteract the boredom of a training program that uses the same activity day after day.

Equipment for Improving Cardiorespiratory Endurance

The extent and variety of fitness and exercise equipment available to the consumer are at times mind boggling (Figure 4–7). Prices of equipment can range from $2 for a jump rope to $60,000 for certain computer-driven isokinetic devices. It is certainly not necessary to purchase

FIGURE 4–7 Fitness equipment. **(A)** Stationary bike. **(B)** Recumbent bike. **(C)** Treadmill. **(D)** Stair climber. **(E)** Elliptical exerciser. **(F)** Rowing machine. **(G)** Upper-extremity ergometer.

(a–c) Courtesy Cybex International; (d) Courtesy Stairmaster; (e) Courtesy Body-Solid, Inc; (f) Stamina Products, Inc.; (g) Courtesy First Degree Fitness expensive exercise equipment to see good results. Many of the same physiological benefits can be achieved from using a $2 jump rope as from running on a $10,000 treadmill.

THE IMPORTANCE OF MUSCULAR STRENGTH, ENDURANCE, AND POWER

The development of **muscular strength** is an essential component of a conditioning program for every athlete. Strength is the ability of a muscle to generate force against some resistance. Most movements in sports are explosive and must include elements of both strength and speed if they are to be effective. If a large amount of force is generated quickly, the movement can be referred to as a **power** movement. Without the ability to generate power, an athlete is limited in his or her performance capabilities.[77]

Muscular strength is closely associated with muscular endurance. **Muscular endurance** is the ability to perform repetitive muscular contractions against some resistance for an extended period of time. As muscular strength increases, there tends to be a corresponding increase in endurance.[59,99] For example, an individual can lift a weight 25 times. If muscular strength is increased by 10 percent through weight training, it is likely that the maximum number of repetitions will be increased because it is easier for the individual to lift the weight.

4–4 Clinical Application Exercise

A college swimmer has been engaged in an off-season weight-training program to increase her muscular strength and endurance. Although she has seen some improvement in her strength, she is concerned that she also seems to be losing flexibility in her shoulders, which she feels is critical to her performance as a swimmer. She has also noticed that her muscles are hypertrophying to some degree and is worried that this may be causing her to lose flexibility. She has just about decided to abandon her weight-training program altogether.

? What can the athletic trainer recommend to her that will allow her to continue to improve her muscular strength and endurance while maintaining or perhaps even improving her flexibility?

Physiological and Biomechanical Factors That Determine Levels of Muscular Strength

Muscular strength is proportional to the cross-sectional diameter of the muscle fibers. The greater the cross-sectional diameter or the bigger a particular muscle, the stronger it is, and thus the more force it is capable of generating. The size of a muscle tends to increase in cross-sectional diameter with weight training. This increase in muscle size is referred to as **hypertrophy.**[51] Conversely, a decrease in the size of a muscle is referred to as **atrophy.**

Size of the Muscle Strength is a function of the number and diameter of muscle fibers composing a given muscle. The number of fibers is an inherited characteristic; thus, an individual with a large number of muscle fibers to begin with has the potential to hypertrophy to a much greater degree than does someone with relatively fewer fibers.[51]

Explanations for Muscle Hypertrophy A number of theories have been proposed to explain why a muscle hypertrophies in response to strength training.[66] Some evidence exists that the number of muscle fibers increases because fibers split in response to training.[37] However, this research has been conducted in animals and should not be generalized to humans. It is generally accepted that the number of fibers is genetically determined and does not seem to increase with training.

Another hypothesis is that because the muscle is working harder in weight training, more blood is required to supply that muscle with oxygen and other nutrients. Thus, the number of capillaries is increased. This hypothesis is only partially correct; few new capillaries are formed during strength training, but a number of dormant capillaries may become filled with blood to meet the increased demand for blood supply.

A third theory to explain this increase in muscle size seems the most credible. Muscle fibers are composed primarily of small protein filaments, called myofilaments, which are the contractile elements in muscle. These myofilaments increase in both size and number as a result of strength training, causing the individual muscle fibers themselves to increase in cross-sectional diameter.[37] This increase is particularly true in men, although women also see some increase in muscle size.[1] More research is needed to further clarify and determine the specific causes of muscle hypertrophy.

Improved Neuromuscular Efficiency Typically with weight training, an individual sees some remarkable gains in strength initially, even though muscle bulk does not necessarily increase. This gain in strength must be attributed to something other than muscle hypertrophy. For a muscle to contract, an impulse must be transmitted from the nervous system to the muscle.

4–5 Clinical Application Exercise

A college freshman on the varsity basketball team lacks motivation to improve her strength and fitness over the summer and during the off-season. The coaches are frustrated with her attitude and go to the athletic trainer for advice.

? How can the athletic trainer convince the athlete of the importance of strength and conditioning?

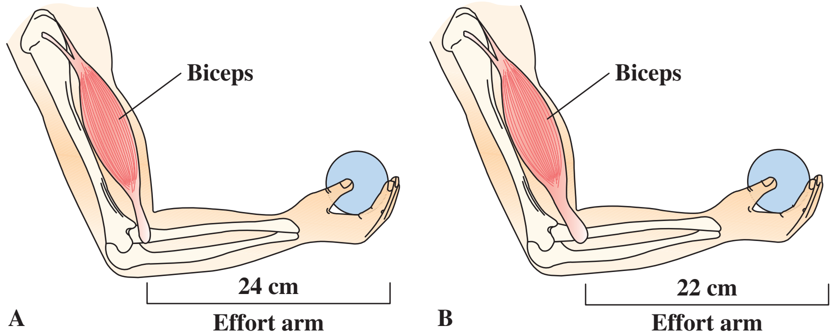

FIGURE 4–8 The position of attachment of the muscle tendon on the arm can affect the ability of that muscle to generate force. Person B should be able to generate greater force than person A because the tendon attachment is closer to the resistance.

Each muscle fiber is innervated by a specific motor unit. By overloading a particular muscle, as in weight training, the muscle is forced to work efficiently. Efficiency is achieved by getting more motor units to fire, causing a stronger contraction of the muscle.[101] Consequently, it is not uncommon to see extremely rapid gains in strength when a weight-training program is first begun due to an improvement in neuromuscular function.[51]

Other Physiological Adaptations to Resistance Exercise In addition to muscle hypertrophy, there are a number of other physiological adaptations to resistance training.[85] The strength of noncontractile structures, including tendons and ligaments, is increased. The mineral content of bone is increased, making the bone stronger and more resistant to fracture. Maximal oxygen uptake is improved when resistance training is of sufficient intensity to elicit heart rates at or above training levels. Several enzymes important in aerobic and anaerobic metabolism also increase.[17,66]

Biomechanical Factors Strength in a given muscle is determined not only by the physical properties of the muscle itself but also by biomechanical factors that dictate how much force can be generated through a system of levers to an external object.[47] If we think of the elbow joint as one of these lever systems, we would have the biceps muscle producing flexion of this joint (Figure 4–8). The position of attachment of the biceps muscle on the lever arm—in this case, the forearm—will largely determine how much force this muscle is capable of generating.[43] If there are two persons, A and B, and person B has a biceps attachment that is farther from the center of the joint than is person A's, then person B should be able to lift heavier weights because the muscle force acts through a longer lever (moment) arm and thus can produce greater torque around the joint.

The length of a muscle determines the tension that can be generated.[47] By varying the length of a muscle, different tensions may be produced. This *length-tension* relationship is illustrated in Figure 4–9. At position B in the curve, the interaction of the crossbridges between the actin and myosin myofilaments within the sarcomere is at a maximum. Setting a muscle at this length will produce the greatest amount of tension. At position A the muscle is shortened, and at position C the muscle is lengthened. In either case, the interaction between the actin and myosin myofilaments through the crossbridges is greatly reduced, and the muscle is not capable of generating significant tension.

Overtraining Overtraining can have a negative effect on the development of muscular strength. Overtraining can result in psychological breakdown (staleness) or physiological breakdown, which may involve musculoskeletal injury, fatigue, or sickness. Engaging in proper and efficient resistance training, eating a proper diet, and getting appropriate rest can minimize the potential negative effects of overtraining.

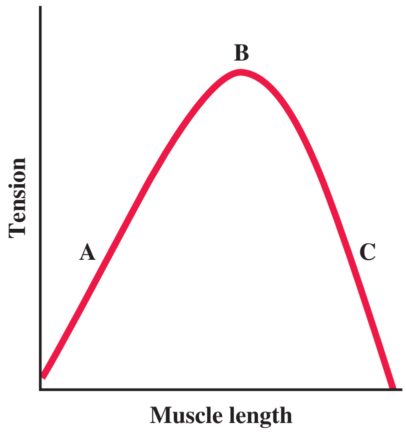

FIGURE 4–9 Because of the length-tension relation in muscle, the greatest tension is developed at point B, with less tension developed at points A and C.

Reversibility If strength training is discontinued or interrupted, the muscle will atrophy, decreasing in both strength and mass. Adaptations in skeletal muscle that occur in response to resistance training may begin to reverse in as little as 48 hours. It does appear that consistent exercise of a muscle is essential to prevent loss of the hypertrophy that occurs due to strength training.

Fast-Twitch versus Slow-Twitch Fibers and Muscular Endurance

Skeletal muscle fibers in a particular motor unit are either *slow-twitch* or *fast-twitch* fibers, each of which has distinctive metabolic and contractile capabilities. Slow-twitch (ST) fibers, also referred to as type I or slow oxidative (SO) fibers, are dense with capillaries and are rich in mitochondria and myoglobin, giving the muscle tissue its characteristic red color. They can carry more oxygen and thus are more resistant to fatigue than are fast-twitch fibers.[17] Slow-twitch fibers are associated primarily with long-duration, aerobic-type activities.[66]

Four basic types of muscle fibers:

- Slow-twitch, or type I
- Fast-twitch type IIa
- Fast-twitch type IIb
- Fast-twitch type IIx

Fast-twitch (FT) fibers are referred to as type II or fast oxidative glycolytic (FOG) fibers. They are capable of producing quick, forceful contractions but have a tendency to fatigue more rapidly than do slow-twitch fibers. Fast-twitch fibers are useful in short-term, high-intensity activities, which mainly involve the anaerobic system. Fast-twitch fibers are capable of producing powerful contractions, whereas slow-twitch fibers produce a long-endurance type of force.

Fast-twitch fibers can be subdivided into three groups, although all three types are capable of rapid contraction. Type IIa fibers, like slow-twitch muscle fibers, are moderately resistant to fatigue. Type IIx, also known as fast glycolytic (FG) and occasionally type IId, are less dense in mitochondria and myoglobin than type IIa. This is the fastest muscle type in humans and it can contract more quickly and with a greater amount of force than type IIa. But these fibers can sustain only short, anaerobic bursts of acitivity before muscle contraction becomes painful. Type IIb fibers are less dense in mitochondria and myoglobin and fatigue rapidly. They are white in color and are considered the "true" fast-twitch fibers.[66]

Any given muscle contains all types of fibers, and the ratio in an individual muscle varies with each person.[17] Those muscles whose primary function is to maintain posture against gravity require more endurance and have a higher percentage of slow-twitch fibers. Muscles that produce powerful, rapid, explosive strength movements tend to have a much greater percentage of fast-twitch fibers. Because this ratio is genetically determined, it may play a large role in determining ability for a given sport activity. Sprinters and weight lifters, for example, have a large percentage of fast-twitch fibers in relation to slow-twitch fibers.[17] Conversely, marathon runners generally have a higher percentage of slow-twitch fibers.

The metabolic capabilities of both fast-twitch and slow-twitch fibers may be improved through specific strength and endurance training. It appears that there can be an almost complete change from slow-twitch to fast-twitch and from fast-twitch to slow-twitch fiber types in response to training.[66] Fibers that are in the process of transitioning from one fiber type to another share some properties of both type I and type II fibers and are referred to as "hybrid" fibers.

4–6 Clinical Application Exercise

A high-school shot-putter has been working intensely on weight training to improve his muscular power. In particular, he has been concentrating on lifting extremely heavy free weights, using a low number of repetitions (three sets of six to eight repetitions). Although his strength has improved significantly over the last several months, he is not seeing the same degree of improvement in his throws, even though his coach says that his technique is very good.

? The athlete is frustrated with his performance and wants to know if there is anything else he can do in his training program that might enhance his performance.

Skeletal Muscle Contractions

Skeletal muscle is capable of three types of contraction: *isometric contraction, concentric contraction,* and *eccentric contraction.*[25] An isometric contraction occurs when the muscle contracts to increase tension but there is no change in the length of the muscle. Considerable force can be generated against some immovable resistance even though no movement occurs. In concentric contraction, the muscle shortens in length as a contraction is developed to overcome or move some resistance. In eccentric contraction, the resistance is greater than the muscular force being produced, and the muscle lengthens while continuing to contract. Concentric and eccentric contractions are both considered to be dynamic movements.[25]

Skeletal muscle is capable of three types of contraction:

- Isometric
- Concentric
- Eccentric

It is critical to understand that functional movements involve acceleration, deceleration, and stabilization in all three planes of motion simultaneously. Functional movements are controlled by neuromuscular mechanoreceptors located within the muscle.[25]