RESISTANCE TRAINING, WHICH includes the regular use of free weights, weight machines, body weight, elastic bands, and other forms of equipment to improve muscular strength, muscular power, and muscular endurance, has become an increasingly popular form of physical activity. Recent recommendations have been made regarding the use of resistance training in healthy populations (2, 43). Resistance training is currently being advocated for use with special populations such as cardiac rehabilitation patients (158) and the elderly (3). It is generally accepted that resistance training increases muscular size, strength, and power and is useful for enhancing athletic performance. Benefits resulting from resistance training are strongly influenced by the large number of training variables that can be manipulated in a program. Variations in load, volume, intensity, active muscle mass, muscle contraction type, rest interval, equipment, technique, initial level of fitness, training status, and program type can all influence the magnitude and duration of the response to resistance exercise and ultimately the adaptations associated with resistance training. Taking all of these factors into consideration, there is an accumulating base of scientific evidence suggesting that a number of health-related benefits may be derived from participation in a well-designed resistance training program. Having reviewed the available scientific literature on resistance training and health, it is the position of the NSCA that:

1. Resistance training may enhance cardiovascular health by mitigating several of the risk factors associated with cardiovascular disease by producing such changes as:
   a. decreases in resting blood pressure, particularly in individuals with elevated pressures;
   b. decreases in exercise heart rate, blood pressure, and rate pressure product at a standard workload;
   c. modest improvements in the blood lipid profile and;
   d. improvements in glucose tolerance and decreases in hemoglobin A1c in patients with diabetes mellitus.

2. Resistance training may result in improvements in body composition by maintaining or increasing lean body mass and producing modest decreases in the relative percentage of body fat.

3. Resistance training can produce increases in bone mineral density and may help delay
or prevent the development of osteoporosis by reducing the age-associated loss of bone mineral density.

4. Resistance training may reduce anxiety and depression and may result in improved self-efficacy and overall psychological well being.

5. Resistance training can reduce the risk of injury during participation in other sports and activities. When performed correctly and properly supervised, it is in itself a safe activity with low injury rates.

6. Resistance training increases muscular strength and endurance, resulting in an increased ability to perform activities of daily living, and reduces demands on musculoskeletal, cardiovascular, and metabolic systems.

Effects on the Cardiovascular System and Cardiovascular Risk Factors

Heart Rate

Heart rate can increase markedly as a result of an acute bout of resistance exercise. The magnitude of the response may be affected by factors such as intensity, load, and the active muscle mass (17, 84, 85, 132, 148). Because resistance exercise is generally performed intermittently, average heart rate values will also be largely influenced by the duration of the rest periods between sets and exercises. Therefore, the average heart rate obtained during a bout of resistance exercise may not accurately represent the extent of the cardiovascular stress experienced, nor can it be used as an accurate estimate of exercise intensity.

Decreases in resting heart rate and submaximal heart rate at a given power output are well-established adaptations to endurance-type training (59, 102). With regard to resistance training, most cross-sectional studies report that resistance-trained athletes have average or below average resting heart rates (115, 134, 135). Decreases (77, 89, 90, 146) or non-significant differences (124, 130, 150) have been observed in training studies. In the studies that have shown reductions in resting heart rate, the change is relatively modest (approximately 3–10%). The differences in results are likely due to differences in training variables employed in the various studies.

Resistance training has been shown to decrease heart rate during submaximal work (8, 50, 121, 124, 144) and during recovery from exercise (89, 109, 145, 146). Lower exercise heart rates as a result of resistance training have been observed during both submaximal cycling exercise (123) and during progressive resistance exercise at the same absolute load (124). It is believed that heart rate is lowered following training by a reduced ratio of sympathetic to parasympathetic nervous system activity.

The observed decreases in heart rate following training are thought to be compensated for by an increase in stroke volume, allowing cardiac output to remain more or less constant at rest or at an absolute submaximal workload. Heart rate is among the factors that determine myocardial oxygen demand. A decrease in heart rate at rest or during submaximal work may result in a reduced myocardial oxygen demand.

Blood Pressure

Blood pressure may be considered the product of cardiac output and total peripheral resistance and is regulated by a complex interaction of neural, metabolic, cardiovascular, and hormonal factors (136). When chronically elevated as in hypertension, it is an independent risk factor for coronary artery disease and is associated with many other cardiovascular disorders (104).

Both systolic and diastolic pressures have been shown to acutely increase as a result of high-force muscular contractions. Highly elevated mean intraarterial systolic and diastolic blood pressures on the order of 350/250 have been reported in bodybuilders performing 2 repetitions at 95% of 1 repetition maximum (1RM) of the leg press (99) and in subjects performing 100% 1RM double-leg press while executing a Valsalva maneuver (117). However, other studies only show elevations to about 230/130 mm Hg (148). The increased systolic and diastolic pressures are believed to result from increased sympathetic drive and a peripheral reflex component originating in the active muscles as a result of occlusion to blood flow (74, 133). The extent of the increased pressures appears to be related to the contraction type, intensity, duration, and amount of muscle mass engaged and breathing technique (117, 119, 144).

Most cross-sectional studies show no significant difference between strength athletes and control subjects for resting blood pressure (40, 98, 138). Similarly, most training studies show no change or a slight decrease in subjects with normal resting blood pressure (39, 40, 74, 150). Studies with hypertensive and mildly hypertensive patients have shown significant reductions in resting blood pressure (54, 61) following resistance training. Recent meta-analyses by Kelly (80, 81) demon-
strated reductions at rest of approximately 4.5 mm Hg systolic and 3.8 mm Hg diastolic blood pressure following short-term resistance training. These results compare favorably with the findings of another meta-analysis performed on aerobic training studies in which reductions of 4.7 mm Hg and 3.1 mm Hg in resting systolic and diastolic blood pressure were demonstrated (56). Although the effects of resistance training on resting blood pressure are mixed, it appears that, when higher volume training or circuit weight training is used, reductions in resting blood pressure may be observed. This is significant because modest reductions in resting diastolic blood pressure have been associated with reduced risk of stroke and development of coronary heart disease (18, 100).

An observed beneficial adaptation to resistance training has been an attenuated rise in blood pressure during exercise (20, 40, 49, 50, 107, 133). A reduction in muscular effort necessary to lift a given weight along with a reduction in stimulation to the cardiovascular control center may contribute to the muted blood pressure response observed following training (133). It is possible that altered baroreceptor sensitivity may be involved in regulating this response (152). Systolic blood pressure is a direct determinant of myocardial oxygen demand. A reduction in systolic blood pressure at a standard load following training would likely reduce myocardial oxygen demand and thus reduce the likelihood of a severe cardiovascular event occurring during resistance exercise or physically demanding daily tasks requiring heavy lifting.

Although caution should be used when prescribing resistance exercise to patients at risk of cardiovascular disease, it does not mean that it should be avoided (36, 101). Certain steps can be taken to minimize the blood pressure response during resistance exercise. These include (a) emphasizing dynamic movements, (b) using proper breathing technique to avoid performing a Valsalva maneuver, (c) reducing or eliminating maximal attempts during training, (d) limiting the number of repetitions performed to or past exhaustion, (e) using moderate amounts of resistance, and (f) emphasizing proper technique.

**Rate Pressure Product**

Rate pressure product (RPP) is an estimate of myocardial work and oxygen demand and may be estimated by the product of heart rate and systolic blood pressure. This measure may be particularly important as it pertains to ischemic heart disease (IHD). Ischemic heart disease includes several disorders that arise from an imbalance of myocardial oxygen supply and demand. During resistance exercise, RPP rises rapidly with the extent of the rise being dependent on such factors as intensity and amount of active muscle mass involved in the movement (5, 86). There also appears to be a progressive rise in RPP with an increasing number of sets at a given intensity (86).

Several studies have reported reduced RPP at rest and during submaximal exercise in healthy (150), elderly (121), and cardiac patients (101) following resistance training. Lower RPPs have also been reported in bodybuilders compared with sedentary control subjects during leg ergometry (16). The reduced RPP observed is likely the combined effects of lower heart rate and blood pressure at a given activity level as previously discussed.

A reduced rate pressure product at rest and during submaximal exercise would be considered a positive adaptation, particularly in individuals who have IHD. Although the RPP that produces angina does not change following exercise, heart rates and blood pressures are lower at matched absolute workloads (60). Therefore, a higher workload would be required to attain the same RPP as a consequence of training. The result of this adaptation is that it would likely reduce the likelihood of an ischemic cardiac event during physical activity.

**Aerobic Power**

Aerobic power, as measured by maximal oxygen uptake (VO₂max), has been classically used as an index of cardiorespiratory fitness but is not considered to be an independent risk factor for the development of coronary artery disease. The value obtained has been found to be dependent on such factors as age, gender, and genetic predisposition. The mode, intensity, duration, and frequency of training as well as an individual’s initial level of cardiorespiratory fitness will all influence changes in VO₂max.

Traditional noncircuit resistance training is not generally associated with increases in aerobic power. However, strength athletes, who perform little or no aerobic endurance exercise, have been shown to have higher VO₂max (34, 134, 149) compared with nonathletes. Several longitudinal studies have shown no change or minimal increases (<5%) in VO₂max following short-term resistance training (35, 68, 116). When using high-volume training, consisting of large muscle mass and multijoint exercises, larger increases (8–10%) in VO₂max have been observed.
increased VO2max likely results from a combination of cardiac, peripheral vascular, and skeletal muscle adaptations that improve oxygen delivery and utilization, but the exact mechanism is unclear. It is possible that increases in the proportion of lean body mass as a result of training may also be involved.

In studies that have employed circuit weight training for rehabilitation of cardiac patients, larger percentage increases in maximal oxygen uptake have been observed, ranging from approximately 11 to 19% (53, 151). Increases in maximal oxygen uptake of 8 and 21% as measured during treadmill exercise and arm ergometry have also been observed in borderline hypertensive subjects who used a circuit weight training program (61).

Increases in aerobic power are beneficial in that individuals have a greater capacity to produce energy via aerobic metabolism. At a standard submaximal power output, there is less reliance on anaerobic metabolism and a greater proportion of energy is derived via aerobic mechanisms. This results in less acute metabolic stress and potentially an increase in work time and less fatigue. However, specific training to increase aerobic power may limit maximal strength and power (27, 66), so careful analysis of program goals is necessary.

Blood Lipids and Lipoproteins

Hyperlipidemia is frequently associated with coronary artery disease, atherosclerosis, diabetes mellitus, and nephrotic syndrome. It is generally accepted that aerobic endurance training improves blood lipid and lipoprotein levels (28), but the effect of resistance training is more controversial. No significant differences in blood lipid and lipoprotein levels have been observed between male weight trainers and sedentary controls (6, 7, 15, 37). However, these studies did not control for such factors as the type, volume, or intensity of training, diet, or androgen use. When controlling androgen use, strength athletes have been shown to have positive lipid profiles (23, 72, 167, 168).

Although contradictory evidence exists, several longitudinal studies (see reference 145) have shown significant improvements in blood lipid and lipoprotein levels resulting from resistance training that include reductions in total cholesterol (3–16%) and low-density lipoprotein (5–39%) and increases in high-density lipoprotein (14–27%). However, these results must be interpreted cautiously due to several methodological limitations that include inadequate control for normal variation of blood lipid and lipoprotein levels, diet, and body composition (73). More research is needed before definitive conclusions can be made regarding the effect of resistance training on blood lipid and lipoprotein profiles.

Glucose Tolerance

Impaired glucose tolerance is associated with an increased risk of many diseases that include non–insulin-dependent diabetes mellitus, coronary artery disease, cataracts, stroke, intermittent claudication, retinopathy, nephropathy, and increased risk of infection. It has been shown that contractile activity mimics the effects of insulin in skeletal muscle by enhancing the translocation of glucose channels from the cytoplasm to the cellular membrane (63). This increases the tissue sensitivity to glucose and facilitates its deposition. Over time, it is likely that this will reduce the degenerative effects of high circulating glucose.

Improved glucose tolerance and insulin sensitivity have been shown in bodybuilders compared with normal individuals (168). Longitudinal studies have also shown that resistance training improves glucose tolerance (112, 139, 140) and the improvement in insulin sensitivity has been shown to be greater as a result of resistance training compared with aerobic training (30). It is likely that resistance training improves glucose tolerance by acutely increasing glucose transport into skeletal muscle during and immediately following an exercise bout and chronically by increasing lean body mass, thereby increasing the amount of tissue available to take up glucose from the blood. This may allow for reduced medication dosages for patients with certain forms of glucose insensitivity and offer improved control and stabilization of glucose levels. Recent studies support this by demonstrating decreased hemoglobin A1c (HbA1c) in diabetic patients engaged in resistance training programs (29, 30, 69). Thus, there is increasing evidence to support the use of resistance training in the management of patients with diabetes mellitus.

Effects on Energy Expenditure and Body Composition

The proportion of fat mass and fat-free mass in relation to the total body mass determines body composition. The fat mass is composed of essential fat that is nec-
essential for normal physiological function, while the storage fat serves primarily as an energy reserve. Obesity, which is defined as the storage of excess energy in the form of body fat, has been linked to a variety of medical disorders that include hypertension, hyperlipidemia, heart disease, coronary artery disease, insulin resistance, diabetes mellitus, and osteoarthritis.

**Energy Expenditure**

Resistance exercise has been found to produce modest increases in energy expenditure (4, 71, 79, 156), with the use of movements employing larger muscle mass resulting in higher expenditures (135). Resistance exercise also increases energy expenditure during recovery as indicated by increases postexercise oxygen consumption (11, 135). Resistance training has been shown to elevate resting metabolic rate, particularly in older individuals (12, 125, 127), and can increase average daily energy expenditure (160).

**Fat Mass**

Although fats are not considered a primary fuel source during resistance exercise, intramuscular (31) and serum triglycerides (162) have been shown to decrease following an acute bout of resistance activity. Postexercise respiratory exchange ratios have been shown to remain below preexercise values for up to 3 hours and to be decreased during sleep in individuals engaging in resistance exercise, indicating shifts in substrate oxidation toward the greater utilization of fats (159). An increased oxidation of fats over time may result in decreased body fat stores. Reductions in intraabdominal fat stores have been observed in older women following resistance training (155). Elevated visceral fat stores, particularly in the abdominal region, have been linked to an increase in the risk of developing cardiovascular disease (CVD). Thus, resistance training may help lower the risk of cardiovascular disease by reducing visceral fat that has been associated with increased risk of CVD.

**Fat-Free Mass**

Cross-sectional studies indicate that individuals who regularly participate in resistance training programs, such as bodybuilders, powerlifters, and Olympic-style weightlifters, possess lower than average percent body fat (145). Fleck and Kraemer (41) have summarized 21 resistance training studies examining changes in percent body fat. The mean duration of these studies was 11.5 weeks and the mean reduction in percent body fat was 2.2%. These results compare favorably with studies involving aerobic endurance activity that show an approximate 2% decrease in body fat for studies 15–20 weeks in duration (165).

Fat-free mass (FFM) is composed of all nonfat tissues, including muscle, bone, organ, and connective tissue. Preservation of FFM is important for maintenance of normal skeletal muscle function, integrity of the bone mass, and resting metabolic rate. Skeletal muscle mass is related to muscular strength (45) and maximal oxygen consumption and contributes to the ability to carry out activities of daily living (53, 56). The total amount of muscle mass is a major factor associated with resting metabolic rate (12, 22). Beginning in midadulthood, the FFM declines at a rate of approximately 3 kg per decade (142). In cross-sectional studies, losses of FFM on the order of 15–30% have been reported when comparing young adult males and females with older individuals approximately 80 years of age (48).

A number of studies have shown that resistance training is capable of maintaining or increasing FFM in young and middle-aged adult males and females (9, 14, 35, 68, 113, 160, 164). In these studies, ranging in duration from 8 to 20 weeks, fat-free mass increased from approximately 1.5 to 3.0 kg.

With regard to maintenance of FFM, the elderly are a population where resistance training may have particular importance. Decreases in muscle mass have been attributed to decreases in the number and size of muscle fibers (51, 92, 96). Both the Type I and Type II fibers decrease in size as a result of the aging process, with the decrease in the Type II fibers being more pronounced (51, 92). Following resistance training, increases in Type I and Type II fiber size (13, 21, 45), muscle area (38, 45), and FFM (12) have been reported. Maintenance of muscle mass would have an impact on the levels of muscular strength as well as on aerobic power and the ability to carry out daily tasks.

**Bone Mineral Density and Osteoporosis**

Osteoporosis is a disease involving a progressive loss of bone mineral density (BMD) that predominantly affects the elderly, especially postmenopausal women. The loss of BMD results in a weakening of the tissue, predisposing it to fractures. Mechanical forces imposed on bone are critical to the maintenance and increase of BMD. Animal and human studies suggest that muscular activity is effective in maintaining BMD if the forces developed reach a minimal effective strain, which is the level re-
quired to stimulate new bone formation. Because of the high forces that may be developed, resistance exercises appear to be specifically suited to prevent the loss of BMD and development of osteoporosis.

A number of studies have found that resistance training increases bone mineral density in a variety of populations (94). Strength athletes have been shown to have higher BMD than controls (19, 78). Longitudinal resistance training studies have shown increases in BMD in both adult (26, 97, 141) and elderly subjects (82, 110, 166), although others have shown no change (14, 64, 70, 106). Most evidence suggests that the increases in BMD are specific to the type of exercises performed and limbs/joints involved in the movement (57, 78). For example, to increase BMD of the femur, it is necessary to include resistance exercises that specifically load the muscles that have their origin or insertion on the femur. Resistance training may have the effect of stimulating bone formation while inhibiting bone resorption during the early phases of a training program (47).

Based on available evidence, it appears that both endurance-type activity and resistance training help to maintain or increase BMD, with resistance training possibly having a greater overall effect.

■ Psychological Status

Anxiety and depression are very common psychiatric disorders (20–30% lifetime prevalence) (83, 131) that significantly compromise quality of life. They are considered risk factors for other diseases such as coronary artery disease, peptic ulcer disease, asthma, headaches, and rheumatoid arthritis (44). Although controversy exists (24), it is the general consensus that exercise is associated with reduced state and trait anxiety (91) and reduced depression (144). Most of the work leading to these consensus statements focused on the effects of aerobic exercise on anxiety and depression. Comparatively, little research has been done with resistance exercise and training. However, the research that has been done suggests that resistance training produces similar improvements in anxiety and depression (118, 137, 157) and may improve self-efficacy and enhance psychological well-being, particularly in populations such as patients with heart disease and the elderly (33, 105, 122).

■ Risk of Injury

Resistance exercises, when performed properly, are extremely safe, with very low rates of injury compared with most other sports and recreational activities (75, 129). Traditional resistance training, including both machine and free weights, has been shown to have an injury rate of 0.0035 per 100 participation hours (58). Powerlifting, which typically involves lifting heavy weight and a low number of repetitions, has also been shown to have very low injury rates—0.0027 per 100 hours (58). This compares favorably with other common activities such as soccer (6.20 per 100 hours), track and field (0.57 per 100 hours), football (0.10 per 100 hours), basketball (0.03 per 100 hours), and gymnastics (0.044 per 100 hours). Resistance exercise was also not associated with serious injury (58). It should be noted that weightlifting and associated exercises, which emphasize explosive free-weight movements, have been shown to have lower injury rates than traditional resistance exercises—0.0017 per 100 hours versus 0.0035 per 100 hours (58). Thus, when properly supervised, free-weight or explosive exercises need not be contraindicated because of increased risk of injury.

The performance of maximal attempts (IRM) has been discouraged by some who believe that they are associated with an increased risk of injury. However, this has never been shown experimentally and most anecdotal evidence suggests that injuries during maximal attempts are extremely rare. It is still usually advisable to avoid maximal attempts in prepubescent or elderly subjects because of immature or compromised musculoskeletal systems. In general, the following guidelines should be followed to minimize the risk of injury during resistance exercise: (a) adequate warm-up should be performed prior to each exercise bout, (b) proper technique should always be used for each exercise, (c) all training should be supervised by qualified personnel, (d) spotters should be used appropriately for each exercise, (e) a minimal number of repetitions should be performed after the onset of fatigue, (f) all equipment should be in proper working order, and (g) the training facility should have ample space for all exercise participants.

Regular participation in a resistance training program has been shown to reduce the rate and seriousness of injury during participation in other sports and activities (25, 52, 62, 88, 95). This is likely due to strengthening of the components of the musculoskeletal system, including ligaments, tendons, and cartilage (93, 143, 153, 154). It has also been shown that elderly subjects, who are at an increased risk of injury resulting from falls, benefit from increased muscle mass, strength, postural stability, and functional...
mobility following resistance training (38, 76). These positive adaptations appear to reduce the number of falls and injuries experienced in the elderly (65, 128).

■ Functional Capacity

Normal daily functioning will likely require an individual to perform activities such as stair climbing, lifting, and carrying heavy objects. Even an activity such as walking requires some level of muscular strength and endurance. In the elderly, a close correlation exists between muscular strength and walking speed (38). It has also been shown that the maintenance of strength throughout life may reduce the prevalence of functional limitations (10) and that strength and muscle cross-sectional area better predict exercise capacity in patients with cardiac disease than hemodynamic measures or peak aerobic power (161). Recent studies in the debilitated elderly (111) and stroke patients (163) have demonstrated that resistance training is effective in improving functional capacity as demonstrated by improvements in strength, chair stand time, balance, and motor performance.

Combinations of dynamic and static contractions are involved in most activities of daily living, with each type of contraction producing a unique physiological response. With resistance training, maximal strength and power levels increase. As a consequence, absolute loads represent a lower percentage of maximal effort, thus reducing the relative exercise intensity.

Increased endurance as a result of resistance training has been observed in such activities as squatting to exhaustion (108, 148), incremental cycling and treadmill running to exhaustion (67, 68, 120, 150), and cycling at constant and relative power outputs (67, 103, 108). Reductions in blood lactate concentrations at an absolute load (124) and elevations in the lactate threshold (103) have also been observed following resistance training. In elderly populations (1), improvements in leg strength, walking endurance, and spontaneous activity were observed in individuals participating in resistance training programs (1, 32). More recently, Hagerman et al. (55) have found significant increases in treadmill performance and maximal oxygen uptake in a group of resistance-trained elderly men. It is apparent that improvements in muscular strength provide a greater reserve and reduce demands on the musculoskeletal, cardiovascular, and metabolic systems, making typical tasks relatively less stressful.

■ Practical Considerations

It is widely recognized that the performance adaptations resulting from resistance training are in accord with the principle of specificity of training, i.e., the greatest improvements in performance are observed in activities similar to the ones performed during the training. This has been shown to exist for training mode, movement pattern, muscle contraction type (e.g., isometric, concentric, eccentric), velocity, and joint angle (see reference 41). It also appears that health-related adaptations result from stimulus-specific changes elicited by the manipulation of program variables. For example, the health benefits related to cardiovascular disease risk factors appear to be linked to training volume. While some benefit may be seen with low-volume training, most evidence suggests that greater improvements occur with higher volume training. Therefore, multiple sets of large muscle mass exercises should be used with moderate to high repetitions when changes in cardiovascular disease risk factors are desired. In contrast with the cardiovascular adaptations, increased bone mineral density appears to be linked to exercise intensity and movement pattern. To increase bone mineral density, it appears necessary to perform exercises with a relatively high load that stimulates specific parts of the skeleton such as the hip or vertebrae. This may best be done by exercises that load the axial skeleton such as the squat. The recognition that different health-related changes are associated with specific program variables will allow for the design of more efficient and beneficial resistance training programs. This may also help explain the seemingly contradictory evidence seen in several areas of the scientific literature because of the considerable variation in the types of regimens used in research. ▲

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