Resistance Exercise in Individuals With and Without Cardiovascular Disease: 2007 Update

A Scientific Statement From the American Heart Association Council on Clinical Cardiology and Council on Nutrition, Physical Activity, and Metabolism

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Abstract**—**Prescribed and supervised resistance training (RT) enhances muscular strength and endurance, functional capacity and independence, and quality of life while reducing disability in persons with and without cardiovascular disease. These benefits have made RT an accepted component of programs for health and fitness. The American Heart Association recommendations describing the rationale for participation in and considerations for prescribing RT were published in 2000. This update provides current information regarding the (1) health benefits of RT, (2) impact of RT on the cardiovascular system structure and function, (3) role of RT in modifying cardiovascular disease risk factors, (4) benefits in selected populations, (5) process of medical evaluation for participation in RT, and (6) prescriptive methods. The purpose of this update is to provide clinicians with recommendations to facilitate the use of this valuable modality. **(*Circulation*. 2007;116:&NA;-.)**

Key Words: AHA Scientific Statements ■ exercise ■ cardiovascular diseases

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Physiological Considerations and Rationale for RT

Muscle contraction has both mechanical and metabolic properties. Mechanical classification describes whether muscle contraction produces movement of the limb. Dynamic (isotonic) exercise, which causes movement of the limb, is also further classified as either concentric (shortening of the muscle fibers, which is the most common type of muscle action) or eccentric (lengthening of the muscle fibers such as might occur when a weight is lowered against gravity). Static (isometric) exercise results in no movement of the limb. The metabolic classification of muscle contraction involves primarily the availability of oxygen for energy production and includes aerobic (oxygen available) or anaerobic (without oxygen) processes. The extent to which an activity is predominantly aerobic or anaerobic depends primarily on its

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This statement was approved by the American Heart Association Science Advisory and Coordinating Committee on June 5, 2007. A single reprint is available by calling 800-242-8721 (US only) or writing the American Heart Association, Public Information, 7272 Greenville Ave, Dallas, TX 75231-4596. Ask for reprint No. 71-0416. To purchase additional reprints, call 843-246-2533 or e-mail kelle.ramsay@wolterskluwer.com.

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Circulation **is available at http://www.circulationaha.org** **DOI: 10.1161/CIRCULATIONAHA.107.185214**

intensity relative to the person's capacity for that type of exercise. Most physical activities involve both dynamic and static contractions and aerobic and anaerobic metabolism. Thus, activities tend to be classified on the basis of their dominant mechanical and/or metabolic characteristics. Because of major differences in the physiological responses during dynamic-aerobic (endurance) exercise compared with heavy dynamic resistance-anaerobic (strength) exercise, these 2 general types of activities need to be dealt with separately when developing exercise recommendations. Lastly, conventional RT typically consists of lifting heavier weights with longer rest periods (a greater anaerobic component), whereas circuit training consists of lifting lighter weights with shorter rest periods between exercises, introducing a greater aerobic component to the workout.[2]

Physiological Responses

The major cardiovascular responses to dynamic-aerobic exercise (endurance exercise) are increases in oxygen uptake ($\dot{V}O_2$), cardiac output, and heart rate (HR), which parallel the intensity of the activity, as well as an early increase and then a plateauing of stroke volume. There is a progressive increase in systolic blood pressure (SBP), with maintenance of or a slight decrease in diastolic blood pressure (DBP), resulting in a concomitant widening of the pulse pressure and a modest increase in mean pressure, with a decrease in peripheral vascular resistance. Blood is shunted from metabolically less active skeletal muscle and the viscera to active skeletal muscle, where increased oxygen extraction widens the systemic arteriovenous oxygen difference. Thus, dynamic-aerobic exercise imposes primarily a volume load on the cardiovascular system, including the myocardium.[3]

During isometric exercise, increases in HR and both SBP and DBP are nearly proportional to the force exerted relative to the greatest possible force that an individual can evoke (percent maximum voluntary contraction [MVC]) rather than the absolute tension developed.[4] Stroke volume remains largely unchanged except at high levels of tension (>50% MVC), wherein it may decrease (see the discussion of Valsalva maneuver below). The result is a moderate increase in cardiac output, with little increase in $\dot{V}O_2$. Despite the increased cardiac output, blood flow to the noncontracting muscles does not significantly increase, probably because of reflex vasoconstriction. At an MVC ≥20% to 30%, the intramuscular pressure exceeds the intravascular pressure in the contracting muscle and significantly reduces localized blood flow, causing muscle ischemia and hypoxia. The combination of vasoconstriction and increased cardiac output results in a disproportionate rise in SBP, DBP, mean BP, and peripheral vascular resistance.[3,4] These pressures continue to rise throughout the duration of the exercise. Thus, a significant pressure load is imposed on the cardiovascular system, presumably to increase perfusion to the contracting skeletal muscle.

The impact of the Valsalva maneuver (a forced expiration is invoked against a closed glottis) and high levels of muscle tension to lift or otherwise move a heavy weight can result in somewhat dramatic changes to the physiological responses to RT. Depending on the duration and intensity of the maneuver and the resistance, an increase in intrathoracic pressure leading to decreased venous return and potentially reduced cardiac output may occur.[5] The physiological responses are an increase in HR to maintain cardiac output and vasoconstriction to maintain BP, which otherwise may decrease with decreasing cardiac output. At the release of the "strain," venous return is dramatically increased, increasing cardiac output, which is now circulating through a somewhat constricted arterial vascular system. The result is a rise in BP, potentially quite dramatic, that may require minutes to return to baseline. During heavy resistance exercise and especially if accompanied by the Valsalva maneuver, symptoms of lightheadedness or dizziness may occur if cardiac output is reduced.[6,7] With relaxation, individuals may experience headache while pressure remains elevated. In patients with heart disease, symptoms of myocardial ischemia may ensue as a result of elevated BP and increased myocardial work.

When heavy dynamic-resistance exercise (strength exercise) such as lifting weights is performed, the cardiovascular responses are a combination of the responses that occur during both dynamic-aerobic exercise and isometric exercise, reflecting a combined volume and pressure load. The level of the developed pressure load depends on the magnitude of the resistance (percent MVC) required and the duration of the muscle contraction in relation to the intervening rest period. Thus, a smaller pressure load on the cardiovascular system will occur during this type of exercise if the relative resistance is not too great, the contraction period is relatively short (1 to 3 seconds), and there is at least a 1- to 2-second rest period between contractions. The magnitude of the volume load on the cardiovascular system during a dynamic-resistance exercise will be greater when the magnitude of the resistance is relatively low (able to complete 20 to 30 repetitions) and the contractions are performed every few seconds. Specifically, and again depending on the duration and intensity of the resistance exercise, HR can substantially increase and may approach age-predicted maximum, that is, HR achieved with treadmill exercise testing. Blood pressure responses, both systolic and diastolic, may potentially surpass values achieved during standard exercise testing. Whereas DBP would be expected to decrease or not change with aerobic exercise, substantial rises in DBP have been observed with RT. However, it must be underscored that such potential HR and BP responses are very unlikely to occur with appropriate instruction and supervision of RT participants because of relatively moderate intensities of effort.

Fitness and Health Benefits

Both endurance and strength training can elicit substantial increases in physical fitness[8,9] and some health-related measures that are described later. Table 1 summarizes many of these benefits and attempts to weigh them according to the current literature. Although both training modalities can favorably modify many of the variables listed, the expected magnitude of the benefits is substantially different. Endurance training induces greater improvements in aerobic capacity and associated cardiopulmonary and metabolic variables and more effectively modifies CVD risk factors. RT enhances

TABLE 1. Comparison of Effects of Aerobic Endurance Training With Strength Training on Health and Fitness Variables

Variable	Aerobic Exercise	Resistance Exercise
Body composition		
Bone mineral density	↑↑	↑↑
Percent body fat	↓↓	↓
Lean body mass	0	↑↑
Muscle strength	0↑	↑↑↑
Glucose metabolism		
Insulin response to glucose challenge	↓↓	↓↓
Basal insulin levels	↓	↓
Insulin sensitivity	↑↑	↑↑
Plasma lipids and lipoproteins		
HDL cholesterol	↑0	↑0
LDL cholesterol	↓0	↓0
Triglycerides	↓↓	↓0
Cardiovascular dynamics		
Resting heart rate	↓↓	0
Stroke volume, resting and maximal	↑↑	0
Cardiac output, rest	0	0
Cardiac output, maximal	↑↑	0
SBP at rest	↓0	0
DBP at rest	↓0	0
$\dot{V}O_2$max	↑↑↑	↑0
Submaximal and maximal endurance time	↑↑↑	↑↑
Submaximal exercise rate-pressure product	↓↓↓	↓↓
Basal metabolic rate	↑0	↑
Health-related quality of life	↑0	↑0

↑ Indicates values increase; ↓, values decrease; 0, values remain unchanged; 1 arrow, small effect; 2 arrows, moderate effect; 3 arrows, large effect; HDL, high-density lipoprotein cholesterol; and LDL, low-density lipoprotein cholesterol. Adapted with permission from Pollock and Vincent.[11]

muscular strength, endurance, and muscle mass to a greater extent.

Body Composition Effects

RT conducted over months or years can have significant positive effects on the composition and amount of muscle, adipose tissue, and bone in men and women of all ages.[10–12] Randomized studies lasting ≥12 weeks consistently show increases in muscle mass and quality (increased strength for same muscle mass), especially in older men.[12] Recent studies have demonstrated that RT in older persons with sarcopenia (loss of skeletal muscle mass that may accompany aging) can result in an increase in muscle mass and quality[13] and that increases in muscle mass are not age dependent. However, these changes tend to be substantially less in women than in men.[14]

An increase in muscle (or lean body) mass as a result of RT contributes to the maintenance of or increase in resting or basal metabolic rate.[15] Such an increase in metabolic rate may complement the increase in caloric expenditure produced by aerobic training to assist with weight control. Because RT tends to increase lean body mass, if body weight remains constant with training, there will be a loss of fat or adipose tissue. This finding has been reported for both young and older adults participating in RT programs.[16,17]

Bone mass and strength tend to increase with exercise when substantial force is placed on the bone by the contraction of muscles and/or gravity. The effect is not systemic, with only those bones subjected to the repeated increase in force responding. Long-term RT studies have observed either no change[18] or significant increases in bone mass.[19] Comparisons of these results are confounded by variations in the training regimens, bone density assessment methods, and participant characteristics.

Quality of Life

Quality of life is a function of one's ability to do what is enjoyed and required to remain independent. In people who have a level of fitness that compromises their daily physical functioning, both endurance exercise and RT may contribute to an improved health-related quality of life.[20] In patients who are on bed rest during treatment for or recovery from various chronic diseases, there tends to be a rapid loss in muscle strength and endurance that can lead to a decline in their ability to perform various activities of daily living, along with a loss of physical independence and quality of life. Inclusion of RT as part of the rehabilitation program should assist in reducing these adverse sequelae.[21–23]

Cardiovascular System Structure and Function

The effects of RT on the cardiovascular system have been studied in individuals with and without CVD and have been summarized in several reviews.[1,24–28] The results represent a consensus of findings in which the lack of unanimity is attributable to multiple factors, including specific type, intensity, and duration of RT; age, sex, race, and genetic endowment; and whether results are adjusted for body size. Most findings apply primarily to men because studies of RT in women are limited.

Studies of cardiac morphology and function have consistently shown that the alterations associated with RT are physiological, although certain cardiac effects exist on a continuum between normal and pathological. Intensive RT characteristically increases left ventricular (LV) wall thickness and mass, with little or no change in LV diameter.[25–28] Although statistically significant, the increase in wall thickness is modest, and values are generally in the upper range of untrained, normal subjects. Some studies have shown that LV wall thickness increases in proportion to the augmentation of trained skeletal muscle mass, with no difference from untrained subjects when wall thickness is indexed to body weight. Whereas aerobic exercise is generally associated with asymmetric LV hypertrophy (albeit with a normal ratio of septal to posterior wall thickness), RT-induced hypertrophy is typically symmetric.[25–28] Echocardiographic studies of myocardial tissue reflectivity in LV hypertrophy after RT are consistent with normal myocardium, in contrast to the findings in cardiac disease that indicate fibrosis.[29] Limited studies in women report no ventricular hypertrophy with RT. LV hypertrophy associated with RT appears to be a response to the pressure load (in contrast to the volume load of aerobic exercise) and serves to reduce the systolic burden per myofiber, thereby preserving normal LV wall stress. Both systolic and diastolic LV function (based on determinants of LV filling velocities and relaxation by noninvasive imaging methods) are normal after RT, consistent with physiological hypertrophy.[25–28,30] Further support for physiological hypertrophy is provided by a greater inotropic response to dobutamine in trained subjects than in control subjects.[31]

The increase in skeletal muscle strength induced by RT results in a lower hemodynamic stress (HR and SBP) for a given skeletal muscle force after RT.[1,24–28] Two other studies also have demonstrated a reduction in resting BP after RT in young men with normal BP and in older men and women with high-normal BP.[32,33] Although RT does not impose a large aerobic burden, some studies have demonstrated a modest increase in peak $\dot{V}O_2$ and decreases in submaximal HR and SBP during aerobic exercise after a program of RT.[24–28] It appears that mild- to moderate-intensity resistance exercise, the type recommended in this advisory (see Prescription of RT), evokes a lower rate-pressure product (HR times SBP, an indirect index of myocardial oxygen demand) than maximum treadmill (aerobic) exercise.[34]

Reports of the effect of RT on endothelial function of peripheral arteries in normal individuals have shown both improved endothelial function[35] and no effect.[36] However, RT in young men reduced plasma concentration of endothelin-1, a potent vasoconstrictor and vascular smooth muscle proliferative agent.[37] Although increased resting regional blood flow has been reported after RT in patients with heart failure (HF),[38] the effect on endothelial function in this group has been inconsistent, with reports ranging from an improvement[39] to no change,[38] which may be attributable to differing methodologies. However, selected patients with chronic HF and coronary heart disease (CHD) have responded to RT with gains in muscular strength, no cardiac alterations, and no untoward events.[24,35,37,38]

In contrast to the increase in central arterial compliance associated with aerobic training, the effects of RT on this parameter have varied. Central arterial compliance was unaltered by whole-body RT in a prospective study of young healthy men.[40] In contrast, an increase in arterial stiffness with RT has been demonstrated in the aorta and carotid arteries in association with an augmented central pulse pressure.[41–43] In these studies, peripheral SBP was mildly increased but in the normal range, and DBP and mean BP were normal. Although it has been suggested that increased stiffness of large arteries may be an adaptation to obviate excessive expansion during severe isometric activity, the clinical implications of this finding are currently unclear. In summary, the influence of RT on both peripheral and central arterial compliance remains inconsistent and controversial at this time.

An imbalance between free radical production and antioxidant protection leads to an oxidative stress state, which may be involved in the aging and disease processes.[44] Acute bouts of exercise can have positive or negative effects on oxidative stress, depending on the type and intensity of the workout and the baseline fitness level of the individual. Although the potential long-term benefits of RT on oxidative stress remain to be fully evaluated, some studies in older adults suggest that low- to moderate-intensity training may attenuate oxidative stress markers.[45,46] One study suggests that RT may provide a "cross-protection" against the oxidative stress generated by aerobic exercise.[47] This mechanism may be of particular importance to the present recommendations that call for moderate-intensity RT as an adjunct to aerobic exercise.

CVD Risk Modification

The metabolic effects of reduced muscle mass secondary to aging, decreased physical activity, or both contribute to the presence of obesity, insulin resistance, type 2 diabetes, dyslipidemia, and hypertension.[48,49] Skeletal muscle, the primary tissue for glucose and triglyceride metabolism, is a determinant of resting metabolic rate, and changes in muscle mass may reduce multiple CVD risk factors.[50–53] Cross-sectional studies have demonstrated that muscular strength is inversely associated with all-cause mortality[54] and the prevalence of metabolic syndrome[55,56] independently of aerobic fitness levels. Nevertheless, data that RT reduces CVD risk are equivocal.

Diabetes

Diabetes mellitus, glucose intolerance, and insulin resistance markedly increase the risk for CVD.[57] Maintaining glycemic control depends on enhancing insulin availability or overcoming insulin resistance. Muscle contraction increases glucose uptake and improves insulin sensitivity in skeletal muscle,[51,58] thereby providing a rationale for its use in individuals with glucose intolerance. Nevertheless, data showing that RT prevents type 2 diabetes are lacking. RT does not appear to alter glucose tolerance or glycemic control[50,51,59–61] unless baseline glucose tolerance is abnormal.[60–64] RT does reduce acute insulin responses in healthy[50,51,65] and diabetic individuals[62,64,66] and glycosylated hemoglobin A1c levels in diabetic individuals.[62,63,67,68]

Blood Pressure

The role of RT in controlling BP has been examined in 2 meta-analyses.[69,70] Unfortunately, only 20% of the outcomes in these 2 analyses were based on an initial resting SBP of >140 mm Hg, with only 13% having an initial resting DBP >90 mm Hg. The range of reduction was 3 to 3.5 mm Hg for resting SBP and DBP, respectively. These changes represented approximate decreases of 2% for SBP and 4% for DBP, respectively. No differences were observed in resting BP when conventional RT was compared with circuit training. Although these BP reductions seem modest, an SBP reduction of 3 mm Hg has been associated with reduced cardiac morbidity by 5% to 9%, stroke by 8% to 14%, and all-cause mortality by 4%.[71] Blood pressure reduction is even more important in individuals with existing hypertension. In 1 study,[72,73] RT combined with aerobic exercise for 10 weeks reduced SBP and DBP by 13 mm Hg each among middle-aged men with hypertension. Conversely, a similar program for 6 months in older adults with hypertension showed decreases in SBP and DBP of 5.3 and 3.7 mm Hg, respectively, among exercisers,[74] suggesting that age may attenuate the BP-lowering effects of exercise training.

Weight Management

Exercise recommendations to treat or prevent obesity have focused mainly on aerobic activities. However, RT may also assist in weight control because it increases muscle mass. In theory, a gain of 1 kg in muscle mass should increase resting energy expenditure by ≈21 kcal/d.[75] Thus, when sustained over time, RT should help to prevent or reverse increases in body fat. Furthermore, even without a change in resting energy expenditure, maintaining muscle mass as individuals get older may prevent age-associated fat gains.[10,76,77] Perhaps of greater importance than total fat reduction, RT contributes to the reduction of visceral adipose tissue, which is associated with the metabolic syndrome.[74,77–81]

Dyslipidemia

Data regarding the effect of RT and increases in muscle mass on lipid metabolism are equivocal. In 1 study of 8499 men, there was a reduced risk of hypercholesterolemia among individuals participating in RT programs.[82] However, only those individuals who participated >4 h/wk maintained this reduced risk when confounding variables were controlled for. In contrast, another study of 1193 women and 5460 men[83] found no association between muscle strength and total cholesterol or low-density lipoprotein cholesterol. However, among men, greater upper- and lower-body strength was associated with lower triglyceride levels. Most intervention studies have not adequately controlled for normal variations in lipoproteins, lacked proper dietary controls, or were not powered to determine the impact of RT. After these factors are accounted for, there is usually no improvement in lipid profiles after RT.[81,84–86] For dyslipidemia and other risk factors that constitute the metabolic syndrome, RT combined with aerobic exercise may be more efficacious, as demonstrated in a 6-month study of older adults.[74,80] Exercisers had significantly increased aerobic and muscle fitness and lean mass and significantly reduced total and abdominal fat and BP. High-density lipoprotein cholesterol increased by 5%. Overall, these changes resulted in a lower prevalence of metabolic syndrome.

Benefit in Women, Older Persons, and Patients With HF

The benefits of RT are due primarily to increases in strength and muscular endurance and have been demonstrated in broad populations of individuals, including studies of women,[87,88] older individuals,[12,89] patients with CHD,[90–93] and those with HF.[94] In patients with CHD, improvements in strength of 24% to 90%[90,91] and walking endurance (15% for the 6-minute walk)[92] have been demonstrated. Clinical and functional benefits of RT are particularly helpful to individuals with physical dysfunction, which has led to studies of individuals with physical frailty related to aging or chronic diseases.[12,88,89,92–97]

Women and Older Persons

RT is beneficial for improving the physical function of many women and elderly persons, particularly those with CHD or who are otherwise frail, because of the substantial benefit from an increased upper- and lower-body muscle strength and endurance.[96,98] In studies of women[87,88] and elders of both genders[12,89,95,97] with physical frailty, RT has been shown to improve several components of physical function, including walking endurance,[96] walking speed,[95] and dynamic balance,[88] in addition to reducing falls in both older men and women.[88,89,98,99]

Even in the oldest persons (nursing home residents; mean age, 87 years), a 10-week period of RT induced significant improvements in strength, gait velocity, and stair-climbing power associated with an increase in thigh muscle cross-sectional area.[95] In some studies of healthy elders, aerobic capacity also increased,[100] although this increase was not seen in other studies.[96] In general, the methodology of exercise prescription of RT for women and older individuals is not different than that for younger men, although specific adjustments may need to be made to accommodate certain individuals and health limitations. Although most studies have been of facility-based RT, favorable results also have been obtained with elders exercising primarily in the home setting.[88,97]

Studies of patients with CHD have examined the value of RT when added to a program of aerobic exercise. These studies found that RT is well tolerated and is associated with improvements in quality of life,[90] strength, and endurance.[91] In an evaluation of the effects of RT alone in a group of older women with CHD with at least a moderate degree of mobility limitation,[92,93] women who underwent RT improved their measured physical performance on a battery of daily physical activities (summary score, 24% improvement), upper- and lower-body strength (18% and 23% improvement, respectively), balance and coordination (29% improvement), and walking endurance (15% improvement) compared with the control group. Neither group increased aerobic capacity. Of note, despite their increased physical capacity, women in this study did not spontaneously take on higher-intensity activities in their daily lives (as measured by questionnaire), although total daily energy expenditure increased by 177 kcal/d as a result of an increase in both total physical activity and resting metabolic rate.[92,100] In addition, there is some evidence that RT in older men and women increases not only resting energy expenditure but also the daily physical activity performed outside of the training sessions, resulting in a significant increase in total daily energy expenditure.[16]

Persons With HF

In patients with HF, despite well-described abnormalities of skeletal muscle,[101] RT traditionally has been discouraged because of concerns for furthering impairment of LV function and potential adverse LV remodeling related to increased afterload during the lifting phase. In reality, at the intensity of RT performed by patients with HF, the hemodynamic responses do not exceed levels attained during standard exercise testing,[102] and adverse remodeling after RT has not been demonstrated.[94] Thus, it appears that RT can be incorporated safely into rehabilitation programs for patients with HF, although further study of this important area is needed.[24,103] In older women with HF randomized to 10 weeks of RT or control, the former was associated with a 43% increase in muscle strength and a 49% increase in 6-minute walk distance, along with a 299% increase in submaximal endurance measured by the number of lifts at an intensity of 90% of baseline 1-repetition maximum (the maximum weight that can be used to complete 1 repetition, 1-RM).[94] Total muscle mass was unchanged, and there were no alterations in echocardiographic measures of cardiac function. Thus, the effects of RT in HF appear to be directed at improving skeletal muscle ultrastructural abnormalities and/or neuromuscular function rather than simply increasing muscle mass.

Safety of RT

Both research findings and clinical experience indicate that resistance exercise is relatively safe. However, most studies of RT have enrolled selected, low-risk individuals, and many are too small to provide reliable estimates of event rates on a population-wide basis.[104] Nonetheless, analogous to the risks associated with aerobic exercise, cardiovascular risks associated with RT are likely determined by the age of the participant, his or her habitual physical activity and fitness level, underlying CVD, and the intensity of RT. Although excessive BP elevations have been documented with high-intensity RT, for example, 80% to 100% of 1-RM performed to exhaustion, such elevations are generally not a concern with low- to moderate-intensity RT performed with correct breathing technique and avoidance of the Valsalva maneuever.[104] Interestingly, there is indirect evidence that RT results in a more favorable balance in myocardial oxygen supply and demand than aerobic exercise because of the lower HR and higher myocardial (diastolic) perfusion pressure.[34]

Isometric exercise, regardless of the percent MVC, generally fails to elicit angina pectoris, ischemic ST-segment depression, or complex ventricular arrhythmias in low-risk cardiac patients.[20] In addition to increased subendocardial perfusion caused by elevated DBP and decreased venous return, the resulting reduction in LV diastolic volume and wall tension contribute to the lower incidence of ischemic responses during isometric exercise.[21] Moreover, the myocardial oxygen supply/demand relationship appears to be favorably altered by the superimposition of static on dynamic effort, so that the magnitude of ischemic ST-segment depression is lessened at a given rate-pressure product.[22]

The use of resistance testing and training in moderate- to high-risk cardiac patients requires good clinical judgment and close monitoring. Studies in healthy adults and low-risk cardiac patients, that is, persons without resting or exercise-induced evidence of myocardial ischemia, severe LV dysfunction, or complex ventricular dysrhythmias, have reported no major adverse cardiovascular events. RT also appears to be safe among patients with controlled hypertension,[105,106] and intra-arterial BPs during weight lifting in cardiac patients are reported to be within a clinically acceptable range at 40% and 60% of 1-RM.[107] No significant cardiovascular events were reported with 1-RM strength testing (bench press, leg press, and knee extension) in 6653 healthy subjects 20 to 69 years of age who had undergone a preliminary medical examination and maximal treadmill testing, and all of whom had resting BP <160/90 mm Hg.[108]

The application of RT in the rehabilitation of patients with CHD has been reviewed.[109] All studies reported improvements in muscular strength and endurance, with similar increases in overall strength for high (80% of 1-RM) and moderate (30% to 40% of 1-RM) training intensities. The absence of anginal symptoms, ischemic ST-segment depression, abnormal hemodynamics, complex ventricular dysrhythmias, and cardiovascular complications suggests that strength testing and training are safe for clinically stable men with CHD who are actively participating in a supervised rehabilitation program. More recent data indicate that women with CHD also can safely benefit from RT.[23]

Medical Evaluation of Appropriateness for RT

The purpose of medical screening and evaluation for RT is to exclude individuals with unstable medical conditions who are at increased risk for untoward events while minimizing barriers to exercise and avoiding unnecessary, potentially costly medical evaluations that themselves may not be without risk. Vigorous or high-intensity RT should not be initiated for persons without prior exposure to more moderate resistance exercise independently of age, health status, or fitness level. Thus, medical testing as recommended by several organizations before "vigorous exercise"[110–112] is not required for RT, which should always be initiated at a low level. In sedentary patients with diabetes, graded exercise testing needs to be performed only when the planned exercise is more vigorous than brisk walking and the 10-year risk of a coronary event is likely to be >10%.[113]

Generally accepted cardiovascular conditions that contraindicate aerobic and RT are included in Table 2. Although patients with hypertrophic cardiomyopathy also are often

TABLE 2. Absolute and Relative Contraindications to Resistance Training

Absolute
Unstable CHD
Decompensated HF
Uncontrolled arrhythmias
Severe pulmonary hypertension (mean pulmonary arterial pressure >55 mm Hg)
Severe and symptomatic aortic stenosis
Acute myocarditis, endocarditis, or pericarditis
Uncontrolled hypertension (>180/110 mm Hg)
Aortic dissection
Marfan syndrome
High-intensity RT (80% to 100% of 1-RM) in patients with active proliferative retinopathy or moderate or worse nonproliferative diabetic retinopathy
Relative (should consult a physician before participation)
Major risk factors for CHD
Diabetes at any age
Uncontrolled hypertension (>160/>100 mm Hg)
Low functional capacity (<4 METs)
Musculoskeletal limitations
Individuals who have implanted pacemakers or defibrillators

advised to avoid RT, a recent AHA statement summarizing recommendations for physical activity and recreational sports participation in young individuals with genetic CVDs suggests that low-intensity weight training with machines may be permissible in selected individuals.[114]

Patients with recent myocardial infarction, percutaneous or surgical coronary revascularization, or other types of open heart surgery should preferably exercise in supervised cardiac rehabilitation programs with risk stratification and monitoring as outlined by the American Association of Cardiovascular and Pulmonary Rehabilitation.[111] Patients with CVD whose symptoms are stable can participate in low- to moderate-intensity RT without further medical diagnostic testing, provided that they have acceptable functional capacity (≥4 METs) as estimated by a questionnaire, for example, the Duke Activity Status Inventory.[115] Patients should be advised to stop exercise and seek medical consultation if their health status changes or if they develop chest discomfort or undue shortness of breath during RT. Low functional capacity (<4 METs) has been associated with higher event rates and a poorer prognosis,[116,117] suggesting that such individuals may warrant additional risk stratification before participating in RT even in the absence of overt symptoms and additional monitoring, especially early in their exercise training program. In addition, repetitive-motion activities such as weight lifting can result in pacing lead fractures and dislodgment.[118] Individuals with such devices should consult with their physicians before engaging in upper-body RT.

In the absence of contraindications, patients with type 2 diabetes should be encouraged to participate in RT.[113] Caution is advised for individuals with diabetic neuropathy because of greater susceptibility to orthostatic hypotension and musculoskeletal injuries due to inadequate proprioception and pain perception. Vigorous RT among individuals with retinopathy is contraindicated because it may trigger vitreous hemorrhage and retinal detachment.[119]

Persons with musculoskeletal limitations, advanced arthritic conditions, severe osteoporosis and neuropathies, or neurological sequelae resulting from prior stroke are at increased risk for physical complications from resistance exercise but can derive substantial benefit from RT and should not be routinely excluded from such activities.[10,120,121] RT with machines as opposed to free weights is likely the safest approach, and such individuals should seek guidance by a trained professional, for example, clinical exercise physiologist or physical therapist, for appropriate machine adjustment, selection of specific exercises, appropriate initial exercise prescription, and subsequent exercise progression.[110]

Prescription of RT

Several guidelines and statements have described recommendations for the prescription of RT (Table 3). The emphasis at the early stage of RT is to allow time for musculoskeletal adaptation and to practice good technique, thus reducing the potential for excessive muscle soreness and injury. The initial resistance or weight load should be set at a moderate level that permits one to achieve the prescribed repetition range

TABLE 3. Guidelines and Statements Regarding Resistance and Flexibility Training

	Resistance Training		Flexibility Training	
Population	Sets; Reps	Stations/Devices*	Frequency	Goal
Healthy/sedentary adults				
2007 AHA Scientific Statement	1 set; 8–12 reps for persons <50–60 y of age; 10–15 reps at reduced levels of resistance for persons 50–60 y of age	8–10 exercises	2–3 d/wk	Stretching the major muscle or tendon groups, 2–3 d/wk
2006 ACSM Guidelines[110]	1 set; 8–12 reps (range, 3–20 reps) performed at a moderate rep duration (≈3 s concentric, ≈3 s eccentric)	8–10 exercises	2-3 nonconsecutive d/wk	Static stretching, major muscle tendon units a minimum of 2–3 d/wk; stretch to the ROM at a point of tightness, 15–30 s/stretch, 2–4 reps/stretch
Elderly persons				
2001 American Geriatrics Society[121]	Low: 40% 1-RM; 10–15 reps	Not specified	2–3 d/wk	3–5 stretches/key muscle group; hold for 20–30 s; 3–5 d/wk
	Moderate: 40%–60% 1-RM; 8–10 reps			
	High: >60% 1-RM; 6–8 reps			
Cardiac patients				
2007 AHA Scientific Statement	1 set; 10–15 reps	8–10 exercises	2–3 d/wk	Stretching the major muscle or tendon groups, 2–3 d/wk
2004 AACVPR guidelines[111]	1 set; 12–15 reps	6–8 exercises	2–3 d/wk	
2006 ACSM guidelines[110]	1 set; 10–15 reps	8–10 exercises	2–3 d/wk	

Reps indicates repetitions; ROM, range of motion; ACSM, American College of Sports Medicine; and AACVPR, American Association of Cardiovascular and Pulmonary Rehabilitation.

*Minimum 1 exercise per major muscle group, for example, chest press, shoulder press, triceps extension, biceps curl, pull-down (upper back), lower-back extension, abdominal crunch/curl-up, quadriceps extension or leg press, leg curls (hamstrings), and calf raise.

TABLE 4. Recommendations for the Initial Prescription of RT

Resistance training should be performed
In a rhythmical manner at a moderate to slow controlled speed
Through a full range of motion, avoiding breathholding and straining (Valsalva maneuver) by exhaling during the contraction or exertion phase of the lift and inhaling during the relaxation phase
Alternating between upper- and lower-body work to allow for adequate rest between exercises
The initial resistance or weight load should
Allow for and be limited to 8–12 repetitions per set for healthy sedentary adults or 10–15 repetitions at a low level of resistance, for example, <40% of 1-RM, for older (>50–60 y of age), more frail persons, or cardiac patients
Be limited to a single set performed 2 d/wk
Involve the major muscle groups of the upper and lower extremities, eg, chest press, shoulder press, triceps extension, biceps curl, pull-down (upper back), lower-back extension, abdominal crunch/curl-up, quadriceps extension or leg press, leg curls (hamstrings), and calf raise

without straining. This is particularly important for patients with CVD. Table 4 describes considerations for the initial prescription of RT.

Recommendations for the frequency and intensity of the RT program also are shown in Table 4. The traditional prescription for RT has involved performing each exercise 3 times (sets), that is, 3 sets of 10 repetitions per set (Figure). However, during the initial training period, single- and multiple-set programs provide nearly the same relative improvement in muscular strength.[122] For the average person beginning a strength training regimen, single-set programs performed a minimum of 2 days per week are recommended over multiple-set programs because they are highly effective, are less time consuming, and promote adherence. If time permits, participants may progress to a regimen of 3 days per week. Because the effect of physical conditioning is specific to the muscle group being trained, RT regimens should include exercises involving a variety of the major muscle groups.[10] Furthermore, for those persons with CVD, the level of resistance should be reduced and number of repetitions increased, resulting in a lower relative effort and reducing the

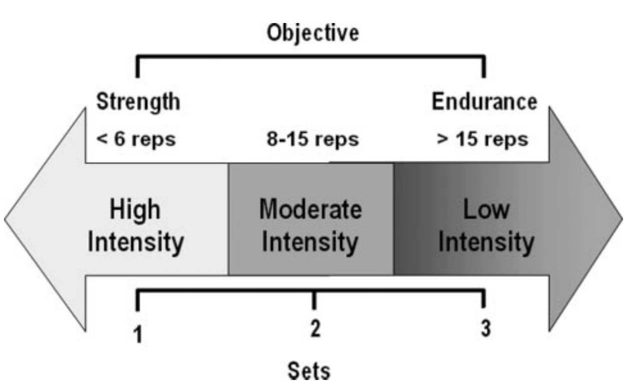

Figure. Classification of weight training intensity (resistance). A lower repetition range with a heavier weight may better optimize strength and power, whereas a higher repetition range with a lighter weight may better enhance muscular endurance. Using weight loads that permit 8 to 15 repetitions (reps) will generally facilitate improvements in muscular strength and endurance.

likelihood of breathholding and straining. Thus, a comprehensive RT program of 8 to 10 exercises can be accomplished in 15 to 20 minutes and should be performed after the aerobic component, which will ensure an adequate warm-up. Multiple-set regimens at a greater training frequency (>2 times/wk) may provide greater benefits for healthy, younger individuals whose goals include maximum gains in strength, lean body mass, and athletic performance.[123,124] Many men can safely perform static-dynamic activity equivalent to carrying up to 30 pounds by 3 weeks after an acute myocardial infarction.[125] Conversely, patients with recent coronary artery bypass surgery should avoid traditional upper-body RT exercises, that is, lifting weights ≥50% of MVC, for up to 8 to 12 weeks to allow for proper healing of the sternum.[126]

To approximate the appropriate limb-specific weight loads for RT, one can determine the maximum weight that can be used to complete 1-RM during a given exercise, for example, bench press, leg press, biceps curl, or knee extension, and then lift a defined percentage of that amount during each set of the exercise. An initial intensity that corresponds to 30% to 40% of 1-RM for the upper body and 50% to 60% of 1-RM for the hips and legs is recommended. Most studies of previously sedentary adults with and without heart disease, including those with HF, reported training workloads of 50% to 80% of 1-RM.[24,127] When determination of 1-RM is deemed inappropriate, the load-repetition relationship for RT may be approximated (Table 5).[128]

As the individual progresses, the exercise dosage can be increased (overload) to facilitate improvements in muscular strength and endurance. Overload can be achieved by modulating several prescriptive variables: increasing the resistance or weight, increasing the repetitions per set, increasing the number of sets per exercise, and decreasing the rest period between sets or exercises. An initial increase in the number of repetitions is recommended before an increase in resistance or weight load. When the participant can comfortably achieve the "upper limit" of the prescribed repetition range, for example, 12 to 15 repetitions, training loads may be increased by ≈5%, which may initially approximate 2 to 5 lb per exercise and 5 to 10 lb per exercise for the arms and legs, respectively. Conventional guidelines, however, often impose a somewhat restrictive weight limit (1 to 5 pounds) for the first 3 to 12 weeks after a cardiac event or intervention because of physician concerns for patients lifting too much weight, particularly in unsupervised activities. An alternative approach for low- to moderate-risk patients, as stratified by the American Association of Cardiovascular and Pulmonary

TABLE 5. Load-Repetition Relationship for Resistance Training

% 1-RM	Repetitions Possible, n
60	17
70	12
80	8
90	5
100	1

Adapted from Dingwall et al.[128] 2006. Copyright John Wiley & Sons Limited. Used with permission.

Rehabilitation, who are participating in supervised cardiac rehabilitation has been proposed for 3 cardiac rehabilitation diagnosis groups (myocardial infarction, pacemaker or implantable cardioverter-defibrillator placement, and coronary artery bypass surgery) that, if used in conjunction with HR and BP measurements, may accelerate their return to their desired levels of daily activity.[129]

To monitor cardiovascular responses to resistance exercise, measures of HR, BP, and perceived exertion are commonly recommended. The HR response to resistance exercise is generally lower than during the aerobic component and may not truly reflect the overall stress on the myocardium. Rather, it is the potential elevation in SBP that may contribute more than HR to the increase in rate-pressure product during resistance exercise.[127] For those able to monitor HR and SBP during resistance exercise, the rate-pressure product should be 20% less than that observed at the angina or ECG ischemic threshold during exercise testing.[110] Furthermore, SBPs measured immediately after and not during the actual weight lifting are likely to underestimate the pressor response.[130]

Individuals should work to a perceived exertion during RT that approximates 11 to 14 ("fairly light" to "somewhat hard") on the Borg category scale,[111] recognizing that the rating will increase over a set of 10 to 15 repetitions. Regardless of the monitoring procedures used, adverse signs and symptoms, for example, dizziness, excessive shortness of breath, chest pain or pressure, and heart rhythm irregularities, are contraindications for continued exercise, and RT should be stopped immediately if any of these occur.[110,111]

The type of resistance exercise equipment may vary considerably in cost, complexity, operational skill/coordination, and time efficiency. The key is to select equipment that is safe, effective, and accessible. In recent years, the use of low-cost approaches that allow for a gradual progression in resistance or weight has grown in popularity, for example, calisthenics, resistance-cord exercises, pulley weights, dumbbells or wrist weights, spring pulleys, and dowel exercises. The use of multiexercise circuit weight training is widely recommended. Weight machines can aid in keeping one's balance and equilibrium, can be easily adjusted to varying resistances, and can provide an inherent "spotter" function, potentially reducing the likelihood of injury. During all types of RT, participants should be advised to maintain a secure but not overly tight grip of the weight handles or bar to prevent an excessive BP response.[110]

Summary

Since the first AHA science advisory regarding RT in 2000, RT has become even more accepted and commonly used in exercise training programs for persons with and without CVD. The potential benefits, not only to cardiovascular health but also to weight management and the prevention of disability and falls, are becoming more widely appreciated. For persons at low risk for cardiac events, extensive cardiovascular screening is probably not necessary, although a graded approach is recommended. For persons at moderate to high risk of such events, RT can be safely undertaken with proper preparation, guidance, and surveillance. Because long-term compliance remains a challenge for adult fitness and exercise-based cardiac rehabilitation programs, the incorporation of RT can provide variety in the training regimen and can increase the potential for maintenance of interest and improved compliance. However, given the extensive evidence of the benefits of aerobic exercise training on the modulation of cardiovascular risk factors, RT should be viewed as a complement to rather than a replacement for aerobic exercise.

Disclosures

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This table represents the relationships of writing group members that may be perceived as actual or reasonably perceived conflicts of interest as reported on the Disclosure Questionnaire, which all members of the writing group are required to complete and submit.

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This table represents the relationships of reviewers that may be perceived as actual or reasonably perceived conflicts of interest as reported on the Disclosure Questionnaire, which all reviewers are required to complete and submit.

References

1. Pollock ML, Franklin BA, Balady GJ, Chaitman BL, Fleg JL, Fletcher B, Limacher M, Piña IL, Stein RA, Williams M, Bazzarre T. Resistance exercise in individuals with and without cardiovascular disease: benefits, rationale, safety, and prescription: an advisory from the Committee on Exercise, Rehabilitation, and Prevention, Council on Clinical Cardiology, American Heart Association: position paper endorsed by the American College of Sports Medicine. *Circulation*. 2000;101:828–833.
2. Stewart KJ. Weight training in coronary artery disease and hypertension. *Prog Cardiovasc Dis*. 1992;35:159–168.
3. Lind AR, McNicol GW. Muscular factors which determine the cardiovascular responses to sustained and rhythmic exercise. *Can Med Assoc J*. 1967;96:706–715.
4. Mitchell JH, Payne FC, Saltin B, Schibye B. The role of muscle mass in the cardiovascular response to static contractions. *J Physiol*. 1980;309:45–54.
5. Harman EA, Frykman PN, Clagett ER, Kraemer WJ. Intra-abdominal and intra-thoracic pressures during lifting and jumping. *Med Sci Sports Exerc*. 1988;20:195–201.
6. Gaffney FA, Sjogaard G, Saltin B. Cardiovascular and metabolic responses to static contraction in man. *Acta Physiol Scand*. 1990;138:249–258.
7. MacDougall JD, Tuxen D, Sale DG, Moroz JR, Sutton JR. Arterial blood pressure response to heavy resistance exercise. *J Appl Physiol*. 1985;58:785–790.
8. US Department of Health and Human Services. *Physical Activity and Health: A Report of the Surgeon General*. Atlanta, Ga: US Department of Health and Human Services, Centers for Disease Control and Prevention, National Center for Chronic Disease Prevention and Health Promotion; 1996.
9. American College of Sports Medicine position stand: the recommended quantity and quality of exercise for developing and maintaining cardiorespiratory and muscular fitness in healthy adults. *Med Sci Sports Exerc*. 1990;22:265–274.
10. American College of Sports Medicine Position Stand: the recommended quantity and quality of exercise for developing and maintaining cardiorespiratory and muscular fitness and flexibility in healthy adults. *Med Sci Sports Exerc*. 1998;30:975–991.
11. Pollock ML, Vincent KR. Resistance training for health. In: *The President's Council on Physical Fitness and Sports Research Digest*. December 1996; series 2, No. 8.
12. Hunter GE, McCarthy JP, Bamman MM. Effects of resistance exercise training on older adults. *Sports Med*. 2004;34:329–348.
13. Kim JS, Cross JM, Bamman MM. Impact of resistance loading on myostatin expression and cell cycle regulation in young and older men and women. *Am J Physiol Endrocrinol Metab*. 2005;288:E1110–E1119.
14. Lemmer JT, Hurlbut DE, Martel GF, Tracy BL, Ivey FM, Metter EJ, Fozard JL, Fleg JL, Hurley BF. Age and gender responses to strength training and detraining. *Med Sci Sports Exerc*. 2000;32:1505–1512.
15. Pratley R, Nicklas B, Rubin M, Miller J, Smith A, Smith M, Hurley B, Goldberg A. Strength training increases resting metabolic rate and norepinephrine levels in healthy 50- to 65-yr-old men. *J Appl Physiol*. 1994;76:133–137.
16. Hunter GR, Wetzstein CJ, Fields DA, Brown A, Bamman MM. Resistance training increases total energy expenditure and free-living physical activity in older adults. *J Appl Physiol*. 2000;89:977–984.
17. McCarthy JP, Agre JC, Graf BK, Pozniak MA, Vailas AC. Compatibility of adaptive responses with combining strength and endurance training. *Med Sci Sports Exerc*. 1995;27:429–436.
18. McCartney N, Hicks AL, Martin J, Webber CE. Long-term resistance training in the elderly: effects on dynamic strength, exercise capacity, muscle, and bone. *J Gerontol A Biol Sci Med Sci*. 1995;50:B97–B104.
19. Engelke K, Kemmler W, Lauber D, Beeskow C, Pintag R, Kalender WA. Exercise maintains bone density at spine and hip EFOPS: a 3-year longitudinal study in early postmenopausal women. *Osteoporos Int*. 2006;17:133–142.
20. DeBusk RF, Valdez R, Houston N, Haskell W. Cardiovascular responses to dynamic and static effort soon after myocardial infarction: application to occupational work assessment. *Circulation*. 1978;58:368–375.
21. Franklin BA, Bonzheim K, Gordon S, Timmis GC. Resistance training in cardiac rehabilitation. *J Cardiopulm Rehabil*. 1991;11:99–107.
22. Bertagnoli K, Hanson P, Ward A. Attenuation of exercise-induced ST depression during combined isometric and dynamic exercise in coronary artery disease. *Am J Cardiol*. 1990;65:314–317.
23. Izawa K, Hirano Y, Yamada S, Oka K, Omiya K, Iijima S. Improvements in physiological outcomes and health-related quality of life following cardiac rehabilitation in patients with acute myocardial infarction. *Circ J*. 2004;68:315–320.
24. Volaklis KA, Tokmakidis SP. Resistance training in patients with heart failure. *Sports Med*. 2005;35:1085–1103.
25. Spirito P, Pelliccia A, Proschan MA, Granata M, Spataro A, Bellone P, Caselli G, Biffi A, Vecchio C, Maron BJ. Morphology of the "athlete's heart" assessed by echocardiography in 947 elite athletes representing 27 sports. *Am J Cardiol*. 1994;74:802–806.
26. Fagard RH. Athlete's heart: a meta-analysis of the echocardiographic experience. *Int J Sports Med*. 1996;17(suppl 3):S140–S144.
27. Maron B, ed. The athlete's heart and cardiovascular disease. *Cardiol Clin*. 1997;15:345–514.
28. Pluim B, Zwinderman AH, van der Laarse A, Van der Wall EE. The athlete's heart: meta-analysis of cardiac structure and function. *Circulation*. 2000;101:336–344.
29. Shapiro LM. The morphologic consequences of systemic training. *Cardiol Clin*. 1997;15:373–379.
30. Suman OE, Hasten D, Turner MJ, Rinder MR, Spina RJ, Ehsani AA. Enhanced inotropic response to dobutamine in strength-trained subjects with left ventricular hypertrophy. *J Appl Physiol*. 2000;88:534–539.
31. Pearson AC, Schiff M, Mrosek D, Labovitz AJ, Williams GA. Left ventricular diastolic function in weight lifters. *Am J Cardiol*. 1986;58:1254–1259.
32. Stone MH, Wilson GD, Blessing D, Rozenek R. Cardiovascular responses to short-term Olympic style weight-training in young men. *Can J Appl Sport Sci*. 1983;8:134–139.
33. Martel GF, Hurlbut DE, Lott ME, Lemmer JT, Ivey FM, Roth SM, Rogers MA, Fleg JL, Hurley BF. Strength training normalizes resting blood pressure in 65- to 73-year-old men and women with high normal blood pressure. *J Am Geriatr Soc*. 1999;47:1215–1221.

34. Featherstone JF, Holly RG, Amsterdam EA. Physiologic responses to weight lifting in coronary artery disease. *Am J Cardiol*. 1993;71: 287–292.
35. Bank AJ, Shammas RA, Mullen K, Chuang PP. Effects of short-term forearm exercise training on resistance vessel endothelial function in normal subjects and patients with heart failure. *J Card Fail*. 1998;4: 193–201.
36. Rakobowchuk M, McGowan CL, de Groot PC, Hartman JW, Phillips SM, MacDonald MJ. Endothelial function of young healthy males following whole body resistance training. *J Appl Physiol*. 2005;98: 2185–2190.
37. Maeda S, Miyauchi T, Iemitsu M, Sugawara J, Nagata Y, Goto K. Resistance exercise training reduces plasma endothelin-1 concentration in healthy young humans. *J Cardiovasc Pharmacol*. 2004;44(suppl 1):S443–S446.
38. Hare D, Ryan TM, Selig SE, Pellizzer AM, Wrigley TV, Krum H. Resistance exercise training increases muscle strength, endurance, and blood flow in patients with chronic heart failure. *Am J Cardiol*. 1999; 83:1674–1677, A7.
39. Katz SD, Yuen J, Bijou R, LeJemtel TH. Training improves endothelium-dependent vasodilation in resistance vessels of patients with heart failure. *J Appl Physiol*. 1997;82:1488–1492.
40. Rakobowchuk M, McGowan CL, de Groot PC, Bruinsma D, Hartman JW, Phillips SM, MacDonald MJ. Effect of whole body resistance training on arterial compliance in young men. *Exp Physiol*. 2005;90: 645–651.
41. Bertovic DA, Waddell TK, Gatzka CD, Cameron JD, Dart AM, Kingwell BA. Muscular strength training is associated with low arterial compliance and high pulse pressure. *Hypertension*. 1999;33:1385–1391.
42. Miyachi M, Donato AJ, Yamamoto K, Takahashi K, Gates PE, Moreau KL, Tanaka H. Greater age-related reduction in central arterial compliance in resistance-trained men. *Hypertension*. 2003;41:130–135.
43. Miyachi M, Kawano H, Sugawara J, Takahashi K, Hayashi K, Yamazaki K, Tabata I, Tanaka H. Unfavorable effects of resistance training on central arterial compliance: a randomized intervention study. *Circulation*. 2004;110:2858–2863.
44. Kamel HK. Sarcopenia and aging. *Nutr Rev*. 2003;61(pt 1):157–167.
45. Parise G, Phillips SM, Kaczor JJ, Tarnopolsky MA. Antioxidant enzyme activity is up-regulated after unilateral resistance exercise training in older adults. *Free Radic Biol Med*. 2005;39:289–295.
46. Parise G, Brose AN, Tarnopolsky MA. Resistance exercise training decreases oxidative damage to DNA and increases cytochrome oxidase activity in older adults. *Exp Gerontol*. 2005;40:173–180.
47. Vincent KR, Vincent HK, Braith RW, Lennon SL, Lowenthal DT. Resistance exercise training attenuates exercise-induced lipid peroxidation in the elderly. *Eur J Appl Physiol*. 2002;87:416–423.
48. Fletcher GF, Balady G, Blair SN, Blumenthal J, Caspersen C, Chaitman B, Epstein S, Sivarajan Froelicher ES, Froelicher VF, Pina IL, Pollock ML. Statement on exercise: benefits and recommendations for physical activity programs for all Americans: a statement for health professionals by the Committee on Exercise and Cardiac Rehabilitation of the Council on Clinical Cardiology, American Heart Association. *Circulation*. 1996; 94:857–862.
49. Klein S, Burke LE, Bray GA, Blair S, Allison DB, Pi-Sunyer X, Hong Y, Eckel RH, for the American Heart Association Council on Nutrition, Physical Activity, and Metabolism. Clinical implications of obesity with specific focus on cardiovascular disease: a statement for professionals from the American Heart Association Council on Nutrition, Physical Activity, and Metabolism: endorsed by the American College of Cardiology Foundation. *Circulation*. 2004;110:2952–2967.
50. Hurley BF, Hagberg JM, Goldberg AP, Seals DR, Ehsani AA, Brennan RE, Holloszy JO. Resistive training can reduce coronary risk factors without altering VO2max or percent body fat. *Med Sci Sports Exerc*. 1988;20:150–154.
51. Miller JP, Pratley RE, Goldberg AP, Gordon P, Rubin M, Treuth MS, Ryan AS, Hurley BF. Strength training increases insulin action in healthy 50- to 65-yr-old men. *J Appl Physiol*. 1994;77:1122–1127.
52. Poehlman ET, Denino WF, Beckett T, Kinaman KA, Dionne IJ, Dvorak R, Ades PA. Effects of endurance and resistance training on total daily energy expenditure in young women: a controlled randomized trial. *J Clin Endocrinol Metab*. 2002;87:1004–1009.
53. Braith RW, Stewart KJ. Resistance exercise training: its role in the prevention of cardiovascular disease. *Circulation*. 2006;113:2642–2650.
54. Fitzgerald SJ, Barlow CE, Kampert JB, Morrow JR, Jackson AW, Blair SN. Muscular fitness and all-cause mortality: prospective observations. *J Physical Activity Health*. 2004;1:7–18.
55. Jurca R, Lamonte MJ, Barlow CE, Kampert JB, Church TS, Blair SN. Association of muscular strength with incidence of metabolic syndrome in men. *Med Sci Sports Exerc*. 2005;37:1849–1855.
56. Jurca R, Lamonte MJ, Church TS, Earnest CP, Fitzgerald SJ, Barlow CE, Jordan AN, Kampert JB, Blair SN. Associations of muscle strength and fitness with metabolic syndrome in men. *Med Sci Sports Exerc*. 2004;36:1301–1307.
57. Harris MI, Flegal KM, Cowie CC, Eberhardt MS, Goldstein DE, Little RR, Wiedmeyer HM, Byrd-Holt DD. Prevalence of diabetes, impaired fasting glucose, and impaired glucose tolerance in U.S. adults: the Third National Health and Nutrition Examination Survey, 1988–1994. *Diabetes Care*. 1998;21:518–524.
58. Smutok MA, Reece C, Kokkinos PF, Farmer CM, Dawson PK, DeVane J, Patterson J, Goldberg AP, Hurley BF. Effects of exercise training modality on glucose tolerance in men with abnormal glucose regulation. *Int J Sports Med*. 1994;15:283–289.
59. Banz WJ, Maher MA, Thompson WG, Bassett DR, Moore W, Ashraf M, Keefer DJ, Zemel MB. Effects of resistance versus aerobic training on coronary artery disease risk factors. *Exp Biol Med (Maywood)*. 2003;228:434–440.
60. Fluckey JD, Hickey MS, Brambrink JK, Hart KK, Alexander K, Craig BW. Effects of resistance exercise on glucose tolerance in normal and glucose-intolerant subjects. *J Appl Physiol*. 1994;77:1087–1092.
61. Ryan AS, Hurlbut DE, Lott ME, Ivey FM, Fleg J, Hurley BF, Goldberg AP. Insulin action after resistive training in insulin resistant older men and women. *J Am Geriatr Soc*. 2001;49:247–253.
62. Castaneda C, Layne JE, Munoz-Orians L, Gordon PL, Walsmith J, Foldvari M, Roubenoff R, Tucker KL, Nelson ME. A randomized controlled trial of resistance exercise training to improve glycemic control in older adults with type 2 diabetes. *Diabetes Care*. 2002;25: 2335–2341.
63. Eriksson J, Taimela S, Eriksson K, Parviainen S, Peltonen J, Kujala U. Resistance training in the treatment of non-insulin-dependent diabetes mellitus. *Int J Sports Med*. 1997;18:242–246.
64. Fenicchia LM, Kanaley JA, Azevedo JL Jr, Miller CS, Weinstock RS, Carhart RL, Ploutz-Snyder LL. Influence of resistance exercise training on glucose control in women with type 2 diabetes. *Metabolism*. 2004; 53:284–289.
65. Reynolds TH, Supiano MA, Dengel DR. Resistance training enhances insulin-mediated glucose disposal with minimal effect on the tumor necrosis factor-alpha system in older hypertensives. *Metabolism*. 2004; 53:397–402.
66. Ibanez J, Izquierdo M, Arguelles I, Forga L, Larrion JL, Garcia-Unciti M, Idoate F, Gorostiaga EM. Twice-weekly progressive resistance training decreases abdominal fat and improves insulin sensitivity in older men with type 2 diabetes. *Diabetes Care*. 2005;28:662–667.
67. Dunstan DW, Daly RM, Owen N, Jolley D, De Courten M, Shaw J, Zimmet P. High-intensity resistance training improves glycemic control in older patients with type 2 diabetes. *Diabetes Care*. 2002;25: 1729–1736.
68. Honkola A, Forsen T, Eriksson J. Resistance training improves the metabolic profile in individuals with type 2 diabetes. *Acta Diabetol*. 1997;34:245–248.
69. Cornelissen VA, Fagard RH. Effect of resistance training on resting blood pressure: a meta-analysis of randomized controlled trials. *J Hypertens*. 2005;23:251–259.
70. Kelley GA, Kelley KS. Progressive resistance exercise and resting blood pressure: a meta-analysis of randomized controlled trials. *Hypertension*. 2000;35:838–843.
71. Whelton SP, Chin A, Xin X, He J. Effect of aerobic exercise on blood pressure: a meta-analysis of randomized, controlled trials. *Ann Intern Med*. 2002;136:493–503.
72. Kelemen MH, Effron MB, Valenti SA, Stewart KJ. Exercise training combined with antihypertensive drug therapy: effects on lipids, blood pressure, and left ventricular mass. *JAMA*. 1990;263:2766–2771.
73. Stewart KJ, Effron MB, Valenti SA, Kelemen MH. Effects of diltiazem or propranolol during exercise training of hypertensive men. *Med Sci Sports Exerc*. 1990;22:171–177.
74. Stewart KJ, Bacher AC, Turner KL, Fleg JL, Hees PS, Shapiro EP, Tayback M, Ouyang P. Effect of exercise on blood pressure in older persons: a randomized controlled trial. *Arch Intern Med*. 2005;165: 756–762.

75. Weinsier RL, Schutz Y, Bracco D. Reexamination of the relationship of resting metabolic rate to fat-free mass and to the metabolically active components of fat-free mass in humans. *Am J Clin Nutr*. 1992;55: 790–794.
76. Schmitz KH, Jensen MD, Kugler KC, Jeffery RW, Leon AS. Strength training for obesity prevention in midlife women. *Int J Obes Relat Metab Disord*. 2003;27:326–333.
77. Treuth MS, Ryan AS, Pratley RE, Rubin MA, Miller JP, Nicklas BJ, Sorkin J, Harman SM, Goldberg AP, Hurley BP. Effects of strength training on total and regional body composition in older men. *J Appl Physiol*. 1994;77:614–620.
78. Ross R, Rissanen J. Mobilization of visceral and subcutaneous adipose tissue in response to energy restriction and exercise. *Am J Clin Nutr*. 1994;60:695–703.
79. Ross R, Rissanen J, Pedwell H, Clifford J, Shragge P. Influence of diet and exercise on skeletal muscle and visceral adipose tissue in men. *J Appl Physiol*. 1996;81:2445–2455.
80. Stewart KJ, Bacher AC, Turner K, Lim JG, Hees PS, Shapiro EP, Tayback M, Ouyang P. Exercise and risk factors associated with metabolic syndrome in older adults. *Am J Prev Med*. 2005;28:9–18.
81. Treuth MS, Hunter GR, Kekes-Szabo T, Weinsier RL, Goran MI. Reduction in intra-abdominal adipose tissue after strength training in older women. *J Appl Physiol*. 1995;78:1425–1431.
82. Tucker LA, Silvester LJ. Strength training and hypercholesterolemia: an epidemiologic study of 8499 employed men. *Am J Health Promot*. 1996;11:35–41.
83. Kohl HW 3rd, Gordon NF, Scott CB, Vaandrager H, Blair SN. Musculoskeletal strength and serum lipid levels in men and women. *Med Sci Sports Exerc*. 1992;24:1080–1087.
84. Manning JM, Dooly-Manning CR, White K, Kampa I, Silas S, Kesselhaut M, Ruoff M. Effects of a resistive training program on lipoprotein–lipid levels in obese women. *Med Sci Sports Exerc*. 1991;23: 1222–1226.
85. Smutok MA, Reece C, Kokkinos PF, Farmer C, Dawson P, Shulman R, DeVane-Bell J, Patterson J, Charabogos C, Goldberg AP, Hurley BF. Aerobic versus strength training for risk factor intervention in middle-aged men at high risk for coronary heart disease. *Metabolism*. 1993;42:177–184.
86. Vincent KR, Braith RW, Bottiglieri T, Vincent HK, Lowenthal DT. Homocysteine and lipoprotein levels following resistance training in older adults. *Prev Cardiol*. 2003;6:197–203.
87. Nelson ME, Fiatarone M, Morganti C, Trice I, Greenberg RA, Evans WJ. Effects of high-intensity strength training on multiple risk factors for osteoporotic fractures: a randomized controlled trial. *JAMA*. 1994; 272:1909–1914.
88. Campbell AJ, Robertson MC, Gardner MM, Norton RN, Tilyard MW, Buchner DM. Randomised controlled trial of a general practice programme of home based exercise to prevent falls in elderly women. *BMJ*. 1997;315:1065–1069.
89. Seguin R, Nelson ME. The benefits of strength training for older adults. *Am J Prev Med*. 2003;25(suppl 2):141–149.
90. Beniamini Y, Rubenstein JJ, Faigenbaum AD, Lichtenstein AH, Crim MC. High-intensity strength training of patients enrolled in an outpatient cardiac rehabilitation program. *J Cardiopulm Rehabil*. 1999;19:8–17.
91. McCartney N, McKelvie RS, Haslam DR, Jones NL. Usefulness of weightlifting training in improving strength and maximal power output in coronary artery disease. *Am J Cardiol*. 1991;67:939–945.
92. Brochu M, Savage P, Lee M, Dee J, Cress ME, Poehlman ET, Tischler M, Ades PA. Effects of resistance training on physical function in older disabled women with coronary heart disease. *J Appl Physiol*. 2002;92: 672–678.
93. Ades PA, Savage PD, Cress ME, Brochu M, Lee NM, Poehlman ET. Resistance training on physical performance in disabled older female cardiac patients. *Med Sci Sports Exerc*. 2003;35:1265–1270.
94. Pu CT, Johnson MT, Forman DE, Hausdorff JM, Roubenoff R, Foldvari M, Fielding RA, Singh MA. Randomized trial of progressive resistance training to counteract the myopathy of chronic heart failure. *J Appl Physiol*. 2001;90:2341–2350.
95. Fiatarone MA, O'Neill EF, Ryan ND, Clements KM, Solares GR, Nelson ME, Roberts SB, Kehayias JJ, Lipsitz LA, Evans WJ. Exercise training and nutritional supplementation for physical frailty in very elderly people. *N Engl J Med*. 1994;330:1769–1775.
96. Ades PA, Ballor DL, Ashikaga T, Utton JL, Nair KS. Weight training improves walking endurance in healthy elderly persons. *Ann Intern Med*. 1996;124:568–572.
97. Jette AM, Lachman M, Giorgetti MM, Assmann SF, Harris BA, Levenson C, Wernick M, Krebs D. Exercise: it's never too late: the Strong-for-Life Program. *Am J Public Health*. 1999;89:66–72.
98. Orr R, de Vos NJ, Sigh NA, Ross DA, Stavrinos TM, Fiatarone-Singh MA. Power training improves balance in healthy older adults. *J Gerontol A Biol Sci Med Sci*. 2006;61:78–85.
99. Vincent KR, Braith RW, Feldman RA, Kallas HE, Lowenthal DT. Improved cardiorespiratory endurance following 6 months of resistance exercise in elderly men and women. *Arch Intern Med*. 2002;162: 673–678.
100. Ades PA, Savage PD, Brochu M, Tischler MD, Lee NM, Poehlman ET. Resistance training increases total daily energy expenditure in disabled older women with coronary heart disease. *J Appl Physiol*. 2005;98: 1280–1285.
101. Harrington D, Coats AJ. Skeletal muscle abnormalities and evidence for their role in symptom generation in chronic heart failure. *Eur Heart J*. 1997;18:1865–1872.
102. McKelvie RS, McCartney N, Tomlinson C, Bauer R, MacDougall JD. Comparison of hemodynamic responses to cycling and resistance exercise in congestive heart failure secondary to ischemic cardiomyopathy. *Am J Cardiol*. 1995;76:977–979.
103. Oka RK, DeMarco T, Haskell WL, Botvinick E, Dae MW, Bolen K, Chatterjee K. Impact of a home-based walking and resistance training program on quality of life in patients with heart failure. *Am J Cardiol*. 2000;85:365–369.
104. McCartney N. Acute responses to resistance training and safety. *Med Sci Sports Exerc*. 1999;31:31–37.
105. Pescatello LS, Franklin BA, Fagard R, Farquhar WB, Kelley GA, Ray CA. American College of Sports Medicine Position Stand: exercise and hypertension. DOI: 10.1249/01.MSS.0000115224.88514.3A. Available at: http://www.acsm-msse.org/pt/pt-core/template-journal/msse/media/0304.pdf. Accessed February 24, 2006.
106. Harris KA, Holly RG. Physiological response to circuit weight training in borderline hypertensive subjects. *Med Sci Sports Exerc*. 1987;19: 246–252.
107. Haslam DR, McCartney SN, McKelvie RS, MacDougall JD. Direct measurements of arterial blood pressure during formal weightlifting in cardiac patients. *J Cardiopulm Rehabil*. 1988;8:213–225.
108. Gordon NF, Kohl HW, Pollock ML, Vaandrager H, Gibbons LW, Blair SN. Cardiovascular safety of maximal strength testing in healthy adults. *Am J Cardiol*. 1995;76:851–853.
109. Wenger NK, Froelicher ES, Smith LK, for the Cardiac Rehabilitation Guideline Panel. *Cardiac Rehabilitation as Secondary Prevention: Clinical Practice Guideline No. 17*. Rockville, Md: US Department of Health and Human Services, Public Health Service, Agency for Health Care Policy and Research and the National Heart, Lung, and Blood Institute; October 1995. AHCPR publication No. 96–0672.
110. American College of Sports Medicine. *ACSM's Guidelines for Exercise Testing and Prescription*. 7th ed. Philadelphia, Pa: Lippincott Williams and Wilkins; 2006.
111. American Association of Cardiovascular and Pulmonary Rehabilitation. *Guidelines for Cardiac Rehabilitation and Secondary Prevention Programs*. 4th ed. Champaign, Ill: Human Kinetics; 2004.
112. Gibbons RJ, Balady GJ, Bricker GJ, Chaitman BR, Fletcher GF, Froelicher VF, Mark DB, McCalister BD, Mooss AN, O'Reilly MG, Winters WL. ACC/AHA 2002 guideline update for exercise testing: a report of the American College of Cardiology/American Heart Association Task Force on Practice Guidelines (Committee on Exercise Testing). *Circulation*. 2002;106:1883–1892.
113. American Diabetes Association. Standards of medical care in diabetes: 2006. *Diabetes Care*. 2006;29(suppl 1):S4–S42.
114. Maron BJ, Chaitman BR, Ackerman MJ, Bayés de Luna A, Corrado D, Crosson JE, Deal BJ, Driscoll DJ, Estes NA, Araújo CG, Liang DH, Mitten MJ, Myerburg RJ, Pelliccia A, Thompson PD, Towbin JA, Van Camp SP, for the Working Groups of the American Heart Association Committee on Exercise, Cardiac Rehabilitation, and Prevention, and Councils on Clinical Cardiology and Cardiovascular Disease in the Young. Recommendations for physical activity and recreational sports participation for young patients with genetic cardiovascular diseases. *Circulation*. 2004;109:2807–2816.
115. Hlatky MA, Boineau RE, Higginbotham MB, Lee KL, Mark DB, Califf RM, Cobb FR, Pryor DB. A brief self-administered questionnaire to determine functional capacity (the Duke Activity Status Index). *Am J Cardiol*. 1989;64:651–654.

116. Blair SN, Kohl HW, Paffenbarger RS Jr, Clark DB, Cooper KH, Gibbons LW. Physical fitness and all-cause mortality: a prospective study of healthy men and women. *JAMA*. 1989;262:2395–2401.
117. Vanhees L, Fagard R, Thijs L, Staessen J, Amery A. Prognostic significance of peak exercise capacity in patients with coronary artery disease. *J Am Coll Cardiol*. 1994;23:358–363.
118. Lampert R, Cannom D, Olshansky B. Safety of sports participation in patients with implantable cardioverter defibrillators: a survey of Heart Rhythm Society members. *J Cardiovasc Electrophysiol*. 2006;17:11–15.
119. Aiello LP, Wong J, Cavallerano J, Bursell SE, Aiello LM. Retinopathy. In: Ruderman N, Devlin JT, Schneider SH, Kriska AM, eds. *Handbook of Exercise in Diabetes*. 2nd ed. Alexandria, Va: American Diabetes Association; 2002:401–413.
120. Gordon NF, Gulanick M, Costa F, Fletcher G, Franklin BA, Roth EJ, Shephard T. Physical activity and exercise recommendations for stroke survivors: an American Heart Association scientific statement from the Council on Clinical Cardiology, Subcommittee on Exercise, Cardiac Rehabilitation, and Prevention; the Council on Cardiovascular Nursing; the Council on Nutrition, Physical Activity, and Metabolism; and the Stroke Council. *Circulation*. 2004;109:2031–2041.
121. American Geriatrics Society Panel on Exercise and Osteoarthritis. Exercise prescription for older adults with osteoarthritis pain: consensus practice recommendations: a supplement to the AGS Clinical Practice Guidelines on the management of chronic pain in older adults.. *J Am Geriatr Soc*. 2001;49:808–823.
122. Feigenbaum MS, Pollock ML. Strength training: rationale for current guidelines for adult fitness programs. *Physician Sports Med*. 1997;25:44–64.
123. Hass CJ, Feigenbaum MS, Franklin BA. Prescription of resistance training for healthy populations. *Sports Med*. 2001;31:953–964.
124. Kraemer WJ, Adams K, Cafarelli E, Dudley GA, Dooly C, Feigenbaum MS, Fleck SJ, Franklin B, Fry AC, Hoffman JR, Newton RU, Potteiger J, Stone MH, Ratamess NA, Triplett-McBride T, for the American College of Sports Medicine. American College of Sports Medicine Position Stand: progression models in resistance training for healthy adults. *Med Sci Sports Exerc*. 2002;34:364–380.
125. Wilke NA, Sheldahl LM, Tristani FE, Hughes CV, Kalbfleisch JH. The safety of static-dynamic effort soon after myocardial infarction. *Am Heart J*. 1985;110:542–545.
126. Vincent KR, Vincent HK. Resistance training for individuals with cardiovascular disease. *J Cardiopulm Rehabil*. 2006;26:207–216.
127. Graves JE, Franklin BA, eds. *Resistance Training for Health and Rehabilitation*. Champaign, Ill: Human Kinetics; 2001.
128. Dingwall H, Ferrier K, Semple J. Exercise prescription in cardiac rehabilitation. In: Thow M, ed. *Exercise Leadership in Cardiac Rehabilitation*. West Sussex, England: Whurr Publishers Ltd; 2006:97–131.
129. Adams J, Cline MJ, Hubbard M, McCullough T, Hartman J. A new paradigm for post-cardiac event resistance exercise guidelines. *Am J Cardiol*. 2006;97:281–286.
130. MacDougall JD, Tuxen D, Sale DG, Moroz JR, Sutton JR. Arterial blood pressure response to heavy resistance exercise. *J Appl Physiol*. 1985;58:785–790.

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Circulation. published online July 16, 2007;
Circulation is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231

Print ISSN: 0009-7322. Online ISSN: 1524-4539