Clinical Cardiology: New Frontiers

Exercise as Cardiovascular Therapy

Roy J. Shephard, MD, PhD, DPE; Gary J. Balady, MD

For many years, cardiac physicians were strongly influenced by Thomas Hilton’s “Rest and Pain” and advocated prolonged rest for the majority of their patients. However, the past 3 decades have seen a complete revolution in this thinking, and moderate to vigorous exercise is now prescribed not only for the prevention of ischemic heart disease but also as a major component of treatment after myocardial infarction, angioplasty and coronary bypass surgery, and heart transplantation and in congenital heart disease and stable congestive heart failure.

This report defines exercise and physical activity, considering their impact on susceptibility to cardiovascular disease. It also examines the physiological effects of regular exercise, suggesting how exercise-induced changes might improve cardiac performance. It discusses the influence of the type, intensity, frequency, duration, and volume of exercise and their respective contributions to the development of a rational exercise prescription, commenting on problems of sustaining compliance and the potential dangers of excessive exercise. A final section of the article suggests possible avenues for future research.

Physical Activity, Exercise, and Fitness

To understand how physical activity and exercise fit into the model of modern cardiovascular health, it is important to understand specific terms and concepts. Physical activity has been defined as any bodily movement produced by skeletal muscles that results in energy expenditure. Exercise can be defined as a subset of physical activity that is planned, structured, repetitive, and purposeful in the sense that improvement or maintenance of physical fitness is the objective. Physical fitness includes cardiorespiratory fitness, muscle strength, body composition, and flexibility, composing a set of attributes that people have or achieve that relates to the ability to perform physical activity. Physical fitness is best assessed by measures of maximal (or peak) oxygen intake (V\text{O}_2). Many studies estimate fitness levels by measurement of either the peak work rate or MET level (where 1 MET = an energy expenditure of 1.0 kcal \cdot kg\(^{-1}\) \cdot min\(^{-1}\), or 3.5 kcal \cdot kg\(^{-1}\) \cdot min\(^{-1}\), or kcal \cdot m\(^{-2}\) \cdot s\(^{-1}\)) achieved during graded exercise tests.

When defining the amount of physical activity or exercise, an important interrelation exists between the total dose of activity and the intensity at which the activity is performed. Dose refers to the total amount of energy expended in physical activities that require repetitive muscular movement (usually expressed in kilojoules or kilocalories). Intensity can be defined in absolute or relative terms. Absolute intensity reflects the rate of energy expenditure during exercise and is usually expressed in METS, kJ \cdot min\(^{-1}\) or kcal \cdot min\(^{-1}\). Relative intensity refers to the relative percentage of maximal aerobic power that is maintained during exercise and is expressed as a percentage of maximal heart rate or a percentage of maximal oxygen intake. For example, brisk walking at 4.8 km/h, 3 mph, has an absolute intensity of approximately 4 METs. In relative terms, this intensity is considered light for a 20-year-old healthy person, but it is a hard intensity for an 80-year-old.

One can achieve that same total dose of physical activity by performing activities at a high intensity for a short duration, or at a lower intensity for a longer duration. Whether or not the health benefits are equivalent when similar doses of activity are performed at different intensities remains an area of great interest. The answer to this question has important public health and clinical implications. Recent guidelines on this topic reflect the current scientific knowledge and consensus and conclude that variations in dose and intensity will yield differing beneficial effects on fitness and cardiovascular risk factors. These may translate to different effects on cardiovascular morbidity and mortality rates.

Physical Activity and Exercise in the Prevention of Cardiovascular Disease

Epidemiologic Observations

Several population-based studies show that incremental levels of regular physical activity are inversely proportional to long-term cardiovascular mortality when controlled for the presence of other risk factors in both men and women. In studies of male college alumni, the risk of death became progressively lower as physical activity dose levels increased from an expenditure of 2.1 to 14.7 MJ/wk, 500 to 3500 kcal/wk. There was a 24% reduction in cardiovascular mortality in subjects whose energy expenditure was >8.4 MJ/wk, 2000 kcal/wk. Alumni who were initially inactive and later increased their activity levels demonstrated significantly reduced cardiovascular risk compared with those who remained inactive. In the large Nurses’ Health Study involving more...
that 73,000 middle-aged women, physical activity was inversely related to the risk of coronary heart disease and stroke. Among patients with known cardiovascular disease, a meta-analysis of 10 randomized clinical trials examining the effects of cardiac rehabilitation after myocardial infarction calculated a 24% reduction in all-cause mortality and a 25% reduction in cardiovascular mortality in the exercise rehabilitation patients compared with control subjects. No differences in nonfatal myocardial infarction were apparent.

Higher levels of physical fitness, when measured with an exercise tolerance test, are associated with a significantly lower subsequent cardiovascular mortality rate among men and women. The relative risk of coronary artery disease in physically inactive compared with active individuals is 2.0. Importantly, the relative risk for cardiovascular mortality in the least fit or least active compared with the most fit or active approaches 6.0. Paffenbarger et al have reported encouraging data that demonstrate that when habitual physical activity levels are increased, subsequent mortality is decreased relative to those who remain physically inactive. These data strongly support the need to increase physical activity and fitness levels among both women and men, with the greatest decrease of mortality rates developing among those who initially are the least fit.

The data regarding exercise intensity are much less clear than those addressing dose. There is a growing body of evidence that shows that regular moderate intensity activity (17 to 29 kJ/min, 4 to 7 kcal/min), performed by men and women of a broad age range, reduces cardiovascular mortality rates. A recent report involving 802 men (age 64 to 84 years) concludes that more intense activity (4 METs) was associated with a reduction of mortality rates among male Harvard alumni.

Possible Biological Mechanisms for Observed Benefits
The specific mechanisms by which physical activity and physical fitness decrease mortality rates have not been well elucidated. Physical activity has been associated with favorable modifications of cardiovascular disease risk through a reduction in obesity, improved distribution of body fat, and lower incidence of non–insulin-dependent diabetes. Regular exercise also yields a modest but beneficial effect on blood pressure and lipoprotein profiles. However, the beneficial effect of physical activity cannot be accounted for solely by means of risk factor reduction, since the association with reduced mortality rates is independent of other coronary risk factors.

Exercise and Risk Factor Modification
Individuals who engage in regular physical activity have a lower prevalence of cardiovascular risk factors. This is not surprising because exercise has been found to yield beneficial effects on several risk factors. Accordingly, exercise is considered an important adjuvant therapy in risk factor modification.

Hypertension
Two cohort studies have demonstrated that regular physical activity prevents the development of hypertension. In addition to preventing hypertension, regular exercise has been found to lower blood pressure. In mildly hypertensive men, short-term physical activity decreased blood pressure for 8 to 12 hours after exercise, and average blood pressure was lower on exercise than on nonexercise days. In hypertensive black men, moderate physical activity performed for 16 to 32 weeks resulted in a decrease in diastolic blood pressure, which was sustained even after reduction in antihypertensive medications. In addition, there was a significant decrease in left ventricular hypertrophy as early as 16 weeks after the initiation of exercise.

Diabetes Mellitus
Physical activity has beneficial effects on both glucose metabolism and insulin sensitivity. These include increased sensitivity to insulin, decreased production of glucose by the liver, larger number of muscle cells that utilize more glucose than adipose tissue, and reduced obesity.

Obesity
Exercise training appears to be an important contributor to weight loss, although the effect of exercise is quite variable. Most controlled exercise training studies show only modest weight loss (≈2 to 3 kg) in the exercise group. When diet is added to exercise programs, the average weight loss is 8.5 kg. A well-controlled, 1-year randomized trial that included 231 subjects demonstrated a significant 8.7-kg weight loss, most of which was body fat, in the exercise and diet intervention group and a significant 5.1-kg weight loss in the diet-only group. Those in the control group increased their weight by an average of 1.7 kg. These data strongly support the role of both exercise and diet in weight loss programs. Body composition and fat distribution are linked to cardiovascular mortality and are improved by exercise. Physically active men and women have a more favorable waist-to-hip ratio (<0.9) than do sedentary individuals.

Lipids
The effect of exercise on lipid levels is an area of active research. There is much variability in the results of exercise/lipid-lowering studies, at least in part because of the heterogeneity of the study methods, populations, exercise interventions, and the use of adjuvant interventions such as diet or pharmacological lipid-lowering agents. A meta-analysis of 95 studies, most of which were not randomized controlled trials, concluded that exercise leads to a reduction of 6.3% in total cholesterol, 10.1% in LDL cholesterol, and 13.4% in cholesterol/HDL cholesterol and 5% increase in HDL cholesterol. It appears that the training intensities required to yield modest improvements in lipids are not as high as those that lead to improvements in fitness levels, as HDL appears to increase across a broad spectrum of exercise intensities. A recent randomized controlled trial of moderate-intensity exercise (equivalent to brisk walking of 16 km/wk, 10 miles/wk), Step 2 AHA diet, and the combination of diet plus exercise was conducted on 180 postmenopausal women and 197 middle-age men. Among those in the diet-plus-exercise
group, an 8% to 12% reduction in LDL and a −2% to 2% change in HDL levels in women and men, respectively, were noted after 1 year. LDL changes were greatest in the diet plus exercise group.32

As estrogen causes an increase in HDL cholesterol, studies regarding women are confounded by menopausal status and estrogen use, which are frequently not reported. A recent study examined the effects of vigorous exercise on HDL cholesterol in women runners.34 HDL cholesterol levels increased with increasing amounts of exercise and continued to rise even in women who ran >64 km/wk. This dose-response relation persisted in premenopausal and postmenopausal women as well as in those receiving oral contraceptives and estrogen replacement therapy. Although the above studies suggest an improvement in lipid profile with exercise training, the effects are quite modest. These improvements may have a favorable effect on cardiovascular risk; however, exercise is unlikely to normalize cholesterol levels in patients with genetically based lipid disorders.

**Thrombosis**
Emerging evidence suggests that exercise training favorably affects the fibrinolytic system. Strenuous endurance exercise for 6 months in healthy older patients resulted in a significant improvement in hemostatic parameters, with a reduction in plasma fibrinogen levels of 13%, an increase in mean tissue plasminogen activator of 39%, an increase in active tissue plasminogen activator of 141%, and a reduction of plasminogen activator inhibitor-1 of 58%.35 Other studies have shown favorable effects on fibrinolytic enzymes after exercise training in younger subjects36 and in patients after myocardial infarction.37 Acute and chronic exercise affect platelet activation. Platelet activation is important in the pathophysiological mechanisms of unstable coronary syndromes and acute myocardial infarction. After acute strenuous exercise of similar duration and intensity, platelet activation and hyperreactivity were increased in sedentary subjects but were unchanged in physically fit subjects.38 After 12 weeks of moderate-intensity exercise in middle-aged, overweight, mildly hypertensive men, secondary platelet aggregation was reduced by 52% compared with a 17% decrease in the control group.39 Thus it appears that acute exercise can lead to increased platelet activity, especially in sedentary individuals, but regular exercise may abolish or improve this response.

**Endothelial Function**
The vascular endothelium plays an important role in the regulation of arterial tone and local platelet aggregation, in part, through the release of endothelium-derived relaxing factor. Endothelium-derived relaxing factor release is stimulated by various mechanisms, including the rise in shear stress associated with acute and chronic increases in blood flow.40 Endothelium-dependent dilation is impaired in patients with coronary atherosclerosis and in patients with coronary risk factors, including hypercholesterolemia, diabetes mellitus, cigarette smoking, and hypertension.41 Emerging evidence suggests that exercise improves endothelial function. In animal studies, treadmill exercise training leads to improvement in endothelium-dependent vasodilation and increases in the gene expression for nitric oxide synthase. Studies involving young, healthy army recruits and patients with heart failure demonstrate improved brachial artery nitric oxide–dependent, flow-mediated dilation after exercise training.42 No study has yet examined the effect of exercise training on coronary artery endothelial function in humans.

**Autonomic Function**
The balance between sympathetic and parasympathetic activity modulates cardiovascular activity. Enhanced sympathetic nervous system activity appears to be associated with an increased risk of cardiac events, particularly in those patients with known heart disease. Using measures of heart rate variability, a well accepted noninvasive technique to assess autonomic tone, cross-sectional studies of healthy men43 reported higher parasympathetic activity among those who were physically trained and fit compared with those who were not. Whether or not exercise affects autonomic tone among patients with cardiovascular disease is unclear. However, improved measures of heart rate variability with exercise training have been reported in patients with chronic heart failure44 and in patients after myocardial infarction.45

**Exercise Training Outcomes in Persons With Cardiovascular Disease**
Regular endurance or resistance training results in specific changes in the muscular, cardiovascular, and neurohumoral systems that lead to improvement in functional capacity and/or strength. These changes are referred to as the training effect and allow an individual to exercise to higher peak work rates with lower heart rates at each submaximal level of exercise. Exercise training at moderate intensity, 3 to 5 times per week, leads to marked improvements in peak fitness levels after 8 to 10 weeks among patients with heart disease, much as in healthy individuals.2 To date, there are more than 20 published studies that have evaluated the efficacy of exercise training among patients with impaired left ventricular function. Improvements of 18% to 25% in peak oxygen intake and 18% to 34% in peak exercise duration have been attained.6 Subjective symptoms, activity profile, and quality-of-life scores are better after training as well.6

Several investigators have demonstrated a diminution of the ischemic response at a given submaximal work rate in cardiac patients after training. Moreover, several provocative studies have reported a decrease in the ischemic response—for example, angina, ST-segment depression,46 nuclear and positron emission tomography scanning perfusion defects47,48—at a given heart rate–blood pressure product after training compared with the pretrained state. Improvement in myocardial contractility in dysfunctional myocardial segments has been reported after exercise training as well.49 These findings suggest that there is an improvement in myocardial oxygen supply (ie, coronary blood flow) at a given level of myocardial oxygen demand. There are many mechanisms or combinations thereof that may explain these findings. Pathological studies in animals reveal that endurance training causes an increase in the size of the superficial coronary arteries and an increased myocardial capillary density. Recently, Belardinelli et al49 has reported an increase in coronary artery collaterals in humans after exercise training.
However, other investigators have not noted these latter changes. Importantly, 3 studies to date have demonstrated angiographic evidence of regression of atherosclerosis as well as reduction in the progression of atherosclerosis among patients who were actively involved in a multifactorial risk reduction program that includes exercise training.47,48,50 However, the observed absolute measures of atherosclerotic change were small. Accordingly, improved myocardial perfusion may be due to changes in coronary vasomotor activity. Recent data suggest that the beneficial effects of exercise training on myocardial perfusion appear to yield important benefits in clinical outcome, including a significant reduction in adverse cardiac events.50,51

The time course during which the above changes take place varies with respect to the specific variable and the specific study. Improvements in functional capacity and myocardial perfusion have been demonstrated to occur as early as 8 weeks after initiation of exercise training.49 Conversely, atherosclerotic regression has been observed after 1 year of exercise47 but has not been studied over shorter periods of training. At this time, it is fair to state that the minimum duration of exercise training that is required to yield the many beneficial effects outlined above is not known and likely differs for each variable.

### Physiological Effects of Regular Exercise
From the viewpoint of the cardiac physician, regular exercise has both indirect and direct effects on the cardiovascular system, both of which can enhance functional capacity and reduce the likelihood of cardiac problems. The indirect benefits may be realized at intensities of effort that have little direct effect on myocardial function. Table 1 outlines the benefits observed with regular exercise.

#### Indirect Effects
Important indirect benefits of exercise include a reduction in cardiovascular risk factors (as discussed above), a strengthening of the skeletal muscles, and a change in certain aspects of lifestyle, particularly a reduction of stress.

#### Muscle Strengthening
During vigorous effort, a high pressure is developed within contracting muscle groups, and this tends to occlude muscle blood flow; after-loading of the heart is increased, and this in turn limits cardiac ejection fraction and stroke volume. Occlusion of the intramuscular vessels begins when the muscles are contracting at ≈15% of their maximal voluntary force, and it becomes complete at some 70% of maximal force.52 In many patients with heart disease, peak muscle force has been weakened by bed rest and/or administration of corticosteroids, and if muscle strength can be enhanced by appropriate resistance exercise, there will be a corresponding improvement in peak cardiac performance. Initially, gains of strength reflect improved coordination of muscle contraction, but as an exercise program continues, there is usually some hypertrophy of the active muscle.

#### Lifestyle Change
The adoption of regular physical activity encourages other advantageous changes of lifestyle, with a resulting reduction in cardiac risk factors. However, benefits are relatively small. In the case of cigarette smoking, endurance athletes are usually nonsmokers, and involvement in endurance activity can contribute to the process of smoking cessation. Abstinence from cigarettes often precedes involvement in physical activity, both characteristics reflecting a health-conscious personality.53 For a similar reason, many athletes consume large quantities of both water-soluble (C) and fat-soluble (E) vitamins, with potential benefit to the vascular system. The possible role of exercise as an appetite suppressant remains controversial.54,55 An acute bout of exercise can lead to a temporary rise in both blood sugar and blood leptin levels, with a short-term suppression of appetite54,56 and possibly an increased thermic effect during subsequent ingestion of food. Thus if exercise is performed just before a meal, it may be helpful both in reducing food intake and in facilitating energy expenditure. In a more long-term perspective, some investigators argue that appetite increases to match the increase in energy expenditure.54 whereas others maintain that an exercise program does not necessarily enhance food intake.57 Weight loss may be promoted by a prolonged elevated postexercise oxygen consumption,58 and in 1 recent study of obese postcoronary patients this effect was large enough to yield a substantial reduction of body fat without specific dieting.59

Some forms of physical activity provide relaxation, with favorable implications for cardiac health;60 indeed, many people claim that the reason that they exercise is because it makes them “feel better.” On the other hand, a strong desire to win a game such as squash may provoke sudden death in a coronary-prone individual,61 and obsessive efforts to fill an

### TABLE 1. Possible Biological Mechanisms for Exercise-Induced Reductions in All-Cause and Cardiac Mortality

<table>
<thead>
<tr>
<th>Cardiovascular influences</th>
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<tbody>
<tr>
<td>Reduction of resting and exercise heart rate</td>
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<tr>
<td>Reduction of resting and exercise blood pressure</td>
</tr>
<tr>
<td>Reduction of myocardial oxygen demand at submaximal levels of physical activity</td>
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<tr>
<td>Expansion of plasma volume</td>
</tr>
<tr>
<td>Increase in myocardial contractility</td>
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<tr>
<td>Increase in peripheral venous tone</td>
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<tr>
<td>Favorable changes in fibrinolytic system</td>
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<tr>
<td>Increased endothelium-dependent vasodilatation</td>
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<tr>
<td>Increased gene expression for nitric oxide synthase</td>
</tr>
<tr>
<td>Enhanced parasympathetic tone</td>
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<tr>
<td>Possible increases in coronary blood flow, coronary collateral vessels, and myocardial capillary density</td>
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</tbody>
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<table>
<thead>
<tr>
<th>Metabolic influences</th>
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<tbody>
<tr>
<td>Reduction of obesity</td>
</tr>
<tr>
<td>Enhanced glucose tolerance</td>
</tr>
<tr>
<td>Improved lipid profile</td>
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</tbody>
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<table>
<thead>
<tr>
<th>Lifestyle influences</th>
</tr>
</thead>
<tbody>
<tr>
<td>Decreased likelihood of smoking</td>
</tr>
<tr>
<td>Possible reduction of stress</td>
</tr>
<tr>
<td>Short-term reduction of appetite</td>
</tr>
</tbody>
</table>

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exercise prescription under difficult circumstances can augment rather than reduce stress.

**Direct Benefits**

The direct cardiovascular benefits of regular physical activity include a slowing of resting heart rate, a reduction of blood pressure, an increase of peripheral venous tone, an expansion of plasma volume, and an increase of myocardial contractility. There may also be an increase of coronary blood flow, and an increase in the threshold for myocardial fibrillation.

**Resting Bradycardia**

A decrease in resting heart rate is perhaps the most obvious manifestation of regular physical activity. Indeed, waking pulse data provide a useful simple index of the response to training. Underlying mechanisms include an altered autonomic balance and an increase of stroke volume (below). There is an increase of parasympathetic nerve activity, possibly reflecting a resetting of the arterial baroreceptors.62 The intrinsic rate of contraction of the atria is also reduced, and there may be a reduced drive from peripheral chemoreceptors, secondary to a strengthening of the skeletal muscles.63 Finally, there may be a downregulation of β-adrenergic receptors in the myocardium.64

Training induces a parallel reduction of heart rate during submaximal exercise. Practical implications include (1) an increase in cardiac reserve and thus a boosting of functional capacity, (2) a decrease in double product at any given rate of working, thus reducing the likelihood of myocardial ischemia, and (3) a lengthening of the diastolic phase of the cardiac cycle, facilitating myocardial perfusion.

**Reduction of Blood Pressure**

Resting blood pressure and blood pressure at any given rate of exercise are lower after training, this trend being augmented by a strengthening of the skeletal musculature; however, pressures remain unchanged at a fixed fraction of maximal oxygen intake. Afterloading of the left ventricle is reduced, allowing an increase of ejection fraction and stroke volume. The peak cardiac output is thus augmented, with an associated gain in functional capacity. Further, at any given rate of submaximal exercise, the lower systolic pressure yields a corresponding reduction in double-product and thus reduces the risk of myocardial ischemia.

**Increased Peripheral Venous Tone**

Training induces an increased peripheral venous tone.65 This increases central blood volume and thus ventricular preload; cardiac stroke volume is increased, and the likelihood of hypotension after a bout of exercise is reduced. Ischemic ST-segment depression and ventricular fibrillation can be precipitated by the sudden fall in blood pressure at the end of exercise. The increase in venous tone helps to limit this problem, although the main remedies are a substantial “cool-down” of light exercise and the avoidance of standing in a hot shower area immediately after vigorous physical activity.65a

**Plasma Volume Expansion**

An expansion of plasma volume is an early response to training, probably mediated by adjustments in the renin/aldosterone system. Ventricular preloading is increased, contributing to the increase of cardiac stroke volume in the trained individual. However, there may be an associated decrease in the hemoglobin content of unit volume of blood, so that oxygen transport per liter of cardiac output is unchanged or even diminished.66

**Increased Myocardial Contractility and Stroke Volume**

Training induces some increase in myocardial contractility.67 This contributes to the increase in cardiac stroke volume. The increase of myocardial contractility boosts the oxygen consumption of the myocardium. However, it also reduces the average ventricular dimensions, reducing wall tension and thereby facilitating perfusion of the critical endocardial zone by perforating branches of the coronary artery.

Training may increase cardiac stroke volume by 20% or more, both at rest and during vigorous exercise. As discussed above, mechanisms include an increase of preloading (caused by increased peripheral venous tone and plasma volume expansion) and a reduction of afterloading (strengthening of the skeletal muscles and a reduction of systolic pressures). In addition, there is an increase of myocardial contractility and (if training is strenuous and prolonged) a ventricular hypertrophy. The enlarged heart of the endurance-trained athlete was once considered a dangerous pathology, but it is now recognized as a normal and desirable physiological response to repeated bouts of endurance exercise.68 The increase of stroke volume leads to a roughly proportional increase in functional capacity. A given physical task can thus be performed at a smaller fraction of the individual’s maximal oxygen intake; the lower heart rate reduces double product and thus the oxygen consumption of the myocardium, and any tendency to myocardial ischemia is decreased. Treadmill training can increase the ventricular fibrillation threshold, although the mechanism underlying this change remains unknown.69

**Principles of Exercise Prescription**

As with pharmacological therapy, exercise requires a prescription, with a consideration of appropriate dosage and possible side effects. Nevertheless, for most sedentary people, any physical activity is better than none, and the prognosis is substantially better for those who begin to exercise than for those who do not. It may thus be unnecessary and even counterproductive to insist on a detailed clinical and laboratory examination, together with fitness testing before exercise is begun. Specific guidelines regarding medical screening and evaluation before initiating a moderate-to-vigorous exercise training program are provided in detail by the American Heart Association70,71 and the American College of Sports Medicine.72 The health of older adults may be quite well served if they perform a little more exercise than the previous week, incorporating this activity into their normal daily lives, for example walking to the store and gardening with hand tools. Assuming that a person feels no more than pleasantly tired a few hours after such exercise, then the aim should be to do a little more in each successive week until the desired level of fitness is attained.

More specific recommendations concerning the type, intensity, frequency, and duration of exercise are provided...
 Resistance training should be performed to cover most of the major muscle groups of the body.

**Intensity**

For many years, those prescribing exercise were strongly influenced by the views of Karvonen and associates, limited studies on university students suggested that aerobic training was induced at a heart rate of 150 bpm but that a heart rate of 135 bpm had no training effect. These observations gave rise to the dogma that the target intensity of effort needed to induce an aerobic training response corresponded to 60% to 70% of the individual’s maximal oxygen intake. More recent data from the Cooper Clinic have shown that the largest reduction in overall mortality occurs on moving from the lowest to the next lowest quintile of fitness. Thus it is now suggested that (1) sedentary older adults can enhance aerobic fitness by exercising at intensities as low as 40% of maximal oxygen intake, and (2) some health benefits are realized even if the intensity of effort is insufficient to augment aerobic power. It is further argued that attempts to reach the “target zone” on first recruitment lead to discouragement through discomfort, injury, or lack of success; however, negative reactions are much less likely if a program is initiated at a low intensity. The current initial recommendation is thus for a moderate intensity of effort such as brisk walking.

In terms of resistance training, the intensity of effort can be prescribed relative to the 1-repetition (1-RM) maximal voluntary force. Individual contractions should be made at 50%, later progressing to 60% of the 1-RM value. Initial intensities as low as 30% 1-RM can be used in more frail or older individuals. One-three sets of 8 to 15 repetitions should be undertaken to exercise the front and back of each major muscle group. Thus attention should be directed to movement about each of the major joints, including hip flexion and extension, knee flexion and extension, ankle dorsiflexion and plantar flexion, shoulder flexion and extension, and elbow flexion and extension. In the absence of resistance equipment, exercises for the same range of joints can be improvised using inner tubes and elastic bands, cuff and hand weights, free weights and dumb-bells, and wall pulleys. Individual contractions should not be held for more than 5 to 6 seconds to avoid a large increase in cardiac afterloading. Such training should be performed at least twice per week.

**Frequency**

Aerobic exercise should be performed on most days of the week. In the early days of cardiac rehabilitation, as many as 3 sessions per week may be undertaken at a cardiac rehabilitation center under close medical supervision. However, the time involved in travel to and from such a center makes this an impractical long-term arrangement for people living in large cities. The supervised sessions can thus be tapered, first to once per week, and then to once per month, with the completion of an “exercise log” to encourage unsupervised but prescribed exercise to a total of at least 5 sessions per week. Fitness gains can probably be maintained by completing at least 3 sessions per week. It may be possible to build much of the required activity into the daily routine—for example, a walk to and from a commuter rail station; in any

### TABLE 2. Exercise Prescription for Endurance and Resistance Training

<table>
<thead>
<tr>
<th>Endurance training</th>
<th>3–5 d/wk</th>
<th>55%–90% maximum HR or 40%–85% maximum VO₂ or HRR</th>
</tr>
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<tbody>
<tr>
<td>Frequency</td>
<td></td>
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</tr>
<tr>
<td>Intensity</td>
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<tr>
<td>Duration</td>
<td>20–60 min</td>
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<tr>
<td>Modality</td>
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<tr>
<td>Lower extremity</td>
<td>Walking</td>
<td></td>
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<tr>
<td>Upper extremity</td>
<td>Rowing</td>
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<tr>
<td>Combined</td>
<td>Arm ergometry</td>
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<tr>
<td></td>
<td>Cross-country ski machine</td>
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<td></td>
<td>Combined arm/leg cycle</td>
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<tr>
<td></td>
<td>Swimming</td>
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<tr>
<td></td>
<td>Aerobics</td>
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<table>
<thead>
<tr>
<th>Resistance training</th>
<th>2–3 d/wk</th>
<th>1–3 sets of 8–15 RM for each muscle group</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Intensity</td>
<td></td>
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</tr>
<tr>
<td>Modality</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lower extremity</td>
<td>Legs extensions, curls, presses</td>
<td></td>
</tr>
<tr>
<td>Upper extremity</td>
<td>Biceps curls</td>
<td></td>
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<tr>
<td></td>
<td>Triceps extensions</td>
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<tr>
<td></td>
<td>Bench/overhead presses</td>
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<tr>
<td></td>
<td>Lateral pulldowns/raises</td>
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<td></td>
<td>Benchovers/arded rowing</td>
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</tbody>
</table>

**Modalities listed here are not all-inclusive. Maximum heart rate (HR) indicates 220 minus age or peak HR on exercise test; VO₂, measured oxygen intake; RM, maximum number of times a load can lifted before fatigue. HRR=(Peak−Resting HR)×Percent+Resting HR.**

below, and a summary of the exercise prescription is provided in Table 2.

**Type**

The prescription should include both aerobic and resistance exercise. Initially, the preferred mode of aerobic exercise is fast walking, progressing to jogging. Several reasons govern this choice: (1) the energy cost of walking varies little from one person to another, so that the desired dose of exercise can be specified relatively precisely in terms of a distance to be covered within a specified time, (2) the activity is familiar to everyone and can be built into the normal day, and (3) there is no need for special equipment, clothing, or experience. As physical condition improves, and the individual becomes familiar with the sensations associated with aerobic training, other large muscle activities—for example, swimming, cycling, rowing, cross-country-skiing, and aerobic dance—can be introduced to provide variety. The energy costs for most of these activities show a substantial interindividual variation, and the intensity of effort must be monitored in terms of heart rate (complicated by the administration of β-blocking agents) or ratings of perceived exertion.

Resistance exercise is necessary to counter the muscle atrophy induced by aging, bed rest, and administration of corticosteroids. A variety of 8 to 10 muscle-resisted activities should be performed to cover most of the major muscle groups of the body.
event, such regular exercise is not easily forgotten or postponed. Muscle hypertrophy has a relatively slow acute time course, and the current recommendation is that muscles are best strengthened by at least 2 sessions of resistance exercise per week.

**Duration**

Within limits, there is an inverse relation between the intensity of aerobic effort and the required minimum duration of exercise sessions. On the basis of the currently recommended intensity of exercise, a minimum of 30 minutes of exercise per day is required. Sedentary people initially find difficulty in sustaining even moderate activity for 30 minutes, and recent recommendations suggest that an almost equal benefit can be obtained if the activity session is split into 2 or even 3 parts.9

**Total Energy Expenditure**

As discussed earlier, many of the benefits of exercise depend in part on the total volume of energy expended (dose). When prescribing everyday activities, it is thus helpful to know their approximate energy cost. Such information allows an assessment of both the intensity of effort and the cumulative energy expenditure. The energy cost of most activities depends on both the body mass of the individual and the pace of the activity. The issue of weight can be circumvented by using MET units. However, the pace must be specified even for something as simple as a walking prescription—for example, a recommended distance to be covered in a specified time. Fine tuning of the prescription, in the face of psychosocial stressors or adverse environmental conditions, can then be based on such markers as perceptions of exertion, perceptions of ventilation, or (in those with a normal heart rate response to exercise) the immediate postexercise heart rate.

**Exercise in Patients With Cardiovascular Disease**

Much data have been accumulated regarding exercise training in patients with cardiovascular disease, specifically those with coronary artery disease, those with heart failure caused by left ventricular systolic dysfunction, and those after coronary artery bypass surgery.74 Very limited data are available regarding patients with valvular disease. Patients with cardiovascular disease should undergo medical evaluation before initiating a regular exercise program of moderate to vigorous intensity. An exercise tolerance test should be performed to establish a safe and effective exercise intensity, whereby 40% to 70% of heart rate reserve (peak exercise heart rate minus resting heart rate) is added to resting heart rate (Table 2). This yields the training heart rate range for moderate intensity exercise. Further details regarding the exercise prescription and monitoring in these patients is described in detail elsewhere.70,75

**Encouraging Compliance**

Motivation remains a major challenge for cardiovascular preventive programs. Often, initial recruitment from a sedentary but apparently healthy population is no greater than 30% to 40%. As many as a half of those recruited to a specific program were previously exercising elsewhere. Moreover, as many as a half of those who are recruited are no longer compliant 6 months later. The usual complaint is a “lack of free time” or a “lack of equipment and facilities.” At first inspection, these complaints may seem unreasonable, but nevertheless the patient has judged that the perceived opportunity costs of the proposed exercise are too great relative to the potential rewards.

Much motivational research is at present concentrated on the “stages of change” hypothesis.76 Concerted and continued effort is needed to evaluate and move each patient toward the adoption of regular exercise. Health care providers may foster this progression using strategies, such as: (1) an increase in the immediacy of rewards by emphasizing current gains in the quality of life rather than focusing on the postponement of chronic disease and death (which may be many years distant) and (2) a decrease in the opportunity costs of physical activity by emphasizing everyday pursuits, such as rapid walking to the store or the station, things that require no medical examination, no preliminary travel, no special clothing, no special equipment, and no expensive club membership.

**Risks of Exercise**

There are now clear guidelines as to the need for preliminary clinical examination, contraindications to exercising, and indications to halt an exercise or test session.71,72 The risk of an adverse coronary event or death during exercise is low. Each year 0.75 and 0.13 per 100 000 young male and female athletes77 and 6 per 100 000 middle-aged men die during vigorous exertion.78 Studies in Finnish men suggest the incidence for all types of exercise is 1 per 11 million hours at age 20 to 39, 1 per 1.3 million at age 40 to 49, and 1 per 900 000 at age 60 to 69; however, episodes are extremely rare in women at all ages.78a Among patients in cardiac rehabilitation programs, who are carefully screened and supervised, the incidence of myocardial infarction has been reported to be 1 per 294 000 person-hours, and the incidence of death was 1 per 784 000 person-hours.79 There is also evidence that heavy exertion may trigger acute myocardial infarction. Several studies78a,80,81 have found that the relative risk of myocardial infarction within 1 hour after strenuous physical exertion was 2 to 6 times greater than that of patients who were sedentary or less active during that hour. However, the risk was inversely related to the amount of leisure time physical activity performed by the subjects. Thus the more active the individual, the lower the risk for development of acute myocardial infarction during strenuous exertion.

There is some evidence that in healthy persons, very prolonged exercise, such as participation in a triathlon, can cause myocardial fatigue with a temporary depression of myocardial function. However, complete recovery appears to occur over a few days, with no evidence of permanent harm.82,83 Questions have been raised about possible but detrimental effects of exercise on left ventricular remodeling and systolic function, particularly among those with left ventricular dysfunction early after anterior myocardial infarction.84 However, several randomized controlled trials of moderate to high intensity exercise training patients after large myocardial infarction have not demonstrated adverse effects on regional wall motion, left ventricular systolic function, or left ventricular chamber dimensions after several months of exercise.85,86
Despite concerns that excessive exercise may precipitate muscle injury and sudden death, the main risk for the sedentary person, and in particular for those with established cardiac disease, is that the volume of activity undertaken will be too small. Both in health and in disease, the overall prognosis is better for the exerciser than for the sedentary person.

**Avenues of Future Research**
The prediction of future trends is usually hazardous, and often the authors of such predictions are quickly proven to be wrong. Nevertheless, we may suggest several areas that seem profitable topics for further investigation.

**Sex Differences**
How far are recently alleged sex differences in the nature of cardiac disease and its treatment a real phenomenon? If real, is the explanation a biological influence such as a difference in hormonal milieu, or is there a sociocultural explanation (for instance, differences in habitual patterns of physical activity, demands of domestic life, and willingness to accept chronic ill-health)?

**Appropriate Dose of Exercise**
Can a meta-analysis be undertaken to put together ineffective individual attempts at determining an appropriate dose of physical activity in men and women of various ages and in various initial states of health? In particular, is there a minimum threshold intensity and volume of activity, or is there some benefit with even a minimal increase in energy expenditure?

**Adjuvants to Exercise**
How does a given dose of exercise interact with various adjuvant treatments such as a restriction of total energy intake or administration of supplements of vitamins C and E? Can excessive exercise initiate endothelial activation, and if so, how does this impact on the risk of cardiovascular disease?

**Quality of Life Issues**
There is a need to compare the effectiveness of exercise relative to alternative treatments, such as surgery or pharmacotherapy, in terms not only of costs, but also the impact on the quality-adjusted life expectancy of the individual. Such analyses will likely stimulate research on the targeting of exercise interventions to those who will benefit most from a given type of physical activity, with an identification of those who will react negatively to exercise (for example, identifying the incipient cardiac catastrophe).

**Motivation and Lifestyle Activities**
Motivation to an adequate level of physical activity will remain a major challenge to researchers in the context of cardiovascular prevention. There will be a growing interest in evaluating alternative approaches to treatment. Physicians may be asked to move from outpatient clinics to exercise facilities, where their advice may be more effective. Attention will also focus on the negative aspects of the medicalization of moderate physical activity, on the opportunity costs of traveling to specialized facilities, and on the possibility of meeting the energy requirements of good health by incorporating physical activity into normal daily life.

**Conclusions**
A recent editorial concluded that a physically active lifestyle may be public health's best buy. There is an urgent need to translate this assessment into practical implementation that will increase the physical activity habits of our patients—both those who are sedentary but ostensibly healthy, and those who have already developed clinical manifestations of cardiac disease.

**Acknowledgments**
Dr Shephard’s studies are supported in part by grants from the Defense and Civil Institute of Environmental Medicine, Toronto, and the Toronto Rehabilitation Center.

**References**


Exercise as Cardiovascular Therapy


Key Words: fitness ischemic heart disease physical activity prevention rehabilitation risk factors training.
Exercise as Cardiovascular Therapy
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Circulation. 1999;99:963-972
doi: 10.1161/01.CIR.99.7.963

Circulation is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231
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Print ISSN: 0009-7322. Online ISSN: 1524-4539

The online version of this article, along with updated information and services, is located on the World Wide Web at:
http://circ.ahajournals.org/content/99/7/963

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