5 Cardiac Rehabilitation

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Epidemiology of Heart Disease

Cardiac disease is a leading cause of morbidity and mortality in the adult population in the United States. The rates of morbidity and mortality from cardiac disease have been steadily declining owing to more aggressive management and public heath awareness. Still, the death rate of coronary artery disease (CAD) was 228.1 per 100,000 population in 1970, and 94.9 per 100,000 in 1994. CAD is also one of the main causes of disability in the United States, with an estimated 7.9 million Americans age 15 years and older with disabilities from cardiovascular conditions in 1991–1992, representing approximately 19% of disabilities from all conditions. Cardiac disease also accounts for a large portion of the total health care expenditures. In 1992, there were 3.9 million hospital admissions, including 2.1 million hospital admissions for myocardial infarction (MI), 800,000 admissions for congestive heart failure (CHF), and 550,000 admissions for arrhythmias. Procedures are also a large part of the hospitalizations, with more than 1 million cardiac catheterizations and 300,000 coronary artery bypass grafts (CABG) performed.

Additionally, new technologies and advances in care of end-stage CHF, transplant, and implantable devices have led to ever increasing numbers of patients with cardiac disease who can benefit from rehabilitation services. The survival from acute events and the widespread use of surgical procedures also has led to an ever increasing number of individuals with dual disability as well, with CAD, CHF, stroke, spinal cord injury, peripheral vascular disease, or other traditional rehabilitation diagnoses as comorbidi-

ties. A good understanding of the basic principles in management of cardiac rehabilitation will help to care for these patients in the rehabilitation setting.

Types of Heart Disease

There are generally four types of cardiac disease that will commonly be encountered by the practicing physiatrist.

1. Because of protocols and improvement in acute management, cardiac rehabilitation of the post-MI patient is now usually handled in an acute 3- to 5-day hospital stay, followed by outpatient rehabilitation.
2. Post-surgical patients, including those who have had CABG, valve replacement, cardiac defect repairs, and devices implanted (automatic internal cardiac defibrillators, etc.), usually will have a smooth and uncomplicated course. Advances in surgery have also made CABG less invasive for many (minimally invasive CABG, off-pump CABG, and robotic surgery are just a few new techniques), but have also expanded the populations to whom these interventions are being offered. This can increase the risk of complications postoperatively in more debilitated patients, and the presence of comorbidities and the possibility of a long, debilitating postoperative course is increased, leading to the need for more intensive rehabilitation interventions.
3. Unlike in the past, the patient with severe CHF or severe arrhythmias is now being referred for cardiac rehabilitation. With appropriate precautions and monitoring, rehabilitation can be very successful in these populations.
4. Finally, the population of transplant patients has their own unique physiology and issues, which make the services of rehabilitation especially helpful in that population.

All of these different populations will be discussed separately in later portions of this chapter.

Overview of Cardiac Rehabilitation

Unfortunately, although rehabilitation services are often available for patients who are eligible for cardiac rehabilitation, only 10–15% of the 1 million survivors of acute MI go on to take part in a cardiac rehabilitation program. The basic goals of cardiac rehabilitation are to restore and improve cardiac function, reduce disability, identify and improve cardiac risk factors, and increase cardiac conditioning. A cardiac rehabilitation program achieves these goals through a program of education, behavior modification, secondary prevention, and exercise. A program of rehabilitation may allow an older debilitated individual to resume activities of normal life without significant cardiac symptomatology. Each of the different types of

Table 1
Coronary Artery Disease Risk Factors

Reversible risks	*Irreversible risks*
• Sedentary lifestyle	• Age
• Cigarette smoking	• Male gender
• Hypertension	• Family history of premature CAD
• Low HDL cholesterol	(before age 55 in a parent or
(<0.9 mmol/L [35 mg/dL])	sibling)
• Hypercholesterolemia	• Past history of CAD
(>5.20 mmol/L [200 mg/dL])	• Past history of occlusive
• High lipoprotein A	peripheral vascular disease
• Abdominal obesity	• Past history of cerebrovascular
• Hypertriglyceridemia	disease
(>2.8 mmol/L [250 mg/dL])	
• Hyperinsulinemia	
• Diabetes mellitus	

CAD, coronary artery disease; HDL, high-density lipoprotein.

cardiac disease lend themselves to a different form of rehabilitation, and the benefits of cardiac conditioning and improved survival are well-documented by numerous studies.

Classic Post-MI Cardiac Rehabilitation Program

Risk-Factor Modification

An essential part of any cardiac rehabilitation program is achievement of a healthier lifestyle through a program of cardiac risk-factor modification. Cardiac risk factors (Table 1) are divided into two major groups: reversible and irreversible risk factors. Irreversible risk factors include male gender, past history of vascular disease, age, and family history. The patient and family have to be educated on the presence of risks, and where appropriate, family counseling can be added. Early and aggressive attention to reversible risk factors is essential in individuals with significant irreversible risks. Reversible risk factors for cardiac disease include obesity, sedentary lifestyle, hyperlipidemia, cigarette smoking, and conditions such as diabetes mellitus and hypertension. Modification of these risk factors is a part of a cardiac rehabilitation program, and should be part of a "heart healthy" lifestyle for all individuals. These same principles also need be applied to the disabled population because they often are at further increased risk through weight loss, immobility, and deconditioning.

Diabetes

Close control of blood sugars has been shown to decrease the risk of cardiac disease through the slowing of the development of atherosclerosis and secondary conditions, such as nephrogenic hypertension. Exercise training can also help to improve diabetic control. The exact benefits of exercise training in combination with good glucose control are still being elucidated.

Hypertension

Control of hypertension has been shown to be beneficial in individuals with normal cardiograms. Reduction of dietary salt and increased exercise to improve conditioning in combination with pharmacological management can significantly improve blood pressure. The major agents for the control of hypertension are divided into β-blockers, α-blockers, diuretics, calcium channel blockers, and angiotensin-converting enzyme inhibitors. Because of the combination of antihypertensive effects and lower myocardial cardiac oxygen consumption through decreased inotropy and heart rate, β-blockers are the most effective agents. Diuretics and angiotensin-converting enzyme inhibitors have also been shown in large trials to have beneficial effects on decreasing cardiac mortality. The cardiac effects of calcium channel blockers are not clear, but some early data may indicate an actual increase in MI with certain agents, and it is recommended that rehabilitation physicians seek the advice of the treating cardiologist or internist for assistance in the optimal management of each individual patient.

Hypercholesterolemia

Lowering cholesterol levels and increasing high-density lipoprotein is associated with decreased risk of cardiac disease. Patients can decrease their lipids by adhering to a low-cholesterol, low-fat diet along with weight reduction, even without the addition of exercise. The American Heart Association recommends that the total amount of calories from fat in the diet should not exceed 30%. Control of cholesterol can be achieved through a three-step program, as outlined in the National Cholesterol Education Program guidelines. Phase 1 is an adoption of nutritional guidelines, lifestyle changes, and general improvement in health habits. Phase II adds fiber supplements and possibly nicotinic acid. Phase III includes lipid-lowering drugs. Lipid-lowering programs have been shown to retard the progression of CAD. With the addition of physical activity, high-density lipoprotein cholesterol concentration can rise 5–16%, but the data on the lowering of low-density lipoprotein cholesterol is still controversial.

Obesity

The multiple metabolic syndrome of obesity, diabetes, hypertension, and hyperlipidemia is associated with increased morbidity and mortality, and the obesity is at the center of the syndrome. Weight loss can decrease blood pressure, improve lipid profile, and improve diabetic control, as well as improve the ability to perform exercise. Attention to proper weight needs to be part of any cardiac rehabilitation program.

Cigarette Smoking

Cigarette smoking is one of the greatest single modifiable risk factors for cardiac disease. Smoking cessation is associated with a 30% decrease in 10-year mortality in individuals with angiographically demonstrated CAD or MI. Smoking accelerates atherosclerosis, contributes to hypertension, and is associated with a sedentary lifestyle. Smokers tend to be less compliant in cardiac rehabilitation programs, and exercise is not associated with decreased cigarette use. However, cardiac rehabilitation coupled with counseling for smoking cessation can lead to a decrease in smoking. Although smoking cessation programs are not a primary rehabilitation function, awareness of available resources and appropriate referrals for patients should be available for all smokers with cardiac or other disease.

Cardiac Anatomy

A good understanding of cardiac anatomy helps in providing cardiac rehabilitation. Of particular importance is a familiarity with the normal distribution of the major arteries of the heart with ischemic distributions and valvular anatomy. Some important functional and anatomical issues are briefly covered here.

The cardiac conduction system facilitates the appropriate sequencing of the contraction of the atria and ventricles at the physiologically appropriate rate. Conduction blocks can occur as a result of MIs, aging, and other conditions. Abnormalities of cardiac conductions, such as congenital defects and accessory tracts, can lead to arrhythmias, both atrial and ventricular, which can lead to life-threatening arrhythmias.

Normally, there are left and right coronary arteries arising from the base of the aorta in the left and right aortic sinuses. The left main coronary artery divides into the left anterior descending and the circumflex arteries, whereas the right coronary artery continues on as a single vessel. Approximately 60% of individuals have right-dominant circulation. Approximately 10–15% of individuals have the posterior descending arise from the left circumflex, in left-dominant circulation. About 30% of individuals have the

Table 2
The Distributions of Infarcts by Anatomy

	Area of infarct	*Associated syndrome*
Left anterior descending	• Anterior wall and septum	† Papillary muscle necrosis † Left heart failure † Left ventricular aneurysm † Anterior wall thrombus † Conduction block † Sudden death
Left circumflex	• Apex and lateral wall	† Apical thrombus † Left heart failure
Left main coronary artery	• Anterior and lateral wall apex	† Massive congestive heart failure † Left ventricular aneurysm † Anterior wall thrombus † Conduction block † Sudden death
Right coronary artery	• Inferior wall and right ventrical	† Sinus node arrest † Bradycardia † Right ventricular failure † Peripheral edema

posterior descending arise from the left circumflex and right coronary arteries in what is described as balanced circulation. Table 2 lists the anatomy and the distributions of infarcts with a description of associated cardiac syndromes.

Cardiac Physiology

The heart is among the most metabolically active organs in the body. Oxygen extraction is nearly maximal at all levels of activity and is nearly 65% (compared with 36% for brain and 26% for the rest of the body). The heart prefers to metabolize aerobically, but is able to perform both anaerobic and aerobic metabolism. Cardiac metabolism uses 40% carbohydrates, with fatty acids making up most of the rest. Coronary blood flow is limited to diastole, especially in the endocardium. In order to meet the demands of exercise, the coronary arteries must dilate, using nitric oxide-mediated pathways. The goal of medical, rehabilitation, and surgical therapies is to restore normal blood flow to the myocardium.

The ability of the heart to generate an increase in cardiac output (CO) is related to the increase in venous return, which increases the length of the myocardial fibers in diastole prior to the initiation of cardiac contraction. With stretch, the overlap of the actin and myosin fibers is maximized and the strength of contraction is maximized. With overstretching, the overlap of myosin and actin begins to decrease, and the strength of contraction declines. This relationship is seen in the Frank–Starling relationship. This is part of the contractile changes in patients with cardiomyopathy, who are so overstretched that they can only increase CO by decreasing myofibril length. Atrial contraction is also important because atrial filling of the ventricles can add 15–20% to the total CO, especially with increased heart rate and in conditions with decreased ventricular compliance. Loss of this atrial "kick" is important in heart failure combined with atrial dysfunction, such as atrial fibrillation.

Basic Cardiac Vocabulary

Aerobic Capacity

Aerobic capacity (VO_2Max) is the work capacity of an individual, and is expressed in milliliters oxygen per kilogram per minute. Oxygen consumption (VO_2) has a linear relationship with workload, increasing up to a plateau which occurs at the VO_2Max. VO_2 reaches steady state after approximately 3–6 minutes of exercise. A decrease in efficiency is represented by an increase in the slope of the line between VO_2 and workload. The work done at submaximal effort is expressed as a percentage defined by VO_2 divided by VO_2Max. The use of percent VO_2Max allows for normalization of data across individuals and for comparison of activities. VO_2Max has been demonstrated to decrease with age in longitudinal studies, such as the Baltimore Longitudinal Study of Aging.

Heart Rate

Heart rate (HR) has a linear increase in relation to VO_2 or other measures of work. Maximum HR is determined by age and can be roughly estimated by subtracting the age of the individual in years from 220. Even with exercise, the maximum HR continues to decline with age. The slope of the line between HR and VO_2 is an indication of physical conditioning.

Stroke Volume

Stroke volume (SV) is the quantity of blood pumped with each heartbeat. The majority of SV increase occurs in early exercise, with the major determinant of SV being diastolic filling time. SV changes very little in

supine exercise, being near maximum at rest, whereas in erect position, it increases in a curvilinear fashion until it reaches maximum at approximately 40% of VO_2Max. SV also decreases with advancing age and in cardiac conditions, which results in decreased compliance, such as left ventricular hypertrophy.

Cardiac Output

CO is the product of the HR and SV. CO increases linearly with work, and in early exercise, is mostly dependent on increased SV, whereas in late exercise, it is mostly determined by increased HR. In general, the relationship between CO and VO_2 is linear with a break in the slope at the anaerobic threshold. The maximum CO is the primary determinant of VO_2Max. CO declines with age without any change in linearity or slope. The CO seen in submaximal work is parallel but lower in upright work compared with supine work. VO_2Max and maximal CO are less in supine than erect positions.

Myocardial Oxygen Consumption

Myocardial oxygen consumption (MVO_2) is the actual oxygen consumption of the heart. MVO_2 rises in a linear fashion with workload, being limited by the anginal threshold. Although MVO_2 can be determined directly with cardiac catheterization, the usual practice is estimate the MVO_2 by using the rate pressure product (RPP). The RPP is the product of the HR and the systolic blood pressure (SBP) divided by 100. In general, activities with the upper extremities and exercises with isometric components to them have a higher MVO_2 for a given VO_2. Activities performed while supine demonstrate a higher MVO_2 at low intensity and a lower MVO_2 at high intensity when compared with activities performed in the erect position. Finally, the MVO_2 increases for any activity when performed in the cold, after smoking, or after eating.

Aerobic Training

Aerobic training is the term to describe exercises that increase cardiopulmonary capacity. The basic principles of aerobic training are dependent on intensity, duration, frequency, and specificity of the exercise.

- *Intensity* of exercise is defined by either the intensity of the exercise performed or the physiological response of the individual. Exercise programs can be directed at a target HR or RPP, a rating of perceived exertion, or at a fixed level of exercise intensity on a treadmill or cycle ergometer. Often, target HR is used for simplicity in writing exercise

prescriptions. Often intensity of exercise can be set at 80–85% of the maximum HR determined on a baseline exercise tolerance test (ETT). It is generally accepted that exercises that evoke 60% or more of the maximal HR will have at least some training effect.

- *Duration* of exercise is usually 20–30 minutes, excluding a 5- to 10-minute warm-up and a similar cooling down period after exercising. In general, exercise at lower intensity requires a longer duration to achieve a training effect than exercises at higher intensity.
- *Frequency* of training is defined as the number of exercise periods in a given time, usually expressed in sessions per week. Training programs should be done three times a week at a minimum, and a low exercise program may require five times a week to achieve a training effect.
- *Specificity* of exercise refers to the types of activities that are performed. If a goal is to increase ambulation, walking exercise is preferred because it will give the best benefit. This principle dictates that the types of activities and muscle groups targeted in exercise should be based on the needs of the individual in vocational and recreational activities. This is also referred to as the law of specificity of conditioning, and is commonly referred to in cardiac conditioning programs.

Effects of Exercise Training

- *Aerobic capacity*: The VO_2Max will increase with training. Resting VO_2 is not changed, and VO_2 at a given workload does not change. The changes are specific to the muscle groups that are trained.
- *Cardiac output*: Resting CO is not changed with training. The maximum CO increases with aerobic training. The relationship between VO_2 and CO does not change during training.
- *Heart rate*: The resting HR decreases after aerobic training, and is lower at any given workload. The maximum HR is not changed.
- *Stroke volume*: The SV is increased at rest and at all levels of exercise after aerobic training. It is the increase in SV that permits a decrease in HR at a given workload.
- *Myocardial oxygen capacity*: The maximum MVO_2 does not change, because it is determined by the anginal threshold. However, at any given workload, the MVO_2 is decreased with training. This allows individuals to increase their exercise capacity and improve function. Training will allow performance of activities at MVO_2 below the anginal threshold that were above the anginal threshold before training. Pharmacological interventions can affect the resting and submaximal MVO_2, but only a revascularization procedure, such as angioplasty or coronary bypass sur-

Table 3
Sample Metabolic Equivalent (MET) Levels

Energy costs of activities of daily living	*METs*	*Energy costs of avocational activities*	*METs*
Sitting at rest	1	Backpacking (45 pounds)	6–11
Dressing	2–3	Baseball (competitive)	5–6
Eating	1–2	Baseball (noncompetitive)	4–5
Hygene (sitting)	1–2	Basketball (competitive)	7–12
Hygene (standing)	2–3	Basketball (noncompetitive)	3–9
Sexual intercourse	3–5	Card playing	1–2
Showering	4–5	Cycling, 5 mph	2–3
Tub bathing	2–3	Cycling, 8 mph	4–5
Walking, 1 mph	1–2	Cycling, 10 mph	5–6
Walking, 2 mph	2–3	Cycling, 12 mph	7–8
Walking, 3 mph	3–3.5	Cycling, 13 mph	8–9
Walking, 3.5 mph	3.5–4	Karate	8–12
Walking, 4 mph	5–6	Running 12 minutes/mile	8–9
Climbing up stairs	4–7	Running 11 minutes/mile	9–10
Bed-making	2–6	Running 9 minutes/mile	10–11
Carrying 18 pounds upstairs	7–8	Skiing crosscountry, 3 mph	6–7
Carrying suitcase	6–7	Skiing crosscountry, 5 mph	9–10
Housework (general)	3–4	Skiing downhill	5–9
Mowing lawn (push power mower)	3–5	Skiing water	5–7
Ironing	2–4	Swimming (backstroke)	7–8
Snow shoveling	6–7	Swimming (breaststroke)	8–9
		Swimming (crawl)	9–10
		Television	1–2
		Tennis (singles)	4–9

Continued

gery, can actually affect the maximum MVO_2. A way to look at this is using metabolic equivalents (METs) to assess energy demand for various activities. The MVO_2 at a given MET level will decline, allowing a patient to perform more activities with less risk. A sample of METs is shown in Table 3.

- *Peripheral resistance*: The peripheral resistance (PR) decreases in response to exercise training. The PR is decreased at rest and at all levels of exercise. The decreased PR leads to a lower RPP and a lower MVO_2 at a given workload and at rest.

In summary, training causes benefits in cardiac patients in two major areas: (1) reduced cardiac risk and (2) improved cardiac conditioning.

Table 3 *(Continued)*
Sample Metabolic Equivalent (MET) Levels

Energy costs of vocational activities	*METs*
Assembly line work	3–5
Carpentry (light)	4–5
Carry 20–44 pounds	4–5
Carry 45–64 pounds	5–6
Carry 65–85 pounds	7–8
Chopping wood	7–8
Desk work	1.5–2
Digging ditches	7–8
Handyman	5–6
Janitorial (light)	2–3
Lift 100 pounds	7–10
Painting	4–5
Sawing hardwood	6–8
Sawing softwood	5–6
Sawing (power)	3–4
Shoveling 10 pounds, 10 per minute	6–7
Shoveling 14 pounds, 10 per minute	7–9
Shoveling 16 pounds, 10 per minute	9–12
Tools (heavy)	5–6
Typing	1.5–2
Wood splitting	6–7

Adapted from Dafoe, WA. Table of Energy Requirements for Activities of Daily Living, Household Tasks, Recreational Activities, and Vocational Activities. In: Pashkow FJ, Dafoe WA, eds. Clinical Cardiac Rehabilitation: A Cardiologist's Guide. Baltimore, MD: Wiiliams and Wilkins; 1993: 359–376.

Cardiac rehabilitation after acute MI reduces the risk of mortality by 20–25% in a 3-year follow-up. This benefit has been seen in multiple groups, including in the elderly, women, and postbypass patients.

Abnormal Physiology

Cardiac disease alters normal cardiac physiology. Myocardial infarction decreases the ejection fraction (EF) of the heart, ischemic heart disease will lower the MVO_2 and VO_2Max that can be achieved. Valvular heart disease

will decrease the maximum CO, either through stenosis or through valvular insufficiency. The end result of the valve disease is a decreased MVO_2 and VO_2Max and increased VO_2 at any level of submaximal exercise. CHF leads to lower VO_2Max, lower SV, higher resting HRs, and decreased CO. Arrhythmias will decrease CO by lowering SV and altering HRs. In severe disease, cardiac transplantation can correct many of the abnormalities from CHF, but a persistently high HR in a deinnervated heart and a limited ability to increase SV can limit exercise response. The rehabilitation considerations in working with patients who have each of these diseases is discussed in detail later in the Heading entitled "Cardiac Rehabilitation Programs in Special Conditions." The effects of these conditions on physiological responses to exercise are compared with normal individuals in Table 4.

Cardiac Rehabilitation Programs

Cardiac rehabilitation programs consist of primary prevention and secondary prevention with cardiac rehabilitation after manifestation of cardiac disease.

Primary prevention programs focus on the reduction of cardiac risk factors. Education alone can have a profound effect on the rate of cardiac disease. Increased physical activity decreases obesity, lowers SBP, and modifies lipid profiles. Primary prevention should begin in childhood in order to establish healthy behavior patterns for life. Ideally, educational interventions should be started in schools with parental support.

Secondary risk-factor modification programs include all of the features of primary prevention programs. Secondary prevention decreases second cardiac events and lowers mortality post-MI. Multiple studies demonstrate the benefits of lowering cholesterol, including the Oslo Study, the Western Electric Study, the Multiple Risk Factor Intervention Trial, Helsinki Heart Study, the National Heart, Lung, and Blood Institute Type II Study, and others. Cessation of cigarette smoking is essential because the risk of heart disease can return to that of nonsmokers after 2 years of not smoking. Secondary programs can also improve hypertension and diabetes management.

Cardiac Rehabilitation of the Post-MI Patient

The rehabilitation of the post-MI patient follows the principles of the classic model of cardiac rehabilitation as first described by Wenger et al. Cardiac rehabilitation is traditionally divided into four stages or phases. Phase I is the acute phase, immediately following the MI up to discharge. Phase I rehabilitation is characterized by early mobilization. Phase II is the convalescent phase, which is done at home and continues the program

Table 4
Abnormal Physiology in Response to Exercise (as Compared With Normal Individuals)

	Aerobic capacity (VO_2Max)	Cardiac output	Heart rate	Stroke volume	Myocardial oxygen capacity (MVO_2)	Peripheral resistance
Ischemic heart disease	Lower	Unchanged or lower	Lower, unchanged, or higher	Unchanged or lower	Lower	Lower, unchanged, or higher
Myocardial infarction	Lower	Lower	Lower, unchanged, or higher	Unchanged or lower	Lower	Unchanged or higher
Congestive heart failure	Lower	Lower	Unchanged or higher	Lower	Lower	Higher
Valvular heart disease	Lower	Lower	Unchanged or higher	Lower, unchanged, or higher	Unchanged or lower	Unchanged or higher
Arrhythmias	Unchanged or lower	Unchanged or lower	Lower, unchanged, or higher	Unchanged or lower	Unchanged or lower	Unchanged
Cardiac Transplant	Lower	Lower	Higher at rest, lower at maximum effort	Lower	Lower	Unchanged or higher

Table 5
Wenger Protocol

Step	Activity
1	Passive range of motion (ROM); ankle pumps; introduction to the program; self-feeding.
2	As above; also dangle at side of bed.
3	Active-assisted ROM; sitting upright in a chair, light recreation, and use of bedside commode.
4	Increased sitting time; light activities with minimal resistance; patient education.
5	Light activities with moderate resistance; unlimited sitting; seated activities of daily living (ADL).
6	Increased resistance; walking to bathroom; standing ADL; up to 1-hour group meetings.
7	Walking up to 100 feet; standing warm-up exercises.
8	Increased walking; walk down stairs (not up); continued education.
9	Increased exercise program, review energy conservation, and pacing techniques.
10	Increase exercises with light weights and ambulation; begin education on home exercise program.
11	Increased duration of activities.
12	Walk down two flights of stairs; continue to increase resistance in exercises.
13	Continue activities, education, and home exercise program teaching.
14	Walk up and down two flights of stairs; complete instruction in home exercise program and in energy conservation and pacing techniques.

Adapted from Bartels MN. Cardiac rehabilitation. In: Physical Medicine and Rehabilitation: The Complete Approach. Grabois M, ed. Chicago: Blackwell Science, 2000.

started in phase I until the myocardial scar has matured. Phase III is the training phase; this usually starts after 4–6 weeks, and is the classic exercise program of conditioning and education. Phase IV is the maintenance phase, and is devoted to keeping the aerobic conditioning gains made in phase III. Risk-factor modifications are taught and reemphasized throughout all phases.

Acute Phase (Phase I)

The innovation in Dr. Wenger's model of cardiac rehabilitation was early mobilization. The classic Wenger cardiac rehabilitation program is outlined in Table 5. The goal of the original program was to get individuals from bed rest to climbing 2 flights of stairs in 14 days. Under current practices, clinicians have modified the classic program of cardiac rehabilitation to allow stays of 3–5 days after MI. The 14 steps of the classic program are

now condensed. Patients are encouraged to be sitting out of bed and in a chair by days 1–2 (steps 1–5), with short distance ambulation and bathroom privileges by days 2–3 (steps 6–9). By days 4–5, the patient learns the home exercise program, climbs stairs, and increases duration of ambulation (steps 10–13). Prior to discharge, the patient has a low-level ETT for risk stratification and completes learning the home program (step 14). Education is started at this time. Cardiac monitoring should be performed under the supervision of a trained physical or occupational therapist or nurse during phase I. The post-MI HR rise should be kept to within 20 bpm of baseline, and the SBP rise within 20 mmHg of baseline. Any decrease of SBP of 10 mmHg or more should stop exercise. The intensity target for the phase I program is activities up to 4 METs, which is within the range of most daily activities.

Convalescent Phase (Phase II)

The convalescent phase is designed to allow the scar over the infarction to mature. The target HR is determined during a low-level ETT, which is performed before discharge and at the end of phase I. This exercise test is performed to a level of 70% maximum HR or a MET level of 5. A Borg rating of perceived exertion scale of 7 (modified scale) or 15 (old scale) can also be used to determine the maximum tolerated exercise. The Borg scale and Modified Borg scale are shown in Table 6. The low-level ETT also has a role for cardiac risk stratification. The classic program consisted of six monitored phase II sessions of 1 hour each with a home exercise program over 6 weeks in the uncomplicated patient. Patients at high risk with the need for monitoring are included in Table 7. A full-level ETT can be performed at the end of the 6-week healing period in preparation for phase III rehabilitation.

Training Phase (Phase III)

The training phase of the cardiac rehabilitation program is started after the symptom-limited full-level ETT. This HR maximum is the one that is used to determine the maximum exertion to be performed by the patient during aerobic training. In patients who are low risk, a program designed to achieve 85% of the maximum HR is safe. Gradation of the program to lower target HRs needs to be tailored to the individual patient based on the results of the ETT and the reason for cessation of exercise. For patients with life threatening arrhythmias or chest pain, a lower target HR should be chosen. Even a target HR of 65–75% of the maximum can be safe and effective in a regular program, and target rates as low as 60% can still yield

Table 6
Borg Scale

Borg scale	Perceived exertion	Modified Borg scale	Perceived exertion
		0.0	Nothing at all
		0.5	Very, very weak
		1.0	Very weak
		1.5	
		2.0	Weak (light)
6		2.5	
7	Very, very light	3.0	Moderate
8		3.5	
9	Very light	4.0	Somewhat strong
10		4.5	
11	Fairly light	5.0	Strong (heavy effort)
12		5.5	
13	Somewhat hard	6.0	
14		6.5	
15	Hard	7.0	Very strong
16		7.5	
17	Very hard	8.0	
18		8.5	
19	Very, very hard	9.0	Very, very strong
20		9.5	
		10.0	Maximal

a training benefit. For the patients at higher risk, monitoring at each increase in activity level is appropriate.

The classic duration of a cardiac training program is 3 sessions per week for 6–8 weeks. As limitations of availability, facilities, and financing imposed by managed care have arisen, creative new at-home programs for low-risk post-MI patients have been developed. These include community-based programs and home programs. In all of these programs, it is important that the patient be able to self-monitor during their exercise program. Guidelines for self-monitoring are covered in detail elsewhere (*see* Key References and Suggested Additional Reading). Each exercise session should begin with a stretching session, followed by a warm-up session, the training exercise, and ending with a cool-down period. It is important to remember that conditioning benefit is related to the specificity of training, and that the conditioning applies to the specific muscles exercised.

Table 7
Patients at High Risk During Cardiac Rehabilitation

Ischemic risk

- Postoperative angina
- LVEF <35%
- NYHA grade III or IV CHF
- Ventricular tachycardia of fibrillation in the postoperative period
- SBP drop of 10 points or more with exercise
- Excessive ventricular ectopy with exercise
- Incapable of self-monitoring
- Myocardial ischemia with exercise

Arrhythmic risk

- Acute infarction within 6 weeks
- Active ischemia by angina or exercise testing
- Significant left ventricular dysfunction (LVEF <30%)
- History of sustained ventricular tachycardia
- History of sustained life-threatening supraventricular arrhythmia
- History of sudden death, not yet stabilized on medical therapy
- Initial therapy of patients with automatic implantable cardioverter defibrillator
- Initial therapy of a patient with a rate adaptive cardiac pacemaker

LVEF, left ventricular ejection fraction; NYHA, New York Heart Association; CHF, congestive heart failure; SBP, systolic blood pressure.

Maintenance Phase (Phase IV)

Although often the least discussed, the maintenance phase of a cardiac conditioning program is the most important part of the program. If the patient stops exercising, the benefits gained from phase III can be lost in a few weeks. The patient should be taught the importance of an ongoing exercise program from the beginning of the cardiac rehabilitation program, and the concept reemphasized throughout. The actual exercises need to be integrated into the patient's lifestyle and interests to assure compliance. The secondary prevention measures also need to be integrated into the patient's lifestyle. The ongoing exercises should be performed at the target HR for at least 30 minutes, three times a week, if at a moderate level. If at a low level, exercises need to be performed five times a week. During the maintenance phase, electrocardiogram monitoring is not necessary.

Cardiac Rehabilitation Programs in Special Conditions

With recent advances in medical technology, there are many conditions that are being referred to cardiac rehabilitation programs. Heart failure, val-

vular heart disease, life-threatening arrhythmias, pre- and posttransplant patients, and patients who have just received left ventricular assist devices, just to name a few, are all now entering rehabilitation programs. Each of these groups is described in this section.

Angina Pectoris

For patients with a stable angina, cardiac rehabilitation can be utilized to improve efficiency of performance below the anginal threshold. It is important to remember that the actual MVO_2 (and thus the maximum HR) at which angina occurs will not change with conditioning. A full-level ETT should be done in order to determine the maximum HR and rule out the potential of life-threatening events. The program of rehabilitation can begin at phase III (training). The primary goal of rehabilitation in this group of patients is aimed at increasing work capacity and education in primary/secondary prevention strategies. Increased conditioning and efficiency of exercise may significantly decrease disability caused by their recurrent chest pain.

Cardiac Rehabilitation After Revascularization Procedures

Post-CABG

Rehabilitation after CABG has a number of benefits. The patients start in a phase III program as soon as healing is completed. Because of the lower level of invasiveness with new techniques, such as minimally invasive CABG, off- pump CABG, robotic surgery, and other techniques, a larger number of patients with severe pre-existing cardiac disease can now tolerate surgery. Unlike the past, patients with low EFs and CHF are also considered candidates for revascularization. There is a role for a symptom-limited cardiac stress test if continued ischemia is considered a risk. Testing can be safely performed at 3–4 weeks after surgery. The exercise test should determine maximal functional capacity, maximal HR, exercise blood pressure response, exercise-induced arrhythmias, and anginal threshold. A complete education program to help modify risk factors and supervised and unsupervised home programs can help with the management of risk of recurrent heart disease.

Cardiac rehabilitation after CABG has two stages: the immediate postoperative period and the later maintenance stage. The in-hospital period usually only lasts 5–7 days. This phase has three parts: (1) intensive mobilization starting postoperative day 1, (2) progressive ambulation and daily exercises, and (3) discharge planning and exercise prescription for the maintenance stage.

Early mobilization should only be delayed for an unstable postoperative course or severe CHF. Early mobilization has several benefits, including decreasing effects of immobility and preventing cardiac deconditioning. Days 2–5 include progressive ambulation and daily exercise. Initial ambulation aims for assistance with distances of 150–200 feet, followed by independent ambulation by the third day. In the last few days prior to discharge, the patient is given a program of self-monitored exercise that allows for a gradual return to previous levels of activity.

The at-home program for a CABG patient is usually conducted as an outpatient procedure. Inpatient rehabilitation may be needed for high-risk patients or those who have had postoperative complications or significant comorbidities. Patients should be stratified according to risk into either low-, moderate-, or high-intensity programs. A low-intensity program is in the area of 2–4 METs, with a target HR of 65–75% of maximum HR. A moderate-intensity program is from 3 to 6.5 METs, with target HR 70–80% of maximum HR. A high-intensity program is from 5 to 8.5 METs with a target HR of 75–85% of maximum HR. In the presence of β-blockade, the target HR is 20 bpm above the resting HR or at a target HR determined through an ETT aiming at a target MET level. Assignment of level of exercise is determined by the objective criteria and patient observation in the postoperative period. A level of exercise that equals a rating of perceived exertion (RPE) of 13 on the Borg scale is a level of training where the patient can be safely prescribed in the outpatient setting. The inpatient program for high-risk patients has to be tailored to the specific needs of the patient in cooperation with the patient's cardiologist.

Postpercutaneous Transluminal Coronary Angioplasty

The rehabilitation of patients after percutaneous transluminal coronary angioplasty (PTCA) is essentially the same as after CABG. Patients with PTCA tend to be younger and have disease limited to only one or two vessels. The exercise program is similar to that of the post-CABG patient with the benefit of no significant postoperative recovery. There can be a role for diagnostic exercise testing before the PTCA, followed by a functional exercise test immediately after PTCA to set parameters for exercise presciption. Although ideal, this approach may not be practical in all settings or with all patients. Risk-factor modification in outpatient programs with both supervised and unsupervised home programs are possible. As after CABG, high-risk patients require closer monitoring and closer physician supervision. For low-risk post-PTCA patients, the usual risk stratification is done.

Cardiac Rehabilitation After Cardiac Transplant Surgery

As cardiac transplantation has improved, the numbers of patients with cardiac transplantation have increased. Five- and 10-year survival has improved, and the focus of rehabiliation programs is to recover from pre-operative invalidism and general muscle weakness. Cardiac physiology after transplant is somewhat different with loss of vagal inhibition to the sinoatrial node, causing an elevated resting HR (often near 100 bpm). There is a reduced SV, but the heart has normal compliance, and CO still increases via the Frank–Starling mechanism. Because there is also no direct sympathetic innervation to the heart, circulating catecholamines induce chronotropic and inotropic responses to increase CO. This leads to a situation of resting tachycardia with a blunted HR response to exercise. Peak HRs are 20–25% lower than in matched controls, and HR recovery after exercise is delayed. Resting hypertension is often seen owing to the effects of anti-rejection medications. If there is any rejection or ischemic injury at the time of transplant, there may be an element of diastolic dysfunction caused by myocardial stiffness.

Deconditioning can be seen pre- and posttransplant. Transplant recipients have a 10–50% loss of lean body mass from the lack of activity and high-dose steroids in the perioperative period. This leads to a decrease in maximum work output and maximum oxygen uptake. At submaximal exercise levels, perceived exertion, minute ventilation, and the ventilatory equivalent for oxygen are all higher, whereas oxygen uptake is the same. At rest, HR and SBP are higher, and with maximum effort work capacity, CO, peak HR, peak SBP, and peak oxygen uptake are all lower. Resting and exertional diastolic blood pressure are higher after cardiac transplantation than in normal controls.

Exercise testing can be done but dyspnea, faintness, and electrocardiogram changes need to be followed vigilantly as the donor-denervated heart cannot demonstrate ischemia through anginal pain. In long-standing transplants, accelerated atheroschlerosis may develop and lead to cardiac ischemia.

Cardiac rehabilitation after heart transplant must address conditioning, as well as cardiac function. In the initial postoperative period, aggressive mobilization is done, similar to post-CABG patients. At the time of discharge, after patients have learned self-monitoring, patients are encouraged to increase ambulation to 1 mile. The home program consists of progressive ambulation, with the pace designed to be at a level of 60–70% of peak effort for 30–60 minutes three to five times a week. The RPE, using the Borg scale, should be maintained at 13 to 14, with the level of activity increasing incre-

mentally to stay at this level. Education about the complicated medical regimen and possible vocational rehabilitation also need to be considered. The benefit of rehabilitation posttransplant includes increased work output, improved exercise tolerance, and improved quality of life.

Valvular Heart Disease

In valvular heart disease, the major problem is often deconditioning along with CHF. In patients receiving surgical correction of the valvular disease, a post-CABG-type program is used. In uncorrected valvular heart disease with heart failure, the program resembles the program for CHF. Training can increase physical work capacity by 60%, decrease RPE, and decrease the RPP by 15% in uncorrected valve disease. Postoperative anticoagulation needs to be accounted for, and in those patients, low-impact exercises are used to avoid hemarthroses and bruising. Otherwise, the training program is similar to that followed for the post-CABG patient.

Cardiomyopathy

One of the fastest growing subsets of the cardiac rehabilitation population is in CHF among individuals with an EF of 30% or less. The major issue is that this population is at higher risk of sudden death and has a high degree of depression because of their chronic cardiac disability. Limited exercise capacity is common in heart failure and is one of the earliest findings.

Patients with heart failure demonstrate inconsistent responses to exercise, and the hemodynamic alterations do not always correlate with overall exercise capacity. In CHF, exercise can cause a drop in EF, a decrease in stroke volume, exertional hypotension, and syncope. In severe CHF, there can be a failure to generate a dynamic exercise response at all. Low endurance and fatigue are also common in CHF, and prolonged fatigue can be seen for hours to days after heavy exertion. Additional factors, such as atrial fibrillation, fluid overload, and medication noncompliance, may further decrease exercise tolerance. Despite these limitations, exercise duration and efficiency can increase by as much as 18–34%, and peak oxygen uptake can increase by 18–25%. Patients will have lower HRs at rest and during submaximal exercise, raised anaerobic thresholds, and increased maximal work loads. This improvement in efficiency of exercise can mean the difference between independent living and dependency for a patient with CHF.

In CHF, unstable angina, decompensated CHF, and unstable arrhythmias are contraindications to cardiac rehabilitation. Screening functional exer-

cise testing is indicated to allow patients to have safe programs, and estimation of EF can be helpful. Prolonged warm-ups and cool downs are needed because these patients often have abnormal hemodynamic responses to exercise. Dynamic exercise is preferred with a target HR 10 bpm below any significant end point. Isometric exercise should be avoided where possible, and limited to 2-minute intervals when performed. Cardiac exercise is best supervised initially until the patient is able to self-monitor to prevent complications. Patients with severe left ventricular dysfunction (EF < 30%) will need telemetry during warm-up, exercise and cool down. In time, this can be stopped once safe exercise levels have been established.

Cardiac Arrhythmias

The risk of death from cardiac arrhythmia during rehabilitation exercises is very low, with one arrest per 112,000 patient hours of exercise reported between 1980 and 1984. Thus, only high-risk patients need continuous monitoring. For patients with life-threatening arrhythmias, the automatic internal cardiac defibrillators is commonly used. Modifications for cardiac rehabilitation program in these patients are limited to not exceeding the target rate that the device is set at. The support and reassurance that can be given to these patients during the exercise program is also important because anxiety about recurrent arrhythmia is a frequent concern.

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