Impaired Aerobic Capacity/Endurance

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Impaired aerobic capacity, also known as impaired endurance, is a common patient impairment that can limit participation in functional, occupational, and recreational activities. Even functional tasks that require only a few minutes can be limited by aerobic capacity. Older adults are particularly vulnerable to impaired aerobic capacity due to anatomic and physiological changes that occur with aging, greater propensity for sedentary be-haviors, and greater risk for disease processes that limit the oxygen transport system.[1] In addition, aerobic capacity is directly infl uenced by the habitual activity pattern of an individual, which may vary across individuals from total inactivity to frequent and intense activity. Any factors that limit habitual physical activity, such as illness, injury, and or travel, will cause adaptations that diminish aerobic capacity. Conversely, any factors that promote habitual physical activity, such as intentional exercise, yard work, and occupation-related physical tasks, will result in adaptations that improve aerobic capacity. In older adults, many physiological, pathological, and psychosocial factors can contribute to restricted physical activity. Figure 1 depicts the persistent vicious cycle that can be created when sedentary behaviors, chronic disease, and functional dependency interact.[2] This lesson will provide an overview of causes and factors contributing to impaired aerobic capacity in older adults and describes physical therapist patient management (examination, evaluation, diagnosis, and interventions) to address decreased endurance and its impact on function.

FACTORS INFLUENCING AEROBIC CAPACITY IN THE OLDER ADULT

~~In older adults, aerobic capacity impairments may be~~ related to a number of issues, including deconditioning, age-related physiological changes, and specifi c pathology. Deconditioning, or decreased physical activity, is common in older adults and often associated with illness, functional limitations, restricted activity, and cognitive limitations. Many age-related physiological changes, such as reduced maximal oxygen consumption because of decreased cardiac performance and skeletal muscle endurance, directly impact aerobic capacity.[1] Also, conditions that affect functional mobility (stroke, Parkinson's disease, osteoarthritis, bone fractures, etc.) are more common in older than in younger adults, thus predisposing older adults to restricted physical activity. Lastly, older adults are also more likely to have cardiovascular, pulmonary, and metabolic pathologies that interfere with oxygen delivery and subsequently aerobic capacity. Physical therapists need to be able to identify and address any of these factors that may be contributing to impaired aerobic capacity in older adults.

Aerobic capacity limitations are associated with declining functional mobility, disability, and loss of independence in older adults. Long-term physical activity is related to postponed disability and longer independent living in older adults, including those with chronic disease.[3] Alexander et al[4] found that measures of submaximal oxygen uptake and maximal oxygen consumption were strongly predictive of functional mobility performance in older adults with and without impairments. An exercise training program of walking improved aerobic capacity and physical function in older adults with low socioeconomic status at risk for disability.[5] The evidence suggests that meeting recommended physical activity guidelines can improve physical function in older adults and help maintain independence and quality of life and reduce risk of frailty.[6,7] In addition, several studies have found that aerobic exercise training has a beneficial impact on locomotor function in older adults,[8] whereas multimodal exercise programs and group-based interventions can also minimize impaired mobility in older adults.[9,10]

PUBLIC HEALTH BENEFITS OF EXERCISE AND PHYSICAL ACTIVITY

The benefits of exercise, and particularly aerobic training, are numerous and extend beyond traditional physical therapy management of a single patient. Promotion

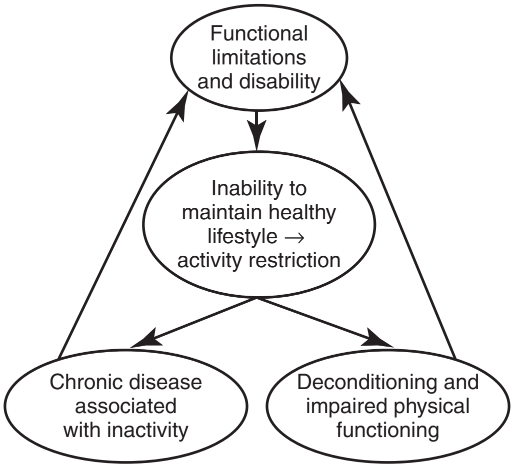

FIGURE 1 Cycle created by impaired aerobic capacity.

of aerobic exercise in almost all patient populations has far-reaching effects on health promotion and disease prevention. Landmark studies by Blair et al[11,12] have demonstrated that the level of aerobic fitness is inversely related to risk of cardiovascular disease and all-cause mortality. Regular aerobic activity reduces the risk of many adverse health outcomes including those summarized in Box 12-1. Major research findings suggest that the health benefits of physical activity occur for all age, racial, and ethnic groups and that the benefits far outweigh the possibility of adverse outcomes.[13-15]

Numerous studies have demonstrated the benefits of aerobic exercise in populations of older adults. Recent studies have demonstrated the ability of older adults, both healthy and with pathology, to increase aerobic capacity with exercise training. Although masters athletes experience age-related decline in maximal aerobic capacity, their aerobic performance is better than that of sedentary older adults.[1] Aerobic exercise training is safe and beneficial even with significant chronic disease such as chronic obstructive pulmonary disease, chronic heart failure, peripheral artery disease, and stroke, which are common in older adults.[16-23] For example, in older patients with chronic obstructive pulmonary disease, 12 weeks of aerobic exercise training combined with resistance exercise training or recreational activities increased peak aerobic capacity and 6-minute walk test distance.[16] In older patients with stable chronic heart failure, a program of aerobic high-intensity interval training was well tolerated and improved aerobic capacity, functional status, and quality of life.[17] Interestingly, arm ergometry cycling and treadmill walking exercise training both increased maximal walking distance and pain-free walking distance in older patients with vascular claudication.[20] Exercise training with lower extremity cycling improved aerobic capacity and functional performance in patients with hemiparesis who were more than 5 months poststroke.[21]

Interestingly, aerobic exercise training has also been shown to improve cognitive function in adults, in addition to motor function, auditory attention, cognitive speed, visual attention, and cognitive flexibility.[24,25] Even a single exercise bout of sufficient intensity may improve cognitive performance in older adults.[26] It has also been proposed that exercise may modify some of the psychological and physiological abnormalities associated with Alzheimer's disease.[27] Because cognitive decline is prevalent in older adults, ways to prevent or attenuate this are clinically relevant in this population.

BOX 1 Summary of Health Benefits Associated with Regular Physical Activity

Adults and Older Adults

Strong evidence
- Lower risk of early death
- Lower risk of coronary heart disease
- Lower risk of stroke
- Lower risk of high blood pressure
- Lower risk of adverse blood lipid profile
- Lower risk of type 2 diabetes
- Lower risk of metabolic syndrome
- Lower risk of colon cancer
- Lower risk of breast cancer
- Prevention of weight gain
- Weight loss, particularly when combined with reduced calorie intake
- Improved cardiorespiratory and muscular fitness
- Prevention of falls
- Reduced depression
- Better cognitive function (for older adults)

Moderate to strong evidence
- Better functional health (for older adults)
- Reduced abdominal obesity

Moderate evidence
- Lower risk of hip fracture
- Lower risk of lung cancer
- Lower risk of endometrial cancer
- Weight maintenance after weight loss
- Increased bone density
- Improved sleep quality

(From US Department of Health and Human Services: 2008 Physical activity guidelines for Americans. ODPHP Publication #U0036 2008:1-76.)

PHYSIOLOGY OF AEROBIC CAPACITY AND EXERCISE

Aerobic capacity reflects the body's ability to take up, deliver, and use oxygen. Many processes are required to ensure that these three steps occur optimally, and dysfunction in any part of this oxygen transport system can interfere with a patient's aerobic capacity. Oxygen consumption ($\dot{V}O_2$) is a physiological measure of how much oxygen the body uses at rest or during activity. Oxygen consumption increases in proportion to intensity of exercise/physical activity and will plateau when maximal ability for oxygen delivery is reached, which is called maximal oxygen consumption ($\dot{V}O_2$ max). Maximal oxygen consumption is directly related to aerobic capacity. Increases in maximal oxygen consumption with exercise training refl ect improvement in aerobic capacity. The Fick equation describes the relationship between oxygen consumption as being equivalent to the cardiac output (heart rate × stroke volume) × arteriovenous oxygen difference, as illustrated in Figure 2 .[28-30] Dysfunction in one or more of these physiological processes can lead to impaired aerobic capacity. This lesson will briefl y discuss how these key physiological variables respond acutely during a single aerobic exercise bout, can be altered by aging or pathology, and adapt chronically to a period of aerobic exercise training.

Heart Rate

During acute aerobic exercise, there is a linear relationship between heart rate and oxygen consumption, as shown in Figure 12-3. Heart rate increases with increasing workload via two mechanisms. At less than 100 beats per minute (bpm), heart rate increases via an inhibition of vagal (parasympathetic) tone. Conversely, as the rate approaches 100 bpm, heart rate increases primarily by stimulation of sympathetic tone. Maximal heart rate is related primarily to age and is estimated by subtracting age from 220.[28-31]

There is an age-related reduction in maximal heart rate that is thought to be due to attenuation of sympathetic drive or decreases in sensitivity and responsiveness of catecholamines.[1,32] Pathological processes that reduce the rise in heart rate with activity can limit aerobic capacity. Impaired function of the autonomic nervous system will decrease heart rate response to activity. Interestingly, autonomic nervous system activity (measured by heart rate variability) decreases with increasing age, especially in frail populations.[33] Disruption of the peripheral autonomic nervous system is a common finding in older adults with diabetes (autonomic peripheral neuropathy)[34,35] and also following heart transplantation ("denervated heart").[36] Interruption of the autonomic nervous system can also occur with lesions in the central nervous system, such as a stroke or cervical spinal cord injury. Chronotropic disorders in older adults are commonly caused by heart rhythm disturbances such as atrioventricular blocks and sick sinus syndrome.[37]

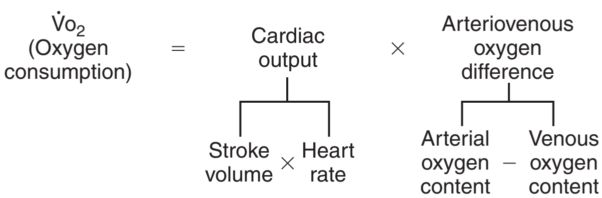

FIGURE 2 Parameters that contribute to aerobic capacity as described by the Fick equation.

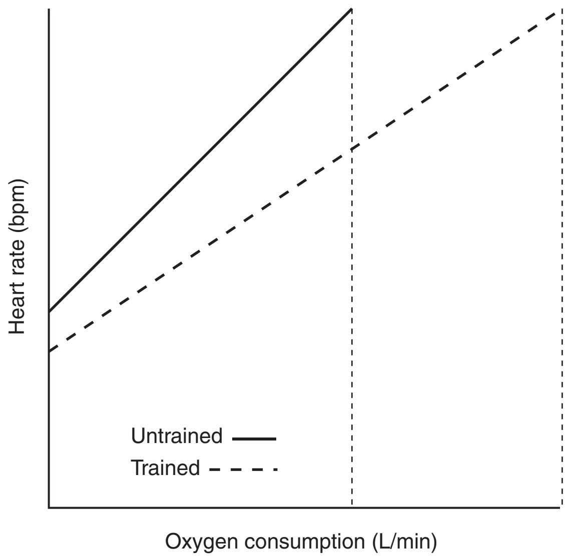

FIGURE 3 Heart rate (HR) response to an aerobic exercise bout and adaptation following aerobic exercise training. *bpm* , beats per minute.

With aerobic exercise training, heart rate is lower at rest and during submaximal exercise.[31,38] Heart rate at rest decreases following aerobic training because of increased parasympathetic activity while sympathetic activity declines. Exercise training results in a proportionally lower heart rate at specified submaximal workloads. Therefore, after a period of exercise training, more work can be performed at a lower heart rate. Maximal heart rate tends to be very stable within individuals and is not altered by exercise training. Following a period of aerobic training, the heart rate during recovery from exercise returns to resting levels more quickly.[28,31]

Stroke Volume

Stroke volume is the difference between the total amount of blood in the ventricles after completely filling (end-diastolic volume) and the amount of blood left behind after ventricular contraction (end-systolic volume). Stroke volume is often described clinically in terms of ejection fraction, which is stroke volume expressed as a percentage of end-diastolic volume. Stroke volume during acute aerobic exercise increases linearly up to intensities of 40% to 60% of maximal oxygen consumption and then plateaus, as illustrated in Figure 12-4. During aerobic exercise, dynamic skeletal muscle contraction and sympathetic-mediated vasoconstriction facilitate greater venous return and therefore ventricular filling. In addition, myocyte fiber stretching and sympathetic stimulation increase cardiac contractility and ventricular emptying. Both greater ventricular filling and emptying result in increased stroke volume during aerobic exercise.[28-31]

The evidence to determine whether or not stroke volume is reduced with aging is equivocal.[32] With

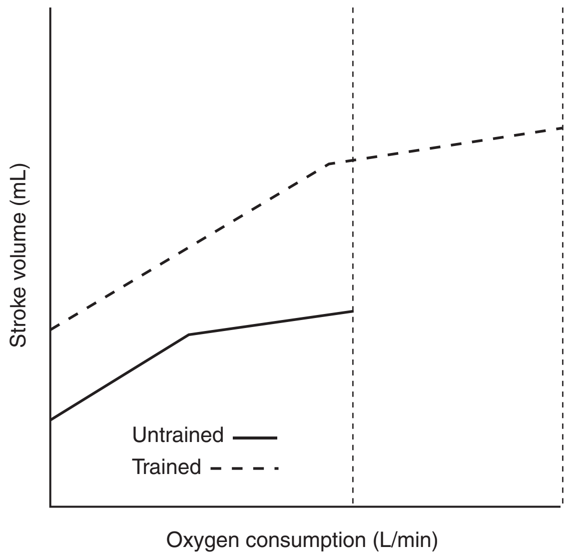

FIGURE 4 Stroke volume (SV) response to an aerobic exercise bout and adaptation following aerobic exercise training.

advanced age (>80 years), ejection fraction at maximal exercise does appear to decline.[1] Any pathological process that reduces ventricular filling or emptying will cause a reduction in stroke volume. With less volume of blood filling the ventricles, there is less volume available to pump out and a reduction in preload on the heart. Ventricular filling is reduced when there is a mechanical barrier present, such as cardiac valve dysfunction, heart fibrosis, or hypertrophic myopathy. All of these problems are associated with chronic heart failure, which is a major cause of disability in older adults. Ventricular filling is also impaired when venous return is reduced, commonly due to loss of active skeletal muscle pump (e.g., extremity paralysis) or impaired autonomic nervous system function (e.g., prolonged bed rest). Ventricular emptying is reduced when cardiac contractility is impaired (e.g., myocardial infarction) or the pressure that the heart has to pump against, or afterload, is elevated (e.g., hypertension). All of these cardiac problems are common in older adults and therefore often contribute to impaired aerobic capacity.

With aerobic exercise training, stroke volume increases at rest as well as during submaximal and maximal exercise. Following aerobic exercise training, ventricular filling (end-diastolic volume) increases due to an increase in plasma blood volume and also more compliant ventricular walls. In addition, ventricular emptying is greater (end-systolic volume) following aerobic exercise training. Ventricular emptying is facilitated by the greater cardiac contractility secondary to enhanced myocyte fiber stretching that occurs during ventricular filling and greater myocyte force production secondary to intrinsic changes and hypertrophy.[28-31]

Cardiac Output

At rest, cardiac output is approximately 5 L/min and with exercise can increase four- to eightfold up to approximately 20 to 40 L/min. The increase in cardiac output with increasing exercise intensity is linear, as illustrated in Figure 12-5. Increases in both stroke volume and heart rate contribute to greater cardiac output during acute aerobic exercise, because cardiac output is the product of heart rate and stroke volume. Oxygen demand is the ultimate stimulus for increasing cardiac output during exercise. With increasing skeletal muscle stimulation, more ATP is needed for cross-bridge cycling and force production. Oxygen is needed for mitochondrial oxidation to continue production of ATP. Greater cardiac output is needed to increase delivery of oxygen to the working muscles in order to meet the greater oxygen demand of heightened cellular energy metabolism.[28,31]

With aging, maximal cardiac output declines secondary to decreases in heart rate and stroke volume.[1] Any factor that diminishes heart rate or stroke volume response during activity can limit aerobic capacity. In older adults, there are a number of pathological processes that can contribute to impairments in cardiac output and therefore aerobic capacity.[39] In addition, deconditioning and bed rest can profoundly diminish cardiac output and aerobic capacity.[31]

With aerobic exercise training, cardiac output at rest and during submaximal exercise does not change significantly. Because cardiac output is directly related to metabolic demand, it remains similar under those conditions before and after exercise training. But at maximal workloads, cardiac output increases significantly following a

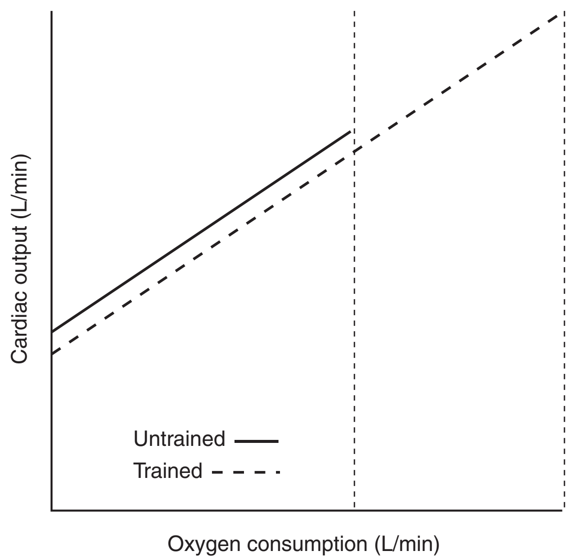

FIGURE 5 Cardiac output (CO) response to an aerobic exercise bout and adaptation following aerobic exercise training.

period of exercise training. This is the result of increases in stroke volume, because heart rate at maximal workloads remains relatively constant. After exercise training, metabolic work capacity (maximal oxygen consumption) is much greater primarily because of a greater cardiac output.[1,28-31]

Arterial Oxygen Content

Arterial oxygen content is determined by the oxygen-carrying capacity of the blood (hemoglobin concentration and red blood cell count) and oxygen loading in the lungs. Gas exchange at the alveolar–capillary interface is influenced by the time it takes a red blood cell to pass from one end of a capillary to the other end (transit time) and the time it takes for complete saturation of hemoglobin with oxygen in the pulmonary capillary (equilibrium time). Pulmonary capillary transit time at rest and during exercise normally exceeds equilibrium time, which allows for complete hemoglobin saturation. During aerobic exercise, transit time shortens because blood flow rate increases. The pulmonary arterioles normally vasodilate during exercise in order to accommodate the increased cardiac output and maintain adequate time for oxygen loading.[40]

Oxygen loading in the lungs is fairly well preserved during early aging but decreased oxygen saturation can be seen in the oldest-old (more than age 85 years).[1] With pathology, equilibrium time can become greater than transit time, leading to oxygen desaturation. This can be due to slowed oxygen diffusion (increased equilibrium time) or less time for oxygen loading (decreased transit time) across the alveolar–capillary interface.[41] This occurs in diseases that cause thickening of the alveolar–capillary membrane (e.g., chronic obstructive pulmonary disease) and low partial pressure of alveolar oxygen (e.g., restrictive pulmonary disease). Decreased transit time occurs when blood flow rate is elevated. This can occur when there is either inadequate vasodilation or an increase in cardiac output or both. Fast pulmonary arterial flow rates can be due to destruction of pulmonary capillaries (e.g., emphysema), a functional reduction in arterial conduits (e.g., pulmonary emboli), or increased cardiac output (e.g., renal failure).[28,41]

Aerobic exercise training does not normally change oxygen loading in the lungs, which is typically at full capacity. Some studies suggest that highly trained athletes have such a large cardiac output that oxygen saturation may drop during maximal exercise. This phenomenon has been attributed to an inability of the pulmonary vasculature to dilate enough to accommodate the increase in cardiac output resulting in a very high flow rate and decreased transit time[28,31]; however, this phenomenon is not likely to occur in most older adults or limit aerobic capacity, even in masters athletes.[1]

Venous Oxygen Content

Venous oxygen content is determined by oxygen delivery, uptake, and use in the peripheral tissues. Oxygen is required for continued regeneration of ATP through oxidative metabolism. Without adequate oxygen, energy production from glucose and fats is severely limited. When limited energy production occurs from inadequate oxygen, the energy for skeletal muscle cross-bridge cycling/muscle contraction must come primarily from anaerobic metabolism of glucose (glycolysis) and very limited use of fat as an energy substrate, leading to the rapid onset of fatigue and impaired aerobic capacity. During aerobic exercise, the lower venous oxygen content is primarily due to greater oxygen demand of the working skeletal muscle and diversion of blood to those capillaries. The other factor that reduces venous oxygen content during exercise is the shunting of blood flow away from nonmetabolically active tissues resulting in greater oxygen extraction from those capillary beds.[28,42]

Peripheral oxygen utilization with aging is often impaired by a variety of mechanisms. Pathology that interferes with blood flow, either on a macrovascular level (e.g., peripheral arterial disease) or a microvascular level (e.g., diabetes), can reduce oxygen utilization by peripheral tissues. Also, cellular changes, such as decreased myoglobin and mitochondrial density, can impair use of oxygen for energy production in skeletal muscle. Impaired aerobic capacity because of the loss of skeletal muscle oxidative capacity is common with decreased use, including deconditioning (e.g., bed rest), immobilization (e.g., extremity casting), peripheral nerve lesions (e.g., nerve entrapment syndromes), and central nervous system pathology (e.g., spinal cord injury).[42,43]

Following a period of aerobic exercise training, venous oxygen levels remain similar to levels measured at rest. At maximal exercise intensities, venous oxygen content may decrease slightly. Lower venous oxygen content with training is due to greater oxygen extraction at the tissue level and more effective distribution of cardiac output due to increased skeletal muscle capillary density. Skeletal muscle extraction and utilization of oxygen is facilitated by many adaptations such as increased skeletal muscle capillary density, mitochondrial proliferation, and increased skeletal muscle myoglobin concentrations.[42,43]

Arteriovenous Oxygen Difference

Gas exchange in the peripheral tissues is reflected in the arteriovenous oxygen difference, the difference between arterial and venous content of oxygen. Blood leaving the lungs normally has an oxygen content of 16 to 24 mL/100 mL blood and an oxygen saturation of approximately 95% to 98%. The arteriovenous oxygen difference at rest is approximately 5 mL/100 mL blood (25%). During acute aerobic exercise, oxygen extraction increases to approximately 15 to 20 mL/100 mL blood (75%-100%), as illustrated in Figure 12-6. The arteriovenous oxygen difference is greater during exercise, normally resulting from lower venous oxygen content in the presence of stable arterial oxygen content.[28-30]

With aging, sedentary people show a decline in arteriovenous oxygen difference during aerobic exercise.[42] A number of pathological processes can contribute to impairments in oxygen delivery and use (arteriovenous difference) and therefore aerobic capacity.[39] In addition, deconditioning and bed rest can profoundly diminish oxygen use in skeletal muscle and therefore aerobic capacity.[42,43]

Following a period of aerobic exercise training, the arteriovenous oxygen difference remains similar at rest. At maximal exercise intensities, the arteriovenous oxygen difference may increase slightly. This increase in arteriovenous oxygen difference is the result of lower venous oxygen content without a change in arterial oxygen content. Interestingly, older women show an increase in arteriovenous difference during exercise after aerobic training but older men do not.[44]

PHYSICAL THERAPY EXAMINATION

History

A comprehensive history of a patient with impaired aerobic capacity helps to elucidate contributory factors and to determine appropriate interventions. In addition, it is important to identify risk factors for cardiovascular disease and appropriate interventions based on risk and patient setting. Screening for cardiovascular risk factors, defi ned in Table 12-1 , serves many purposes, including determining need for referrals to other professionals, selecting specifi c tests and measures, establishing the prognosis, and developing a plan of care. [13] History and screening determine if a patient has experienced any signs or symptoms highly suggestive of signifi cant cardiovascular or pulmonary disease. These signs and symptoms include shortness of breath at rest or with mild exertion, pain, discomfort (or other anginal equivalent) in the chest, neck, jaw, arms, or other areas that may result from cardiac ischemia, orthopnea, paroxysmal nocturnal dyspnea, bilateral ankle edema, palpitations, tachycardia, intermittent leg claudication, known heart murmur, and undue fatigue with usual activities. [13]

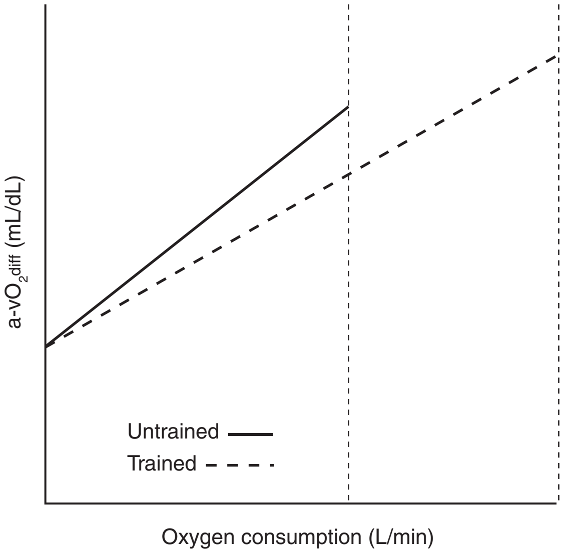

FIGURE 6 Arteriovenous oxygen difference (a-vO$_2$diff) response to an aerobic exercise bout and adaptation following aerobic exercise training.

Systems Review

The examination of a patient with impaired aerobic capacity should include a systems review of the anatomic and physiological status of the four primary Practice Pattern systems, in addition to communication ability, affect, cognition, language, and learning style. [14] With aerobic capacity impairment, screening of the integumentary, musculoskeletal, and neuromuscular systems provides invaluable information for patient evaluation, diagnosis, prognosis, and intervention planning. Assessment of heart rate, respiratory rate, blood pressure, and edema is recommended for cardiovascular and pulmonary system screening. Integumentary system screening includes assessment of skin integrity, skin color, and presence of scar. Musculoskeletal system screening includes assessment of body symmetry, joint range of motion, muscle strength, height, and weight. Neuromuscular system screening includes assessment of balance, locomotion, transfers, and motor control. [14]

Tests and Measures

Signs and Symptoms in Response to Increased Oxygen Demand. Assessment of a patient's cardiovascular and pulmonary response to functional activity/ aerobic exercise can provide important information about any aerobic capacity impairments, and factors contributing to it. Baseline measurement of resting vital signs, including heart rate, blood pressure, respiratory rate, and oxygen saturation provides valuable information regarding the patient's physiological state. Measuring these vital signs during aerobic exercise and comparing them to the patient's resting values can be used to evaluate aerobic capacity. As discussed in the first part of this lesson, aerobic exercise or activity stresses the oxygen delivery system and produces predictable changes in vital signs. Heart rate should increase proportionately to the metabolic demand placed on the body. Systolic blood pressure refl ects cardiac output and therefore should also go up in proportion to the metabolic demand of the

TABLE 1	Cardiovascular Disease Risk Factors
Positive Risk Factors	**Defining Criteria**
Age	Men ages 45 years or older; women ages 55 years or older
Family history	Myocardial infarction, coronary revascularization, or sudden death before age 55 years in father or other male first-degree relative, or before age 65 years in mother or other female first-degree relative
Cigarette smoking	Current cigarette smoker or those who quit within the previous 6 months or exposure to environmental tobacco smoke
Sedentary lifestyle	Not participating in at least 30 minutes of moderate intensity (40% to 60% VO_2R) physical activity on at least 3 days of the week for at least 3 months
Obesity*	Body mass index $\geq$30 kg/m^2 *or* waist girth >102 cm (40 in.) for men and >88 cm (35 in.) for women
Hypertension	Systolic blood pressure (BP) $\geq$140 mmHg and/or diastolic BP $\geq$90 mmHg, confirmed by measurements on at least two separate occasions, *or* on antihypertensive medication
Dyslipidemia	Low-density lipoprotein (LDL-C) cholesterol $\geq$130 mg/dL (3.37 mmol/L) *or* high-density lipoprotein (HDL-C) cholesterol <40 mg/dL (1.04 mmol/L) *or* on lipid-lowering medication. If total serum cholesterol is all that is available, use $\geq$200 mg/dL (5.18 mmol/L)
Prediabetes	Impaired fasting glucose (IFG) = fasting plasma glucose $\geq$100 mg/dL (5.50 mmol/L) but <126 mg/dL (6.93 mmol/L) *or* impaired glucose tolerance (IGT) = 2-hour values in oral glucose tolerance test (OGTT) $\geq$140 mg/dL (7.70 mmol/L) but <200 mg/dL (11.00 mmol/L) confirmed by measurements on at least two separate occasions
Negative Risk Factors	**Defining Criteria**
High serum HDL cholesterol†	$\geq$60 mg/dL (1.55 mmol/L)

*Professional opinions vary regarding the most appropriate markers and thresholds for obesity; therefore, allied health professionals should use clinical judgment when evaluating this risk factor.

†Note: It is common to sum risk factors in making clinical judgments. If HDL is high, subtract one risk factor from the sum of positive risk factors, because high HDL decreases CVD risk.

(Adapted from Thompson WR, Gordon NF, Pescatello LS, editors: ACSM's guidelines for exercise testing and prescription. Philadelphia, PA, 2010, Wolters Kluwer/Lippincott Williams & Wilkins.)

exercise or activity. Diastolic blood pressure reflects total peripheral resistance, which remains relatively stable in most people during aerobic exercise. Respiratory rate increases with mild- to moderate-intensity aerobic exercise and then plateaus as exercise intensity continues to increase. Oxygen saturation should remain stable with aerobic exercise because arterial oxygen content should not change under normal conditions.

Patient symptoms can also be used to assess aerobic capacity. Onset of symptoms such as fatigue, shortness of breath, and weakness during exercise are often too ubiquitous and nonspecific to provide clinically useful information. However, several established symptom scales can be used to objectively ascertain patient symptoms such as dyspnea, angina, claudication, and perceived exertion (Box 12-2). In addition, assessment of pain can help to differentiate among competing hypotheses about the genesis of an activity limitation that might also be due to impaired aerobic capacity. Patient symptoms during aerobic exercise can also provide information regarding central perfusion (e.g., syncope, lightheadedness, or change in mental status) and peripheral perfusion (e.g., extremity tingling, numbness, or coldness).

6-Minute Walk Test. Walk tests are commonly used clinically to measure aerobic capacity in older adults. Walk tests provide information about patient endurance/aerobic capacity and functional activities that require household and community ambulation. Cooper originally described a 12-minute run test in 1968, which was subsequently modified to a 12-minute walk test and then to both 2- and 6-minute walk tests.[45,46] Walk tests are very inexpensive to administer because they require minimal equipment, facility space, expertise, and time. They can be used for a wide variety of patients and practice settings.[47-52] Walk tests are particularly useful for patients that require use of an assistive device for ambulation or that have very low exercise tolerance. In addition, walk tests pose very little risk to patients because the exercise intensity is completely controlled by the patient and rest intervals can be taken as necessary. Distance is the primary outcome measured with walk tests. Patients are instructed to walk as far as possible in the designated amount of time (2, 6, or 12 minutes) on an established, standardized pathway. It is important that the patients' self-selected walking speed not be altered by obstacles or traffic in the pathway, others walking alongside them, or the therapist guarding/assisting.[53,54] Standardization of walk test procedures is crucial for optimal reliability, sensitivity, and interpretation of results. It is important to provide consistent verbal encouragement during walk tests, choosing either no feedback or similar verbal phrases at each administration. Guyatt et al[55] found that verbal encouragement during a 6-minute

BOX 2	Commonly Used Symptom Scales

Angina Scale
1 Mild, barely noticeable
2 Moderate, bothersome
3 Moderately severe, very uncomfortable
4 Most severe or intense pain ever experienced

Dyspnea Scale
1 Light, barely noticeable
2 Moderate, bothersome
3 Moderately severe, very uncomfortable
4 Most severe or intense dyspnea ever experienced

Claudication Scale
1 Definite discomfort or pain, but only at initial or modest levels (established, but minimal)
2 Moderate discomfort or pain from which the patient's attention can be diverted (e.g., by conversation)
3 Intense pain (short of grade 4) from which the patient's attention cannot be diverted
4 Excruciating and unbearable pain

Rating of Perceived Exertion (RPE)
0 = Nothing at all
1 = Very light
2 = Fairly light
3 = Moderate
4 = Some what hard
5 = Hard
6
7 = Very hard
8
9
10 = Very, very hard

walk test improved performance and increased within-person variability in patients with chronic airflow limitation and heart failure. Although multiple trials of a walk test are ideal to minimize the effects of learning,[54,56-59] this is often not feasible in a clinical setting, especially with older patients who have low aerobic capacity. Finally, the length and shape of the walking course influences distance covered on a walk; therefore, it is important to standardize the walking course for comparison of repeated measurements (i.e., initial and discharge tests). Shorter courses produce shorter walk test distances than longer courses, and linear courses produce shorter walk test distance than circular and rectangular courses.[53]

Walk test distance can be evaluated by comparing the patient's distance to reference values. When used as an outcome measure, change in walk test distance reflects change in aerobic capacity with intervention. Gibbons et al[60] reported 6-minute walk test distances for multiple repetitions in healthy subjects between the ages of 20 and 80 years. Their normative data for subjects between ages 60 and 80 years were 688.8 ± 89.3 m for men and 584 ± 53 m for women. Lusardi et al[61] identified normative distances for community-dwelling older adults when completing the 6-minute walk test once under typical clinical conditions, including use of an assistive device as needed.[61] She found that 60- to 69-year-old subjects (men and women combined) walked 420.4 m ± 105.4 m during the 6-minute walk test and 80- to 89-year-olds walked 292.1 ± 112.7 m. Steffen et al[62] evaluated community-dwelling older adults but eliminated subjects requiring use of assistive devices. She obtained scores more similar to Gibbons's for 60- to 69-year-olds (572 ± 92 m for males; 538 ± 92 m for females), and for 80- to 89-year-olds (417 ± 73 m for males; 392 ± 85 m for females).

Graded Exercise Testing. Graded exercise testing can be used to assess aerobic capacity objectively and has been used extensively in the past but is not as widely used now because of its time/cost burden and indirect relationship to functional ability. Briefly, graded exercise testing can be used to (1) diagnose cardiovascular and/or pulmonary disease, (2) determine disease severity/risk stratification, (3) evaluate functional ability, (4) establish baseline for exercise prescription or disease progress, and (5) evaluate intervention effectiveness. Data collection during graded exercise testing often includes measurement of heart rate, electrocardiographic (ECG) information, oxygen saturation, blood pressure, rating of perceived exertion (RPE), and signs and symptoms. Graded exercise test modes include treadmill walking/running, leg cycle ergometry, arm cycle ergometry, and stair stepping. Recently, Mendelsohn et al[63] described the validity of a graded exercise test as good to excellent using reciprocal upper and lower body forward and backward exercise using a NuStep in frail older adults. Graded exercise tests most often employ continuous protocols consisting of progressive preset stages of increasing work intensities with no rest intervals. Graded exercise tests can be submaximal (i.e., stopped at a preset exercise intensity), symptom limited (i.e., stopped when a specified contraindication presents), or maximal (i.e., patient exercises to volitional exhaustion). Outcomes of a graded exercise test include oxygen consumption, heart rate, RPE, and sign/symptom threshold. Oxygen consumption can be directly measured if metabolic instrumentation is available, but more commonly it is estimated using established equations.[13]

Graded exercise testing may be administered by a physical therapist in some circumstances, such as when trying to determine whether a patient's maximal aerobic capacity is limiting function. For example, when a patient wants to return to a specific occupational or recreational activity, it is often important to determine if the associated aerobic demands are safe. Graded exercise testing may also be used to determine symptom threshold. For example, in patients with claudication, treadmill walking at a specific speed and grade frequently will provoke leg pain. Graded exercise testing can also be used when a walk test is not feasible. For example, in patients with lower extremity paralysis testing with an upper body ergometer is most feasible.

Self-Report Measures. Self-report assessment measures can be useful in reflecting the functional impact of impaired aerobic capacity on physical activity level, participation, and health-related quality of life in older adults. Self-report assessments require patients to answer questions and rate statements regarding subjective perception of their functional ability. Self-report instruments are ideal for measuring patient perception of constructs, such as pain, difficulty, and depression, especially in home and community environments in addition to clinical settings. Functional ability is often measured using generic, self-report quality of life instruments. A primary disadvantage of generic health-related self-report instruments is they may not be as sensitive to change as disease-specific health-related self-report instruments.[64-66]

Generic health-related quality of life instruments, such as the Medical Outcomes Study Short Form 36 Health Survey (SF-36) or RAND 36-Items Health Survey, are commonly used in older adults. These instruments have been used extensively to study health-related quality of life in patients with impaired aerobic capacity secondary to cardiopulmonary problems since they have well-documented degrees of reliability, validity, and sensitivity.[64,67-69] Ten of the twelve items of the Physical Function subscale of this instrument reflect aerobic capacity (Table 12-2). To improve time efficiency and reduce response burden, this subscale can be used independent from the entire instrument.

Disease-specific self-report instruments also reflect patient aerobic capacity and often are more sensitive to change than generic self-report instruments. But many of the cardiovascular and pulmonary self-report instruments available rely on concurrent symptoms such as angina (Seattle Angina Questionnaire), dyspnea (Minnesota Living with Heart Failure Questionnaire, Kansas City Cardiomyopathy Questionnaire), or pain (Heart Surgery Symptom Inventory), which limits their use to specific populations of older patients.[70-73] The Duke Activity Status Index[74] is a self-report measure of aerobic capacity as it relates to functional activities. Although the Duke Activity Status Index is a disease-specific instrument, it was developed for patients with cardiovascular disease, which is very prevalent in older adults, affecting 73% of those between the ages of 60 and 79 years. The Duke Activity Status Index measures functional capacity using 12 questions regarding the ability to perform specific tasks. The questions are answered on a nominal scale (yes/no) and scores are weighted relative to the metabolic demand of the task (Table 12-3). The summary score generated from the Duke Activity Status Index reflects an estimation of the patient's maximal oxygen consumption; therefore, higher scores indicate better aerobic capacity than lower scores with a maximal possible score of 65.7.[75,76] The Duke Activity Status Index has been used in numerous populations of older patients to quantify aerobic capacity.[77-79]

The Physical Activity Scale for the Elderly (PASE) is a 10-item self-report questionnaire designed to assess leisure, household, and occupational activity in adults. This instrument measures physical activity participation involving tasks beyond activities of daily living. The PASE has been used to assess activity level in a variety of study designs ranging from retrospective to epidemiologic, and patient populations with chronic heart failure, pulmonary disease, and coronary heart disease.[80-82] In a study with 277 subjects, the PASE test–retest reliability coefficient was 0.75.[80] The PASE validity was examined

TABLE 2 Items in the Physical Function Subscale of the RAND-36 Item Health Survey and the SF-36

The following items are about activities you might do during a typical day. Does your health now limit you in these activities? If so, how?

	(Circle One Number on Each Line)		
	Yes, limited a lot	**Yes, limited a little**	**No, not limited at all**
3. Vigorous activities, such as running, lifting heavy objects, participating in strenuous sports	1	2	3
4. Moderate activities, such as moving a table, pushing a vacuum cleaner, bowling, or playing golf	1	2	3
5. Lifting or carrying groceries	1	2	3
6. Climbing several flights of stairs	1	2	3
7. Climbing one flight of stairs	1	2	3
8. Bending, kneeling, or stooping	1	2	3
9. Walking more than a mile	1	2	3
10. Walking several blocks	1	2	3
11. Walking one block	1	2	3
12. Bathing or dressing yourself	1	2	3

(From Hays RD, Sherbourne CD, Mazel RM: The RAND-36-Item health survey 1.0. Health Econ 2:217-227, 1993.)

TABLE 3 Duke Activity Status Index

Can you...	Weighted score
1. take care of yourself, that is, eating, dressing, bathing, or using the toilet?	2.75
2. walk indoors, such as around your house?	1.75
3. walk a block or two on level ground?	2.75
4. climb a flight of stairs or walk up a hill?	5.50
5. run a short distance?	8.00
6. do light work around the house, such as dusting or washing dishes?	2.70
7. do moderate work around the house, such as vacuuming, sweeping floors, or carrying groceries?	3.50
8. do heavy work around the house, such as scrubbing floors, or lifting or moving heavy furniture?	8.00
9. do yard work, such as raking leaves, weeding, or pushing a power mower?	4.50
10. have sexual relations?	5.25
11. participate in moderate-intensity recreational activities, such as golf, bowling, dancing, doubles tennis, or throwing a baseball or football?	6.00
12. participate in strenuous sports, such as swimming, single tennis, football, basketball, or skiing?	7.50
Total	

(Modified from Hlatky MA, Boineau RE, Higginbotham MB, et al: A brief self-administered questionnaire to determine functional capacity (The Duke Activity Status Index). Am J Cardiol 64:651-654, 1989.)

by comparison with accelerometry data ($r = 0.49$). The PASE was significantly correlated with strength, resting heart rate, systolic blood pressure, peak oxygen uptake, and quality of life ($P < 0.05$, $r = |0.13 - 0.42|$).[80] Although the PASE does not directly measure aerobic capacity, the level of daily physical activity parameters associated with aerobic capacity are directly related.

EVALUATION, DIAGNOSIS, AND PROGNOSIS

The evaluation, diagnosis, and prognosis of older adults with aerobic capacity impairment require integration of oxygen uptake, transport, delivery and utilization systems knowledge, physical therapy management strategies, and patient history and examination findings. Evaluation of older adults with aerobic capacity impairment should include screening for referral, identification of contributing pathologies with concomitant impairments, activity limitations, participation restrictions and disability, and differential diagnosis of cause(s). Lastly, anticipated prognosis related to improvement in aerobic capacity and the expected outcomes of remediating poor aerobic capacity should be determined.

Decisions to Refer

Evaluation of the older patient with an aerobic capacity impairment first requires that the physical therapist identify any history, signs, or symptoms suggestive of major medical issues that are undiagnosed or poorly managed. For example, if an older patient is referred to physical therapy with a diagnosis of bilateral knee osteoarthritis, but other examination findings highly suggest peripheral arterial disease (skin atrophic changes, absent dorsal pedal and posterior tibial pulses, onset of calf pain with walking and relief with rest, etc.), it would be appropriate to refer the patient for medical follow-up. Also consider an older patient with known hypertension being treated with antihypertensive medication who presents to physical therapy with a blood pressure of 212/116 mmHg. This patient should be referred back to the physician before beginning physical therapy intervention that involves exercise or substantial physical activity. Next, screening for cardiovascular disease risk is completed by utilizing information obtained in the patient examination, including history of known disease, signs and symptoms, and presence of risk factors. This information can then be used to determine appropriate referral to a physician, if it has not already taken place (i.e., Direct-access), exercise testing, and exercise intervention. Physical therapists often detect currently undiagnosed abnormalities in the cardiovascular and pulmonary systems in older adults because assessment involves physical activity. Lastly, the presence of contraindications for exercise participation and indications for stopping exercise should be determined, as outlined in Box 3 .[13]

Evaluation of Vital Signs

Evaluation of the patient's vital signs at rest can provide insight on factors contributing to aerobic impairment based on the oxygen delivery model. Resting bradycardia in older adults is most often due to medications (i.e., β-blockers) or a cardiac dysrhythmia such as atrioventricular block or sick sinus syndrome.[37] Resting tachycardia in older adults may be due to hypotension, atrial

BOX 3 Aerobic Exercise Contraindications and Stopping Points

Absolute Exercise Contraindications
- Unstable angina
- Uncontrolled cardiac dysrhythmias causing symptoms of hemodynamic compromise
- Uncontrolled symptomatic heart failure
- Acute or suspected major cardiovascular event (including severe aortic stenosis, pulmonary embolus or infarction, myocarditis, pericarditis, or dissecting aneurysm)
- Acute systemic infection, accompanied by fever, body aches, or swollen lymph glands
- A recent significant change in resting ECG suggestive of ischemia, myocardial infarction, or other acute cardiac event*

Relative† Exercise Contraindications
- Known significant cardiac disease (including left main coronary stenosis, moderate stenotic valvular disease, hypertrophic cardiomyopathy, high-degree atrioventricular block,* ventricular aneurysm)
- Severe arterial hypertension (systolic BP of >200 mmHg or a diastolic BP of >110 mmHg) at rest
- Tachydysrhythmia or bradydysrhythmia*
- Electrolyte abnormalities
- Uncontrolled metabolic disease
- Chronic infectious disease
- Mental or physical impairment leading to inability to exercise safely

Absolute Indications for Terminating Exercise
- Drop in systolic BP of >10 mmHg from baseline despite an increase in workload when accompanied by other evidence of ischemia
- Moderately severe angina (>2/4)
- Increasing nervous system symptoms
- Signs of poor perfusion
- Subject's desire to stop
- Technical difficulty with monitoring equipment
- Sustained ventricular tachycardia*
- ST elevation (+1.0 mm) in leads without diagnostic Q-waves*

Relative Indications for Terminating Exercise
- Drop in systolic BP of >10 mmHg from baseline despite an increase in workload in the absence of other evidence of ischemia
- Increasing chest pain
- Hypertensive response (systolic BP of >250 mmHg or diastolic BP of > 115 mmHg)
- Fatigue, shortness of breath/wheezing, leg cramps, or claudication
- ST or QRS changes such as excessive ST depression (>2 mm ST-segment depression)*
- Arrhythmias other than sustained ventricular tachycardia (including multifocal premature ventricular contractions (PVCs), triplets of PVCs, supraventricular tachycardia, heart blocks, or bradyarrhythmias)*
- Development of bundle-branch block or intraventricular conduction delay that cannot be distinguished from ventricular tachycardia*

*Assume that ECG monitoring is available.
†Relative contraindications can be superseded if there are benefits.
(*Adapted from Thompson WR, Gordon NF, Pescatello LS, editors: ACSM's guidelines for exercise testing and prescription. Philadelphia, PA, 2010, Wolters Kluwer/ Lippincott Williams & Wilkins.)*

fi brillation or fl utter, cardiac autonomic disruption, or ventricular tachycardia. Systolic hypertension at rest in older adults is most often due to uncontrolled essential hypertension. [74] Systolic hypotension at rest occurs when cardiac output is low, such as with orthostatic hypotension, atrial fi brillation/fl utter, heart failure, or volume depletion/dehydration. Oxygen desaturation at rest occurs when there is impaired oxygen diffusion between the alveolar capillary membrane. This phenomenon can occur when diffusion is slowed as a result of low oxygen concentrations in the alveoli or thickening of the interface. In addition, oxygen desaturation can also occur when blood fl ow through the pulmonary capillaries is increased, reducing time for oxygen exchange. Normal vital sign ranges at rest and implications are summarized in Table 4 .

Vital sign response during aerobic activity can help to elucidate causes of aerobic capacity impairment. When physiological response to aerobic exercise is abnormal, the underlying cause of impaired oxygen delivery may be determined. Both a decrease in or a failure to increase heart rate or systolic blood pressure with exercise suggest that the heart is unable to respond to increased oxygen demand. A rise in diastolic blood pressure during aerobic exercise may indicate coronary artery disease and poses a dangerous threat to patient safety because it reduces coronary perfusion. Oxygen desaturation during exercise in older adults often occurs when increased pulmonary capillary flow reduces time for oxygen uptake in the presence of impaired diffusion. Oxygen desaturation during aerobic exercise does not reflect increased oxygen demand in the peripheral tissues, that is, skeletal muscles.

TABLE 4 Summary of Vital Sign Interpretation

Vital Sign	Normal Range (resting)	Implications
Heart rate	60-100 bpm	<60 bpm ➔ no action if asymptomatic and normal ECG refer to physician if symptomatic refer to physician if no ECG available and there is no history of dysrhythmia or chronotropic medication use 120-150 bpm ➔ precaution to initiating activity/exercise refer to physician >150 bpm ➔ contraindication to initiating activity/exercise refer to physician immediately With exercise/activity ➔ increases in proportion to workload significant drop is an indication to stop exercise
dBP	70-90 mmHg	<70 mmHg ➔ no action if asymptomatic refer to physician if symptomatic >115 mmHg ➔ contraindication to initiating activity/exercise refer to physician With exercise/activity ➔ remains similar to resting or may drop slightly increase >115 is an indication to stop exercise
sBP	100-140 mmHg	<100 mmHg ➔ no action if asymptomatic refer to physician if symptomatic >200 mmHg ➔ contraindication to initiating activity/exercise refer to physician With exercise/activity ➔ increases in proportion to workload >250 mmHg is an indication to stop exercise
SpO_2	≥90%	86%-89% ➔ consider adding or increasing supplemental oxygen refer to physician if previously undiagnosed ≤85% ➔ add or increase supplemental oxygen contraindication to initiating activity/exercise refer to physician if remains <90% With exercise/activity ➔ should remain ≥90% 86%-89% relative indication to stop exercise ≤85% absolute indication to stop exercise

Oxygen Consumption, Saturation and Energy Expenditure

In most adults, including older adults, maximal cardiac output is the physiological variable that limits maximal oxygen consumption and therefore aerobic capacity. During maximal aerobic exercise, the capacity for increasing ventilation is much greater than the capacity for increasing cardiac output.[28,31] Also there is a strong correlation between cardiac output and aerobic capacity measured by maximal oxygen consumption. Even during maximal exercise of older adults, oxygen saturation is maintained higher than 90%, suggesting no limitation in pulmonary gas exchange. But when pathology affects oxygen loading across the alveolar–capillary interface, exercise may cause oxygen desaturation and therefore be a limiting factor in maximal aerobic capacity. Limitations in skeletal muscle oxygen extraction/utilization are not thought to normally limit aerobic capacity but can be regarded as contributory factors. Sometimes a patient's apparent impaired aerobic capacity is not limited at all by oxygen delivery and utilization but rather by an adverse symptom such as pain or fear of falling.[83]

Sometimes older patients may present with what appears initially to be an impairment in aerobic capacity, but is actually a high energy expenditure for physical activity. One common clinical example of high energy expenditure during physical activity is the increased metabolic demand during movement associated with obesity. Another cause of high energy expenditure during activity, particularly walking, is decreased movement economy (i.e., greater oxygen consumption than normal is required for a particular workload). Reduced economy can occur whenever movement coordination is altered, for example, with hemiparesis or lower extremity amputation. Although aerobic capacity may not be significantly impaired under these conditions, older patients are performing functional activities at a higher percentage of their maximal aerobic capacity that can contribute to onset of fatigue.

Diagnostic Classification

The *Guide to Physical Therapist Practice* classifications used most often for patients with impaired aerobic capacity are the Cardiovascular/Pulmonary Preferred Practice Patterns. Pattern B: Impaired Aerobic Capacity/ Endurance Associated with Deconditioning may include the following exam findings: decreased endurance, increased cardiovascular or pulmonary response to low-level workloads, increased perceived exertion with functional activities, and inability to perform routine work tasks as a result of shortness of breath. Pathologies that may be included under this practice pattern are acquired immune deficiency syndrome, cancer, cardiovascular disorders, chronic system failure, musculoskeletal disorders, neuromuscular disorders, and pulmonary disorders. Some of the anticipated outcomes of physical therapy intervention for older adults with impaired aerobic capacity include the following: (1) symptoms associated with increased oxygen demand are decreased; (2) tissue perfusion and oxygenation are enhanced; (3) endurance is increased; (4) energy expenditure per unit of work is decreased; (5) ability to perform physical tasks is improved; and (6) ability to resume roles in self-care, home management, work, community, and leisure is improved. Improvements in risk reduction/prevention and health status are anticipated outcomes for older patients with impaired aerobic capacity as well.[14]

Factors Affecting Prognosis

The prognosis for improving aerobic capacity in older adults is multifactorial and depends on the patient's prior level of physical inactivity, degree of pathology affecting the oxygen transport system, and activity restrictions that impede habitual activity level and participation in aerobic exercise. Factors that influence prognosis of a patient with impaired aerobic capacity are listed in Box 4. The physiological adaptations that occur secondary to inactivity/bed rest and increased habitual activity level have a dose-response effect. The greater the change in activity level, the greater the degree of physiological adaptation that will occur. Consider the example of an older patient with New York Heart Association class III heart failure (dyspnea with ordinary activities). A prognosis for moderate improvement in aerobic capacity sufficient to increase household ambulation distances would be reasonable for this patient. In contrast, a reasonable prognosis for improvement in aerobic capacity for an older adult who was previously healthy but now diagnosed with pneumonia severe enough to require hospitalization and ventilatory support (e.g., bilevel positive-airway pressure) for 6 days, would be full return to previous activities.

BOX 4 Factors That Influence Prognosis of a Patient with Impaired Aerobic Capacity

- Accessibility and availability of resources
- Adherence to the intervention program
- Age
- Anatomic and physiological changes related to growth and development
- Caregiver consistency or expertise
- Chronicity or severity of the current condition
- Cognitive status
- Comorbidities, complications, or secondary impairments
- Concurrent medical, surgical, and therapeutic interventions
- Decline in functional independence
- Level of impairment
- Level of physical function
- Living environment
- Multisite or multisystem involvement
- Nutritional status
- Overall health status
- Potential discharge destinations
- Premorbid conditions
- Probability of prolonged impairment, functional limitation, or disability
- Psychological and socioeconomic factors
- Psychomotor abilities
- Social support
- Stability of the condition

(*Data from American Physical Therapy Association: Guide to physical therapist practice, ed 2. Phys Ther, 81:9-744, 2001.*)

PLAN OF CARE INTERVENTIONS

Therapeutic exercise, functional training, and prescription of assistive, adaptive, or supportive devices are the most frequently used interventions to improve aerobic capacity in older adults with aerobic capacity limitations. Other types of procedural interventions are appropriate when they address secondary issues that may be limiting aerobic capacity or ability to participate in therapeutic exercise or functional training. For example, use of airway clearance techniques would be appropriate to improve oxygen loading and therefore aerobic capacity for patients with pulmonary mucus retention.

Exercise

Therapeutic exercise is the cornerstone for treating older patients with impaired aerobic capacity. When prescribing exercise for older adults to improve aerobic capacity, the general principles of exercise should be considered. The overload principle of exercise training states that increases in habitual aerobic workload above that normally experienced will cause adaptations that improve maximal aerobic capacity. Conversely, the reversibility principle of training indicates that restrictions in habitual aerobic workload below that normally experienced will cause adaptations that impair maximal aerobic capacity. The greatest degree of improvement in aerobic capacity will occur during activities that are most similar to the training stimulus/activity (aka specificity of training). Conversely, some degree of improvement in aerobic capacity will occur even during activities that are dissimilar to the training stimulus/activity (aka generality of training principle).[13]

Traditionally, the four components of an aerobic exercise prescription are mode, intensity, duration, and frequency. The greatest improvements in aerobic capacity occur when the *mode* of exercise involves the use of large muscle groups contracting rhythmically over prolonged periods of time. Aerobic exercise modes can be categorized into weight-bearing (high- and low-impact) and non–weight-bearing activities. Examples of aerobic exercise modes in each category are provided in Box 12-5. When selecting a mode of aerobic exercise for a patient, physical therapists should also consider risk of injury, likelihood of adherence, and unique vocational/recreational objectives. It is important to select a mode of exercise that is not too metabolically demanding so that it can be continued for a period of time long enough to stimulate aerobic adaptation.

Aerobic exercise *intensity* can be based on heart rate (10 to 20 bpm below onset of adverse signs or symptoms or 60% to 90% of maximal heart rate) or on the individual's RPE (4 to 6 on a 10-point scale; or 12 to 16 on a 19-point scale).[13,14,84] Maximal heart rate (HR_{max}) can be predicted from age or determined by maximal graded exercise test. The most commonly used equation to predict maximal heart rate is the Karvonen, $HR_{max} = 220 - age$, but some studies have suggested that this overestimates in adults older than age 40 years and underestimates in adults age 40 years and younger.[13,85,86] As an alternative, maximal heart rate can be calculated using a formula developed by Gellish et al, $HR_{max} = 206.9 - (0.67 \times age)$.[13,87] Exercise intensity has also been defined qualitatively as moderate (physical activity that noticeably increases breathing, sweating, and heart rate) or vigorous (physical activity that substantially increases breathing, sweating, and heart rate).[88]

Aerobic exercise *duration* equal to 20 to 60 minutes of continuous activity is generally recommended for disease risk reduction. However, discontinuous activity can be used in very deconditioned patients when initiating aerobic exercise. Patients with functional capacities of less than 3 to 5 metabolic equivalents (METs) benefit from multiple (i.e., 2 to 4 times per day) and short (i.e., total sum of 20 to 30 minutes) exercise sessions. Recommended aerobic exercise *frequency* is "on most days," but even exercising with limited frequency is better than no exercise at all.[13,88] It is important to note that these recommended thresholds for aerobic exercise are based on epidemiologic evidence for obtaining health benefits.

Newer physical activity guidelines intertwine aspects of intensity, duration, and frequency. The *Physical Activity Guidelines for Americans* recommend that older adults participate in 150 minutes a week of moderate-intensity or 75 minutes a week of vigorous-intensity aerobic exercise.[88,89] Furthermore, aerobic exercise should preferably be performed in episodes of at least 10 minutes and spread throughout the week. It is also acknowledged that additional health benefits are provided by greater amounts of aerobic activity.[88,89] Moderate-intensity exercise is defined as increases in energy expenditure by 3.0 to 5.9 times more than the energy expended at rest (aka METs) or a perceived exertion of 5 to 6 of 10. Vigorous-intensity exercise is defined as increases in energy expenditure by 6.0 or greater times more than the energy expended at rest (METs) or a perceived exertion of 7 to 8 of 10.[88,89]

BOX 5 Example Modes of Aerobic Exercise

Weight-Bearing, High Impact	Weight-Bearing, Low Impact	Non–Weight-Bearing, Nonimpact
Jogging	Walking	Swimming
Aerobic dancing (with jumping)	Leg cycle ergometry	Pool "cycling"/ "kicking"
Stepping (remove feet)	Aerobic dancing (without jumping)	Arm cycle ergometry
Jumping rope	Stepping (stationary feet)	Rowing
Calisthenics	Cross-country skiing	Chair aerobics
	Pool aerobics/walking	

Progression of aerobic exercise in older patients should be individualized and based on the patient's anticipated goals and expected outcomes. Often the initial phase of an aerobic exercise program progression is aimed at attaining the minimum intensity, duration, and frequency for a specific mode of exercise. The improvement phase of an aerobic exercise program progression utilizes a combination of adjustments in mode, intensity, duration, or frequency of exercise to reach a specific exercise capacity goal. For example, often to reach functional milestones, such as walking 150 feet without rest, it is more important to increase the duration rather than the intensity of aerobic capacity training. The exercise prescription parameters that optimally increase aerobic capacity have not been fully elucidated and most likely vary with patient characteristics. For example, Sisson et al[90] found that the volume of aerobic exercise was the most important predictor of improved aerobic capacity in sedentary, postmenopausal women. In addition, Bocalini et al[38] found greater improvement in aerobic capacity in older women participating in water-based versus land-based programs. Whereas both low- and high-intensity aerobic exercise training lowered systolic blood pressure in older adults, only high-intensity exercise training reduced weight and improved lipid profile.[91] Interestingly, Kruger et al[92] reported that often the prescribed dose of aerobic exercise used in research trials was lower than what is currently recommended.

The maintenance phase of an aerobic exercise program involves indefinite continuation of a specified exercise mode, intensity, duration, and frequency to preserve the existing aerobic exercise capacity. Many factors, such as lack of time, fear of injury, or level of importance placed on exercise may influence older patients' ability to engage in continued exercise.[93,94] Some studies suggest that older adults actually have greater self-efficacy (confidence) for symptom management, exercise participation, and physical activity than younger adults.[83,95] It is possible that age brings experience in coping with health problems, and in turn, these coping skills better prepare older adults to engage in physical activity. Over time, older adults may acquire self-management skills for exercise participation despite experiencing symptoms related to chronic conditions.[96,97]

Physical Activity

Another strategy for improving aerobic capacity and health is to increase total energy expended during daily physical activity. Physical activity includes both structured exercise and nonstructured lifestyle activities (physical activity not performed with the intention to constitute a structured period of exercise). Use of pedometers to promote increased physical activity through walking has gained popularity because they are inexpensive and easy to use. Research studies have supported the efficacy of using pedometers to increase physical activity and decrease body mass index and systolic blood pressure. Interestingly, this decrease in body mass index was associated with older age and having an identified step goal.[98] In addition, evidence suggests that there is an inverse relationship between body weight and physical activity. However, there is also a dose-response effect of physical activity on weight, with higher doses capable of providing greater weight loss. Guidelines for prevention of weight gain are 150 to 250 minutes per week of moderately vigorous physical activity with an energy equivalent of approximately 1200 to 2000 kcal/week.[99]

Functional Training

Functional training and physical activity can also be used for older patients with impaired aerobic capacity.[83] Improvement in functional ability often leads to more physical activity, which in turn further improves aerobic capacity. Improvements in balance ability may also contribute to increased aerobic capacity, because fear of falling is related to activity restriction and more sedentary behaviors. In some patients with impaired aerobic capacity (e.g., end-stage respiratory failure), improvement may not be possible, but using strategies that allow optimal function with a deficit in aerobic capacity can be employed. These energy conservation strategies minimize the energy demand of functional tasks by modification, organization, and prioritization. For example, tasks performed in sitting versus standing expend less energy (e.g., preparing food sitting at a table instead of standing at a counter). Another strategy is to plan daily activities to minimize redundancies in movement (e.g., organize a shopping list in the order that items are found in the store). Also, individuals should be encouraged to prioritize activities that are most important for them to do before the onset of fatigue (e.g., finish a woodworking project for a grandchild's birthday), or delegate tasks that are less important (e.g., ask someone else to fix a broken cabinet door). Box 12-6 provides examples of energy conservation techniques that patients with low aerobic capacity can employ.

Device Prescription

Prescription of a supportive or assistive device can help to improve aerobic capacity in some older patients. Oxygen therapy can help improve oxygen delivery in patients who have decreased arterial oxygen saturation. Although physical therapists do not prescribe supplemental oxygen, they often identify patients who would benefit from it and help patients optimize its use especially during activity. Many types of assistive devices may help to improve function and minimize disability in patients with impaired aerobic capacity. For example, four-wheeled walkers with a seat ("Rollators") are often used

BOX 6	Patient Instructional Sheet Highlighting Energy Conservation Techniques

Strategies to conserve energy as you go about your daily activities

- Simplify tasks by planning in advance: get everything ready first, eliminate unnecessary work, and organize your working environment so that everything is handy.
- Break up large tasks into several parts or components.
- Prioritize daily activities to complete the most important tasks first or when you tend to have the most energy during the day.
- Avoid a lot of activity in the first hour after eating. Your body requires a good deal of energy to digest food after eating, and this means less energy available for other things.
- Pace yourself: slow, steady movements will accomplish more with less energy than fast, erratic movements. For example, when going upstairs take one step at a time, with brief rests as needed. Consider having a chair at the top of the stairs to rest, in case you need it.
- Maintain good posture and body mechanics during all activities. Poor posture and body mechanics contribute to fatigue.
- Use a small cart with wheels to transport items, whenever possible. Pushing objects in a cart requires much less energy and is safer than carrying them.
- Store frequently used items in convenient locations close to where they will be used and at shoulder to knee heights—not too high or too low.
- Keep a set of commonly used items on each level of your home.
- Avoid extreme temperatures during activity. Your heart, lungs, and muscles must use additional energy when your body is very hot or very cold.
- Sit during as many tasks as possible. Sitting requires less muscle activity than standing and therefore less energy.
- Complete tasks at waist level and close to your body, whenever possible. You expend more energy when bending down and reaching overhead during activity.
- Never hold your breath. Use pursed-lip breathing whenever you feel out of breath. Breathe out during the most demanding part of a task.
- Use supplemental oxygen during activity, if your doctor has prescribed it for you. Make sure that the flow rate is set correctly. If it is difficult for you to carry your portable oxygen tank, contact your oxygen supplier for alternative methods (many types of tanks and carrying cases are available).
- Get help when you need it! Family and friends are often more than happy to lend a helping hand. Many services may be available to you, such as Meals on Wheels or home health care.

by patients with impaired aerobic capacity to improve function by providing a seat for rest when needed, a basket to carry items, and upper extremity support which may facilitate respiratory muscle activity.[100] Other ambulatory aids can improve aerobic capacity by allowing mobility when weight-bearing is restricted or balance is impaired.

CASE EXAMPLE

History and Interview

Mr. C was a 76-year-old man who developed severe chest pain while lifting bales of hay. His wife took him to the nearest hospital, where his pain was resolved with nitroglycerin. He was diagnosed with acute myocardial infarction and then transferred to the nearest cardiac surgical center. Diagnostic cardiac catheterization was performed, which revealed 80% stenosis in the midportion of the left anterior descending artery, 90% stenosis in the circumflex artery, and 100% occlusion in the second diagonal and right coronary artery. Subsequently, Mr. C underwent emergent coronary artery bypass surgery of four vessels using the left internal mammary artery and left saphenous vein as conduit vessels. His surgery was performed without placing him on extracorporeal circulation (aka cardiopulmonary bypass machine) so his heart remained beating (aka off-pump or beating-heart surgery). Surgical access was via a median sternotomy. Mr. C was discharged from the hospital 6 days after surgery.

Mr. C was referred for outpatient rehabilitation and his initial physical therapy visit was 2 days after hospital discharge. His previous medical history included a right shoulder fracture, hypertension, and type 2 diabetes, but no major surgical procedures. His medications included aspirin, atorvastatin (Lipitor), lansoprazole (Prevacid), atenolol (Lopressor), ferrous sulfate, amlodipine besylate (Norvasc), rosiglitazone maleate (Avandia), insulin (Humulin), albuterol inhaler, hydrocodone/acetaminophen (Lortab), and furosemide (Lasix). Mr. C lived in a rural town (30 miles from a hospital) and with his wife in a two-level single-family home. He reported that he quit smoking 10 years ago, did not exercise regularly, and had a diet high in red meat products. Mr. C's family history was unremarkable for cardiovascular disease or other chronic diseases.

Prior to this episode of care, Mr. C worked the cattle farm that he owned, which required him to lift 70-lb bales of hay. The patient's goal was to return to all previous activities, including farming, but his family wanted him to "retire." Mr. C was independent with all activities of daily living (ADLs), instrumental ADLs (IADLs), and occupational tasks prior to the acute myocardial infarction and open heart surgery. At the initial physical therapy visit, he reported needing assistance with getting into and out of bed, standing up, walking, driving, and all work activities. His current symptoms included chest pain, shortness of breath/dyspnea, severe fatigue, and swelling in his hands and feet.

Systems Review and Examination

Mr. C was alert and oriented to person, place, time, and situation; responded appropriately to questions 80% of the time; and followed multistep directions. He reported that he learned best through demonstration. Mr. C had significant hearing loss, which was partially corrected by bilateral hearing aids, although he stated that he did not like to turn his hearing aids on very often "because it would wear out the batteries." Mr. C was a high school graduate and when questioned regarding his current learning needs, reported that he did not think that he had any. His wife accompanied him and stated that she would like to know what the family needs to do to help him recover.

Integumentary Screening. On integumentary inspection, he had sternal and left lower extremity incisions with staples still present and an abdominal chest tube site open with small amounts of clear serous drainage. He reported pain at the median sternotomy incision site with deep breathing. His dorsal pedal and posterior tibial pulses were right 1 of 3, left 0 of 3, and radial pulses bilaterally 2 of 3; his skin temperature was normal throughout the extremities and trunk.

Musculoskeletal Screening. Mr. C's chest wall motion was limited symmetrically in the upper and lower chest wall with deep breathing. Point tenderness was present in the anterior and posterior chest wall. His postural examination revealed forward head, rounded shoulders, and anterior pelvic tilt.

Active range of motion in his elbows, wrist, hand, lumbar spine, hips, and knees bilaterally were all within normal limits. Mr. C's cervical spine active range of motion was impaired, with all movements to ~50% of normal. His shoulder active range of motion was 110 degrees bilaterally and abduction was 90 degrees bilaterally. No overpressure was applied in the cervical spine and upper extremities because of his recent median sternotomy. Mr. C's ankle plantar flexion was 20 degrees and dorsiflexion was 5 degrees on the left with a tissue approximation end-feel. His right ankle active range of motion was within normal limits.

Mr. C's strength was at least 3 of 5 throughout the trunk and extremities but no resistance was applied in view of the fact that he was less than 2 weeks status post cardiac catheterization and median sternotomy.

Mr. C's height was 68 in. and weight was 229 lbs at the time of the initial physical therapy visit. Based on the body weight reported in his medical chart records, it appeared that his body weight had increased 20 lbs over the past week.

Neuromuscular Screening. Sensation to light touch was intact throughout the bilateral upper and lower extremities and intact on the plantar surface of both feet when tested with a 5.06 monofilament.

Deep tendon reflexes were normal bilaterally in the patellar and Achilles tendons. No clonus was detected with rapid wrist extension or dorsiflexion bilaterally. Mr. C's balance was normal in sitting and impaired in standing, with standing static balance subjectively rated good (4/5) and standing dynamic subjectively rated fair (3/5). Motor function was normal in his upper extremities, with rapid alternating forearm pronation and supination and normal in his lower extremities with heel to shin movement.

Mr. C had impaired functional mobility with limited weight bearing through his upper extremities secondary to the median sternotomy. He required verbal cues and moderate assistance from one person to go from supine to short sitting and back. He transitioned from short sitting to stand with assistance from one person and no upper extremity assist. Mr. C ambulated using a front-wheeled walker and contact guard assist. He was able to ascend and descend five steps using one railing and contact guard assist. His gait pattern was remarkable for decreased step length and heel strike bilaterally during swing.

Cardiovascular and Pulmonary Tests and Measures. Mr. C's general appearance revealed no jugular vein distension, digital cyanosis or clubbing, or signs/symptoms of acute distress. He had visible peripheral edema bilaterally in his feet and hands; the edema in his feet was so severe that he was unable to wear any of his shoes and was wearing slippers. Girth measurements were taken in his lower extremities to objectively assess the amount of edema.

Girth (cm)	Metatarsal heads	Malleoli	Lower leg
Right	28	27	42
Left	39.5	30.2	43

Lung auscultation revealed inspiratory crackles over the 8th to 10th intercostal spaces left posterior chest wall, which improved with activity. Mr. C's heart sounds were a normal S1 and S2 with no murmur, S3, S4, or pericardial friction rub. Mr. C's cough was infrequent, effective with splinting, and not productive. His phonation was normal and breathing pattern was shallow in depth with a regular rhythm.

Mr. C performed a 6-minute walk test during his initial physical therapy visit. During this test, he walked 330 feet using his front-wheeled walker and required one sitting rest period of 2 minutes as a result of overall fatigue. His vital signs were measured before, during, and after the walk test. He denied any adverse symptoms (chest pain, syncope, dyspnea, etc.) during ambulation.

Vital signs	Heart rate (bpm)	Blood pressure (mmHg)	Oxygen saturation (%)	Supplemental oxygen (L/min)
Resting (sitting in chair)	70	138/76	97	None – room air
Walking after 3 minutes	93	X	94	None – room air
Walking after 6 minutes	92	147/54	90	None – room air
Recovery after 5 minutes	74	136/56	97	None – room air

Additional self-report outcome measures that Mr. C completed included the RAND 36-Item Health Survey, a measure of generic quality of life, and the Duke Activity Status Index, a measure of disease-specific functional ability. Initial and discharge results from these outcome measures are presented in Table 5 .

Evaluation

Given the amount of edema in Mr. C's hands and feet bilaterally and his apparent rapid weight gain, it seemed that the patient had significant fluid retention and volume overload. His cardiothoracic surgeon was contacted and Mr. C was seen in his office later that day for adjustment of his medications. Mr. C did not present with signs or symptoms of other postoperative complications, such as pneumonia, deep vein thrombosis/pulmonary emboli, incisional infection, or sternal dehiscence.

The patient's current level of knowledge regarding health-promoting behaviors including aerobic exercise was minimal. His readiness for learning was moderate or precontemplative, but his spouse was very supportive of his participation in cardiac rehabilitation and need for lifestyle modifications. Mr. C's only barrier to learning was a hearing impairment, which was not problematic when he wore and turned on his hearing aids. His coronary heart disease risk factors included age/gender, hypertension, dyslipidemia, diabetes, obesity, and physical inactivity.

Mr. C's aerobic capacity was significantly impaired, which was apparent in his scores on the outcome measures relative to age-matched norms (see Table 12-5). His physiological response to aerobic exercise was normal as reflected in his change in vital signs. Mr. C's heart rate and systolic blood pressure increased with activity and returned to baseline during recovery, indicating appropriate cardiac rate and contractility responses. His diastolic blood pressure went down slightly from rest to exercise, possibly indicating an orthostatic response to position change and vasodilation of skeletal muscle vasculature. Mr. C's oxygen saturation remained at or greater than 90% throughout the initial physical therapy visit, demonstrating that gas exchange in the lungs at rest and during exercise was normal.

In this patient, several factors likely contributed to aerobic capacity impairment. His cardiac function and therefore output may have been limited by the acute myocardial infarction, recent open heart surgery, and fluid overload. Despite being on a β-blocker, his heart rate at rest and during activity was within normal ranges, indicating that impairments in cardiac output were primarily related to stroke volume. He also most likely experienced both central and peripheral physiological changes from his recent bed rest and restricted activity level that resulted in a decline in aerobic capacity. Additional factors that may have limited Mr. C's 6-minute walk test distance/activity tolerance include fear of injury, illness, falling, or pain.

Diagnosis and Prognosis

Mr. C was categorized under Cardiopulmonary Preferred Practice Pattern D: Impaired Aerobic Capacity and Endurance Associated with Cardiac Pump Dysfunction. Box 12-4 lists factors that can influence the prognosis of a patient with impaired aerobic capacity. Many of these factors directly mediated the anticipated prognosis for Mr. C. For example, if we consider his age, severity of the current condition, and level of physical function, recovery prognosis would be somewhat guarded. But if we also consider his overall health, cognitive status, social support, and chronicity of his current condition, then his prognosis for return to previous activity level would be much better. Based on his previous and current functional status (physical, cognitive, and psychosocial), medical/surgical history, socioeconomic support system, and his desire to return to full activity, it was determined that Mr. C's prognosis for return to

TABLE 5 Patient Case Example Outcome Measure Scores

Outcome Tool	Normative Values	Initial Score	Discharge Score
6-Minute walk test (feet)	2122	330	957
Duke Activity Status Index	48	4.5	41
RAND 36-Item Health Survey (%)	64	13	49
Physical functioning	70	5	75
Role limitation due to physical health	53	0	0
Role limitation due to emotional problems	66	0	0
Energy	52	0	65
Emotional well-being	70	3	48
Social functioning	79	25	38
Pain	71	0	78
General health	57	38	50

previous ADL/IADLs was good to excellent and prognosis for return to previous occupational activities was fair to good. Of particular concern for Mr. C was lifting heavy items, because after 2 months of median sternotomy precautions he would have significant disuse atrophy and weakness in the upper extremity and trunk muscles. In addition, high-intensity, static contractions of multiple muscle groups increase systolic and diastolic blood pressure, which in turn causes an elevation in myocardial work and oxygen demand.

Anticipated outcomes after 12 weeks included the following: (1) patient will be independent with all bed mobility and transfers, (2) patient will ambulate 1000 feet in 6 minutes with no assistive device, and (3) patient will lift 20 lbs from the floor to waist height 10 times.

Plan of Care Interventions

Anticipated episodes of care included three directly supervised visits per week for 12 weeks. Continuous ECG monitoring was used during each exercise session. Aerobic exercise training included treadmill walking, LE cycle ergometry, and eventually upper body cycle ergometry at an intensity of 1.5 METs (HR = 75 to 85, RPE = 4 to 5). Mr. C started with two 6-minute bouts of aerobic exercise that were lengthened progressively until he was able to participate in 30 minutes of continuous activity. Breathing strategies included deep breathing with a 3-second inspiratory hold and splinted coughing to prevent atelectasis and pneumonia. Flexibility exercises included heel cord, quadriceps, and hamstring stretches for five repetitions using a 10- to 20-second hold. Strengthening exercises included toe raises, sit-to-stand, unilateral hip abduction in standing starting with one set of five repetitions and progressing to three sets of ten repetitions. Functional training initially included bed mobility and transfer tasks and progressed to lifting a crate from floor to chair ten times with 10 to 20 lbs.

Outcomes

After a 12-week period of exercise training/rehabilitation, Mr. C demonstrated considerable improvement in aerobic capacity and functional status. As illustrated in Table 12-5, his distance on the 6-minute walk test and scores on the RAND 36-Item Health Survey and Duke Activity Status Index increased, indicating better aerobic capacity, quality of life, and functional capabilities. Mr. C's distance on the 6-minute walk test increased nearly threefold, indicating substantial improvement in his aerobic capacity. His increase in aerobic capacity most likely directly contributed to improvements in physical activity performance (as reflected by the Duke Activity Status Index) and functional activity performance (as reflected by the RAND 36-Item Health Survey), particularly physical functioning, energy, pain, and general health. Mr. C still had significant disability in role limitation as a result of physical and emotional health. This was most likely related to the fact that he had not been able to fully return to farming activities and this was an important part of his perceived self-identity and social role.