

The Use of Exercise in the Management of Type 1 and Type 2 Diabetes

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- Prediabetes • Metabolic syndrome • Exercise prescription
- Exercise training • Strength training

Diabetes Mellitus is an illness that requires intensive, daily medical care and patient self-management education to both reduce the risk of acute complications and to improve long-term outcomes. Clinical interventions used to improve the management of diabetes include medical therapy, nutritional therapy, diabetes self-management education, psychosocial assessment and care, hypoglycemia awareness management, immunizations, and exercise.¹ Exercise is also an effective intervention in individuals with a high risk for developing diabetes, that is, individuals with either impaired fasting glucose (IFG) or glucose tolerance and metabolic syndrome. This article first reviews the data supporting the effectiveness of exercise evaluation and prescription programs in promoting cardiovascular health. Subsequently, the use of and restrictions to exercise in improving the management and reducing potential complications from type 1 and type 2 diabetes (T1D and T2D) in children, adolescents, and adults are discussed.

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DIABETES CLASSIFICATION

Type 1 Diabetes

Also known as either immune-mediated diabetes, insulin-dependent diabetes, or juvenile onset diabetes, T1D accounts for ~5% to 10% of diabetes in the United States. T1D is caused by autoimmune destruction of β cells of the pancreas and usually leads to absolute insulin deficiency. The rate of β -cell destruction is rapid in infants and children and relatively slower in adults. Individuals present with either severe metabolic decompensation with ketoacidosis or modest, fasting hyperglycemia that can rapidly change to severe hyperglycemia or ketoacidosis in the presence of infection or other stressors. Some individuals with T1D, particularly adults, maintain residual β -cell function for many years. Most of these individuals eventually become insulin dependent.^{1,2}

A subset of patients with T1D, primarily African Americans and Asians, develop diabetes and can present with ketoacidosis, yet do not have evidence of autoimmune β -cell destruction. This form of T1D appears to have a hereditary basis, but the pathogenesis is unclear. These individuals may experience episodic, severe metabolic decompensation including ketoacidosis and need intermittent insulin replacement therapy.

Type 2 Diabetes

Approximately 90% to 95% of individuals with diabetes have T2D, also known as either non-insulin-dependent diabetes or adult-onset diabetes. Individuals with T2D have insulin resistance, which ranges from predominantly insulin resistance and relative insulin deficiency to predominantly insulin resistance with an insulin secretory defect.² These patients usually do not require insulin treatment early in the course of their disease, but as many as 50% eventually become insulin dependent to maintain metabolic control.

There is a strong genetic predisposition to the development of T2D. It is a polygenic disorder, and although multiple risk alleles have been identified, the complex genetics of this form of diabetes is not well defined.² Women with a history of gestational diabetes mellitus (GDM) and individuals with either hypertension or dyslipidemia, or both, are also at increased risk. The risk of developing T2D increases with age, obesity, and sedentary lifestyle. Notably, T2D diagnosis is often delayed for several years, partly because hyperglycemia develops gradually, and the classic symptoms of polyuria and polydipsia are not prominent during the early stages. However, most of these patients have signs of prediabetes or metabolic syndrome, which can be treated by virtually identical exercise management techniques.

Other Types of Diabetes

Other, less common forms of diabetes include autosomal dominant genetic defects in β -cell function and insulin action, diabetes secondary to diseases of the pancreas (eg, pancreatitis), diabetes secondary to endocrine pathology (eg, acromegaly, Cushing's syndrome), drug- or chemical-induced diabetes, uncommon forms of immune-mediated diabetes, genetic syndromes associated with diabetes, and GDM.

GDM refers to any degree of glucose intolerance that is first noted during pregnancy. In the last trimester, insulin resistance progressively increases secondary to changes in body weight and the release of hormones by the placentas, which in turn antagonize insulin action. GDM complicates ~4% of pregnancies in the United States (~135,000 annually).

DIAGNOSIS

The American Diabetes Association (ADA) recommends use of the fasting glucose test to diagnose diabetes in children and nonpregnant, *symptomatic* adults.¹ The current criteria for the diagnosis of diabetes include 1 of the following:

1. Fasting blood glucose greater than or equal to 126 mg/dL (7.0 mmol/L). Fasting is defined as zero-caloric intake for at least 8 hours before the test.^f
2. Symptoms of hyperglycemia and a *casual* blood glucose greater than or equal to 200 mg/dL (11.1 mmol/L). *Casual* is defined as any time of day without regard to time since the last meal. The classic symptoms of hyperglycemia include polyuria, polydipsia, and unexplained weight loss.
3. Two-hour blood glucose greater than or equal to 200 mg/dL (11.1 mmol/L) during an oral glucose tolerance test (OGTT), using a glucose load containing the equivalent of 75 g anhydrous glucose dissolved in water.^f

Diagnosis of Prediabetes

Individuals who are hyperglycemic but do not meet the definition of diabetes can be categorized as having prediabetes by either IFG, fasting blood glucose 100 mg/dL (5.6 mmol/L) to 125 mg/dL (6.9 mmol/L), or impaired glucose tolerance (IGT), 2-hour blood glucose 140 mg/dL (7.8 mmol/L) to 199 mg/dL (11.0 mmol/L).¹ Both IFG and IGT are associated with increased risk for the future development of diabetes and increased risk for cardiovascular disease (CVD).⁴

The metabolic syndrome is a prediabetic state that is associated with increased cardiometabolic risk.^{5,6} Both the National Cholesterol Education Program (NCEP) Expert Panel on Detection, Evaluation, and Treatment of High Blood Cholesterol in Adults (Adult Treatment Panel III [NCEP-ATP III])^{7,8} and the International Diabetes Federation (IDF)⁹ criteria use 5 risk factors—waist circumference, triglycerides, blood pressure, HDL cholesterol, and fasting glucose—to determine the presence of metabolic syndrome. The NCEP-ATP III guidelines require the presence of any 3 of 5 risk factors, whereas the IDF criteria require elevated waist circumference, because of the relationship between abdominal obesity and cardiometabolic risk,^{9,10} and 2 of the remaining 4 risk factors. However, the 5 risk factors are not used as continuous variables but rather counted as “present” or “absent.” Therefore, the efficacy of these screening tools is less than optimal for assigning risk for the metabolic syndrome.¹⁰

Diagnosis of Diabetes and Prediabetes in Asymptomatic Individuals

Many asymptomatic individuals who wish to engage in exercise programs would benefit from testing to detect prediabetes and diabetes before exercise evaluation. The ADA has developed guidelines for asymptomatic patients who should be considered for testing.¹

Screening for T1D

Screening for T1D is not recommended, because individuals typically present with acute symptoms and elevated blood glucose concentrations. Consequently, the majority of cases of T1D are diagnosed soon after the onset of hyperglycemia.

^f In the absence of unequivocal hyperglycemia, these criteria should be confirmed by repeat testing on a different day³.

Testing for T2D in children

Incidence of T2D has increased in children, adolescents, and especially in minority groups.^{11,12} The ADA recommends the following criteria for testing asymptomatic children with T2D:

1. Overweight (body mass index [BMI] >85% percentile for age and sex, weight for height >85% percentile, or weight >120% of ideal body weight) *and* any 2 of the following risk factors:
 - a. Family history of T2D in either first- or second-degree relatives
 - b. Race ethnicity—Native American, African American, Latino, Asian American, or Pacific Islander)
 - c. Signs of insulin resistance or conditions associated with insulin resistance
 - d. Maternal history of diabetes or GDM

It is recommended that evaluation of these risk factors begin at either age 10 years or at the onset of puberty, if puberty occurs at a younger age. Follow-up testing is indicated every 2 years in identified children, using fasting blood glucose as the preferred test.

Testing for prediabetes and T2D in adults

Diagnosis of T2D is often delayed until complications occur, and it is estimated that approximately one-third of all individuals with T2D may remain undiagnosed.¹ The ADA recommends that all individuals older than 45 years of age be tested for prediabetes and T2D, because age is a major risk factor for the development of diabetes.¹ Younger adults should be evaluated if they are overweight (BMI >25 kg/m²) *and* have 1 or more of the following risk factors: physical inactivity, first-degree relative with diabetes, are members of a high-risk ethnic group, women who delivered a baby weighing more than 9 lb or were diagnosed with GDM, hypertension, low high-density lipoprotein (HDL) cholesterol (<35 mg/dL), and/or elevated triglyceride (>250 mg/dL), women with polycystic ovarian syndrome, prior evidence of IGT or IFG, other clinical conditions associated with insulin resistance (eg, severe obesity), or a history of CVD. Either fasting blood glucose testing or 2-hour OGTT testing are acceptable screening tools. If the tests are normal, repeat testing should be performed every 3 years.¹

EVALUATION OF THE DIABETIC ATHLETE BEFORE EXERCISE

A 2004 statement by the ADA recommended that before increasing patterns of physical activity or beginning an exercise program, diabetic patients should undergo a detailed medical evaluation with appropriate diagnostic studies. The medical examination should screen for the presence of both macro- and microvascular complications and for signs and symptoms of cardiovascular, renal, and ocular disease.¹³

T2D is associated with an increased risk for CVD.^{1,5,6} However, recommendations for routine screening for coronary artery disease (CAD) in asymptomatic patients with T2D,¹⁴ aside from commencement of a moderate- to vigorous-intensity exercise program, has been questioned—based on a report on asymptomatic patients with T2D aged 50 to 75 years that showed 1 in 5 patients had silent myocardial ischemia.¹⁵ The same study also suggested that the recommended screening algorithm of 2 or more risk factors did not accurately identify a large number of patients with test abnormalities.¹⁵ Also, a recent report suggested that routine screening of asymptomatic diabetic patients for CAD is not warranted,¹⁶ and the ADA recommends that clinical judgment should be used on an individual basis.¹

The ADA has also provided guidelines for graded exercise testing (GXT). Current recommendations include a GXT before initiating a moderate- to vigorous-intensity

exercise program as part of a lifestyle-intervention strategy in diabetics older than 35 years of age. Between 25 and 35 years of age, GXT is recommended if the diabetic individual either has T2D for more than 10 years, T1D more than 15 years, risk factors for CAD, microvascular disease, macrovascular disease, or autonomic neuropathy.¹³

GXT can be used for diagnostic, prognostic, and therapeutic purposes and is especially helpful for designing appropriate exercise prescription programs.¹⁷ For example, in high-risk individuals with an intermediate probability of significant CAD, results of a GXT can provide clinical diagnostic information, particularly when used in the context of other clinical data.¹⁷ Moreover, it is well accepted that low levels of fitness and muscular strength, as well as elevated levels of fatness, independently affect risk factors for CVD in both diabetic and nondiabetic individuals and are independent risk factors for all-cause and cardiovascular mortality.^{18–21} Furthermore, in males with T2D, the presence of an equivocal or abnormal GXT is associated with a higher risk of all-cause CVD and CAD mortality even after adjusting for fasting blood glucose, smoking, BMI, hypercholesterolemia, hypertension, family history of CVD or diabetes, abnormal resting electrocardiogram (ECG), and fitness.²² Therefore, an exercise evaluation protocol should be used to assess both potential clinical limitations to exercise and exercise capacity to allow for the development of an exercise prescription designed to improve fitness.

Exercise Testing for Adults

The treadmill and bicycle ergometer are most commonly used for exercise testing protocols. The advantage of the treadmill is that it is more representative of activities of daily living (ADLs) (eg, walking), and it incorporates greater amounts of total muscle mass, which results in higher maximal oxygen consumption (Vo_2 max) values. Although handrails are often used for balance, holding on to the handrails during exercise testing will affect the accuracy of the estimation of energetics and exercise capacity.¹⁷ The cycle ergometer is less expensive, uses less space, and is preferable for individuals in whom balance on the treadmill may be a limiting factor.

Although numerous exercise testing protocols are available, the protocol used should be formulated according to the desired outcome measures and characteristics of the patient. The Bruce protocol is the most popular exercise evaluation procedure. It employs relatively large increases in oxygen demands per stage. Ramp protocols with more uniform increases in metabolic responses and hemodynamics are also recommended for exercise evaluation. Exercise test monitoring of heart rate (HR), blood pressure, ECG, subjective ratings of symptoms, gas exchange responses, and blood gases have all been suggested, depending on the goal of the exercise evaluation and the clinical state of the patient. The American College of Sports Medicine (ACSM) has well-defined absolute and relative guidelines for exercise test termination.¹⁷

Exercise Testing for Children

The principles used in either treadmill or cycle ergometer testing in adults are similar for children and adolescents. However, because children are relatively immature, they need encouragement and positive support by an experienced testing staff to obtain accurate results.¹⁷ Although both treadmill and cycle ergometer protocols have been used in children, the treadmill is more appropriate for young children, because it requires the child to maintain the pace of the belt, rather than providing a volitional effort to maintain an appropriate revolutions per minute on the bicycle.

Other difficulties encountered during cycle ergometer exercise testing in children include the size of the bicycle, seat height, handlebar height and position, and pedal crank length. In addition, children and adults have different physiologic responses to

exercise. Children have lower, absolute submaximal, and VO_2 max values (L/min) but higher, relative VO_2 max values (mL/kg/min) compared with those of adults. Although the HR response to submaximal and maximal exercise is higher in children, they have lower cardiac output, stroke volume, blood lactate concentrations, ventilation, and respiratory exchange ratios compared with those of adults.¹⁷

GUIDELINES FOR EXERCISE PRESCRIPTION

In order to achieve optimal benefits in health, well-being, and quality of life, exercise prescription should include programs for improving cardiorespiratory fitness, body composition, and muscular fitness.¹⁷ It is important to encourage young people to participate in physical activities that are appropriate for their age, that are enjoyable, and that offer variety. Recently, the US Department of Health and Human Services provided the 2008 Physical Activity Guidelines for Americans.²³ The following recommendations are part of the guidelines:

Guidelines for Children

1. Children and adolescents should perform more than or equal to 60 minutes of physical activity daily.
2. Aerobic: Most of the more than or equal to 60 minutes of daily physical activity should be either moderate- or vigorous-intensity, aerobic physical activity and should include vigorous-intensity physical activity at least 3 d/wk.
3. Muscle strengthening: As part of more than or equal to 60 minutes of daily physical activity, children and adolescents should include muscle-strengthening physical activity on at least 3 d/wk.
4. Bone strengthening: As part of more than or equal to 60 minutes of daily physical activity, children and adolescents should include bone-strengthening physical activity on at least 3 d/wk.

Guidelines for Adults

1. All adults should avoid inactivity. Some physical activity is better than none, and adults who participate in any amount of physical activity gain some health benefits.
2. For substantial health benefits, adults should perform at least 150 min/wk of moderate-intensity or 75 min/wk of vigorous-intensity aerobic physical activity or an equivalent combination of moderate- and vigorous-intensity aerobic activity.
3. Aerobic activity should be performed in intervals of at least 10 minutes, and preferably, it should be divided throughout the week.
4. For additional and more extensive health benefits, adults should increase their aerobic physical activity to 300 min/wk of moderate-intensity or 150 min/wk of vigorous-intensity aerobic physical activity or an equivalent combination of moderate- and vigorous-intensity activity. Additional health benefits are gained by engaging in physical activity beyond this amount.
5. Adults should also perform muscle-strengthening activities that are moderate or high intensity and involve all major muscle groups on 2 or more days a week, because these activities provide additional health benefits.

Guidelines for Older Adults

The guidelines for adults also apply to older adults. In addition, the following guidelines are specifically for older adults:

1. When older adults cannot perform 150 minutes of moderate-intensity aerobic activity a week because of chronic conditions, they should try and be physically active to the best of their ability.
2. Older adults should perform exercises that maintain or improve balance if they are at increased risk for falls.
3. Older adults should determine their level of effort for physical activity relative to their level of fitness.
4. Older adults with chronic conditions should understand their limitations in performing regular physical activity safely.

Guidelines for Safe Physical Activity

To perform physical activity safely and reduce the risk of injuries and other adverse events, individuals should be educated on and adhere to the following principles:

1. Understand the risks and yet be confident that physical activity is safe for almost everyone.
2. Choose to perform types of physical activity that are appropriate for their current fitness level and health goals, because some activities are safer than others.
3. Increase physical activity gradually over time as needed to meet guidelines or health goals.
4. Inactive people should “start low and go slow” by gradually increasing frequency and time of exercise.
5. Protect themselves by using appropriate gear and sports equipment, exercise in safe environments, follow rules and policies, and make sensible choices about when, where, and how to be active.
6. People with chronic conditions and symptoms should consult their health care provider regarding appropriate types and amounts of activity.

Guidelines for Adults with Disabilities

1. Adults with disabilities, who are able to, should perform at least 150 min/wk of moderate-intensity or 75 min/wk of vigorous-intensity aerobic activity or an equivalent combination of moderate- and vigorous-intensity aerobic activity. Aerobic activity should be performed in episodes of at least 10 minutes, and preferably, it should be divided throughout the week.
2. Adults with disabilities, who are able to, should also perform muscle-strengthening activities of moderate or high intensity that involve all major muscle groups on 2 or more days per week, as these activities provide additional health benefits.
3. When adults with disabilities are not able to meet the guidelines, they should engage in regular physical activity according to their abilities and should avoid inactivity.
4. Adults with disabilities should consult their health care provider regarding appropriate types and amounts of activity.

Guidelines for People with Chronic Medical Conditions

1. Adults with chronic conditions obtain important health benefits from regular physical activity.
2. When adults with chronic conditions perform physical activity within the limits of their abilities, physical activity is safe.
3. Adults with chronic conditions should consult their health care provider regarding appropriate types and amounts of activity.

PRINCIPLES OF EXERCISE PRESCRIPTION

There exists an art and a science to thorough, meaningful exercise prescription. We recommend that an exercise physiologist be involved in developing appropriate programs for both prediabetic and diabetic individuals. All prescribed exercise programs (*conditioning* phase), should be preceded by a *warm-up* phase and followed by a *cool-down* phase. Exercises during these phases should involve large muscle, low-intensity activity and stretching. Other recommended activities may include either yoga or relaxation training. The conditioning phase should be designed to improve both cardiorespiratory fitness (VO_2 max) and local muscle fitness (blood lactate response to exercise).^{17,24} Components of a thorough prescription for the conditioning phase should detail advice for exercise duration, intensity, frequency, mode, rate of progression, and specificity. Finally, training programs that use both upper-extremity and lower-extremity exercises should be prescribed.

Cardiorespiratory Exercise Prescription

Exercise duration

For most cardiorespiratory programs, the ACSM recommends 20 to 60 minutes of either continuous or intermittent exercise. For individuals who have difficulty exercising continuously, recent data have indicated that multiple bouts of shorter-duration exercise can provide similar benefits as one continuous bout of exercise.^{25–27}

Exercise intensity

Exercise of an appropriate intensity is key for improvement in cardiorespiratory fitness. The combination of exercise intensity and duration determines caloric expenditure during exercise. The determination of exercise intensity is dependent upon the health and fitness status of the individual. ACSM recommends exercise intensity of 40/50 to 85% of oxygen uptake reserve (VO_2 reserve is the difference between VO_2 max and resting oxygen consumption).¹⁷ Because oxygen consumption is not always measured during exercise evaluation programs, percentages of heart rate reserve and percentages of estimated maximal heart rate (HR) are often used as surrogate makers of VO_2 max. ACSM recommends 40/50 to 85% of HR reserve (HR reserve is calculated as the difference between HR max and resting HR times the desired training intensity + resting heart rate) or 64/70% to 94% of maximal HR (maximal HR can be estimated by subtracting the patients age from 220) for exercise prescription. For low-fit or de-conditioned individuals the lower portion of the ranges are recommended initially (eg, 40–50% of VO_2 max or HR reserve, 64–70% of age predicted maximal HR) and intensity can be increased as fitness improves. For most individuals exercise intensities of corresponding to 60–80% of HR reserve or 77–90% of age predicted maximal HR will result in improved cardiorespiratory fitness provided that frequency and duration of exercise are adequate.¹⁷ It should be noted that the estimation of maximal HR is quite variable with one standard deviation associated with the equation $220 - \text{age}$ being ~ 10 to 12 beats per minute. In addition, use of medications such as b-blockers, preclude the use of HR for exercise prescription.

Ratings of perceived exertion (RPE) are also useful for exercise prescription. The most common RPE scale was developed by Gunnar Borg²⁸ and is shown below:

- 6
- 7 Very, very light
- 8
- 9 Very light
- 10

- 11 Fairly light
- 12
- 13 Somewhat hard
- 14
- 15 Hard
- 16
- 17 Very hard
- 18
- 19 Very, very hard
- 20

ACSM recommends RPE values of 12 to 16 for exercise prescription designed to improve cardiorespiratory fitness.¹⁷ Another advantage of using the RPE scale is that RPE are reasonable markers of the blood lactate response to exercise with the lactate threshold being associated with RPE values of ~10 to 12 and blood lactate concentrations of 4.0 mM being associated with RPE of ~15 to 17.^{29,30} Similar to the use of HR there is considerable variability in RPE among individuals.

Exercise frequency

ACSM recommends an exercise frequency of 3 to 5 days per week.¹⁷ For those exercising at the higher end of the exercise intensity range 3 days per week (every other day) is sufficient to improve (or maintain) VO_2 max. For those at the lower end of the exercise intensity range, exercise more than 3 times per week (eg, 5 × weekly) may be needed. For those individuals who are interested in exercising 5 to 6 days per week and can exercise at the higher end of the exercise intensity continuum a hard easy hard easy regimen of intensity should be applied (eg, M, W, F, high intensity; T, Th, S, low intensity) to avoid overtraining and overuse injuries.

Exercise mode

The most effective modes of exercise to improve cardiorespiratory fitness involve the recruitment of large muscle groups in rhythmic aerobic forms of activity. Activities such as walking, hiking, jogging, running, cycling, swimming, elliptical machines, rowing, dancing, skating, cross-country skiing, and aerobic games such as ultimate Frisbee have all been used to improve cardiorespiratory fitness. Sports such as racquetball, handball, soccer, and basketball are also effective provided they are played at high intensity for an adequate duration.¹⁷ Individual likes and dislikes as well as capabilities should be taken into consideration to avoid boredom-related noncompliance with exercise programs.

Exercise progression

Exercise progression is dependent on the functional capacity, medical status, and goals of each individual. At the onset of an exercise program, there will be an initial conditioning stage in which improvements will be observed because of the transition from sedentary behavior to regular exercise. This phase is critical to preparing the individual, both for the musculoskeletal stress of exercise and to develop a lifetime approach to exercise. Therefore, during the first 6 weeks, the conditioning phase should be preceded by a longer warm-up phase and should incorporate activities designed to minimize muscle soreness, discomfort, and injury. Exercise intensity should be gradually increased during the first 6 weeks to minimize dropout.

Between 6 weeks and 6 months, or even up to 1 year, exercise frequency and duration are increased, followed by a gradual increase in exercise intensity. Finally, individuals should be transitioned to the maintenance phase after they have met their fitness

goals associated with consistent levels of exercise duration, intensity, and frequency needed to maintain cardiorespiratory fitness.¹⁷

Specificity of training

Although most rhythmic exercises that are aerobic in nature and recruit large muscle groups will improve cardiorespiratory fitness, muscle adaptations will only occur within the muscles being recruited. This phenomena is referred to as specificity of training. For example, if one trains running and improves VO_2 max measured on a treadmill, swimming VO_2 max will not necessarily improve.³¹ Local muscle responses, measured using the blood lactate response to exercise, are affected to a greater extent by training specificity than is VO_2 max.³² This concept should be taken into consideration when developing an exercise prescription for pre-diabetic and diabetic patients. In particular, training programs that utilize both upper extremity and lower extremity exercise should be part of the exercise prescription.

Resistance Exercise Prescription

For many years, resistance training was overlooked in favor of cardiorespiratory training for patients with or at risk for developing diabetes and CAD. However, adequate muscular strength and endurance are critical for ADLs. When muscular strength and endurance are insufficient to perform ADLs, functional independence is compromised. Therefore, resistance training is recommended as part of an overall exercise prescription and should be performed on 2 to 3 nonconsecutive days of the week.¹⁷ ACSM recommends the following resistance training guidelines:¹⁷

1. Chose a mode of exercise (free weights, bands, machines) that is comfortable through a pain-free range of motion.
2. Perform 8 to 10 exercises that train the major muscles of the hips, thigh, legs, back, chest, shoulders, arms, and abdomen.
3. Perform 1 set of each exercise to volitional fatigue while maintaining proper form.
4. Although the traditional recommendations of 8 to 12 repetitions is still appropriate, choose a range of repetitions between 3 and 20 that can be performed at a moderate repetition duration (~ 3 seconds).
5. Exercise each muscle group on 2 to 3 nonconsecutive days of the week.
6. Adhere as closely as possible to the specific techniques for performing a given exercise.
7. Allow enough recovery time so that the next exercise can be performed with proper form.
8. For people with high cardiovascular risk or chronic disease (eg, hypertension, diabetes), stop the exercise as the concentric phase of the exercise becomes difficult (RPE 15–16).
9. Perform the lifting (concentric) and lowering (eccentric) phases of the exercise in a controlled manner.
10. Breathe normally during lifting because breath holding can increase blood pressure.
11. Whenever possible, train with a partner who can provide feedback, assistance, and motivation.

We recommend that the aforementioned list be modified based on recent data, which suggest that higher-intensity strength training (80% of 1 rep max [RM]) may be required for meaningful benefits in older individuals.³³

EXERCISE PRESCRIPTION AND SPECIAL CONSIDERATIONS FOR DIABETIC INDIVIDUALS

Benefits of Regular Exercise in the Management of Diabetes

The benefits of regular exercise in the management of diabetes and other disease states associated with diabetes are numerous and beyond the scope of this review and will only be discussed briefly (for a recent review on the effects of exercise and diet on chronic disease see ref.³⁴).

In several large cohort studies, high risk, prediabetic individuals who completed diet and exercise lifestyle-intervention therapy (eg, 150 min/wk of moderate intensity exercise) dramatically reduced progression to diabetes.^{35–37} Importantly, lifestyle modification was generalizable across race and gender, and it was more effective than treatment with the biguanide, metformin.³⁶

Exercise and increased fitness are also associated with a reduced risk of complications from diabetes complications and reduced mortality in individuals with either T1D or T2D.^{38,39} Clinical benefits of regular exercise and increased fitness in diabetic patients include reduced abdominal visceral fat,^{40–42} improved lipid profiles,⁴² increased insulin sensitivity and decreased insulin resistance,^{43,44} improved endothelial function,^{45,46} reduced inflammation,^{47,48} reduced blood pressure,⁴⁹ and improved hemostasis.⁵⁰ Although most exercise interventions have examined aerobic, endurance training responses, there is an emerging body of evidence that indicates that resistance training also improves outcome measures in patients with diabetes.^{51,52}

Type 1 Diabetes

The ADA suggests that all levels of physical activity, including leisure activities, recreational sports, and competitive professional performance, can be performed by people with T1D who do not have complications and have optimal blood glucose control.¹³ Because exercise increases insulin sensitivity, it is important that individuals with T1D adjust their insulin and nutritional needs, to exercise safely and participate in high-performance activities. It is important to regularly collect self-monitored blood glucose data in response to physical activity and, subsequently, in concert with the medical staff, develop individualized treatment algorithms to improve performance and enhance safety.¹³

Type 2 Diabetes

Exercise along with diet and medication has long been the cornerstone in the management of diabetes. A recent consensus statement from the ADA provides evidence for the effectiveness of both aerobic and resistance training in the management of T2D.⁵³ Current recommendations for T2D include 150 minutes of moderate-intensity exercise per week and, in the absence of comorbid contraindications, resistance training for 2 d/wk.¹

Hyperglycemia

Exercise can worsen hyperglycemia and ketosis in T1D ketotic individuals deprived of insulin for 12 to 48 hours.^{1,53,54} Prior ADA position statements for exercise in T1D individuals had called for avoidance of physical activity if fasting blood glucose levels were more than 250 mg/dL (>13.9 mmol/L) in the presence of ketosis, and that in the absence of ketosis, exercise be performed with caution if glucose levels were more than 300 mg/dL (16.7 mmol/L).⁵⁵ However, in T1D individuals with ketosis, vigorous physical activity is contraindicated. It should be noted that if individuals feel well, hyperglycemia without ketosis (urine and blood ketones negative) does

not preclude exercise,¹ provided they adhere to the aforementioned guidelines of blood glucose monitoring and individualized insulin needs.

In individuals with T2D, the current recommendation to avoid physical activity with blood glucose more than 300 mg/dL, even in the absence of ketosis, is probably more cautious than necessary, especially in a postprandial state.⁵³ In the absence of severe insulin deficiency, light- or moderate-intensity exercise would tend to decrease blood glucose. Therefore, if an individual feels well, is adequately hydrated, and is not ketotic, exercise is recommended.^{1,53}

Hypoglycemia

Acute exercise increases insulin-stimulated glucose disposal in both healthy and insulin-resistant skeletal muscles.^{56,57} In individuals medicated with either insulin or insulin secretagogues, physical activity can cause hypoglycemia if medication dose or carbohydrate consumption is inadequately adjusted. The risk of exercise-induced hypoglycemia is increased if prolonged exercise is performed at peak exogenous insulin levels. It is, therefore, recommended that blood glucose levels be monitored before exercise, carbohydrates be ingested if glucose levels are less than 100 mg/dL and as needed during exercise to avoid hypoglycemia, and that carbohydrates be available both during and after physical activity.¹³

Because hypoglycemia is rare in diabetic individuals not treated with insulin or insulin secretagogues, preventive measures for exercise-induced hypoglycemia are less stringent for patients treated solely by diet, metformin, α -glucosidase inhibitors, or thiazolidinediones.^{1,53} The exercise response in subjects taking pramlintide (synthetic amylin analog) or exenatide (incretin analog) has not been studied, but neither is likely to cause hypoglycemia when used as monotherapy or combined with only metformin or a thiazolidinedione.⁵³

Hypertension

General exercise prescription guidelines apply to hypertensive individuals with the following special considerations:¹⁷

1. Exercise is contraindicated if resting systolic blood pressure (SBP) is greater than 200 mm Hg or diastolic blood pressure (DBP) is greater than 100 mm Hg.
2. Individuals with marked elevation of BP (>160/100) should not add exercise training until after the initiation of pharmacologic therapy.
3. β blockers attenuate HR response to exercise and may decrease exercise capacity, especially in individuals without myocardial ischemia.
4. Use of HR for exercise prescription is not advised for patients on β blockers. Instead of HR, an RPE scale should be used to prescribe exercise intensity.
5. β blockers and diuretics may impair thermoregulation during exercise, particularly in hot and humid environments.
6. α blockers, β blockers, calcium channel blockers, and vasodilators may provoke postexercise hypotension. Therefore, a gradual cool-down phase should be emphasized.
7. Diuretics may decrease serum potassium and increase the risk for cardiac dysrhythmias and false-positive GXT.
8. Breathe normally and avoid Valsalva maneuvers—forced exhalation against a closed glottis—during resistance exercise.

For diabetic patients who are hypertensive, recommended treatment goals are SBP lower than 130 mm Hg and DBP lower than 80 mm Hg.¹ Lifestyle therapy is

recommended for patients with SBP less than 140 mm Hg or DBP less than 90 mm Hg for up to 3 months. For those who either fail a 3-month trial lifestyle-therapy intervention or have SBP greater than or equal to 140 mm Hg or DBP greater than or equal to 90 mm Hg, pharmacologic therapy is recommended in addition to lifestyle therapy. Either angiotensin converting enzyme inhibitors or angiotensin receptor blockers are recommended based on individual tolerance. If necessary, a thiazide diuretic can be added.¹

Retinopathy

Neither aerobic training nor resistance exercise has adverse effects on either vision, progression of mild nonproliferative diabetic retinopathy, or macular edema. The risk of vitreous hemorrhage or retinal detachment is increased in individuals with proliferative or severe nonproliferative diabetic retinopathy.⁵³ Therefore, we recommend that vigorous aerobic and resistance exercises should be avoided in this subset of individuals.

Peripheral Neuropathy

The current recommendation for patients with severe peripheral neuropathy is to engage in non-weight-bearing exercise, such as swimming, cycling, and arm exercise. This should reduce the risk of skin breakdown, infection, and the development of Charcot joint destruction.⁵³

Autonomic Neuropathy

Autonomic neuropathy is strongly associated with increased risk of CVD.¹⁵ Therefore, it is recommended that individuals with autonomic neuropathy undergo a thorough cardiac evaluation before increasing the intensity of physical activity.⁵³

Albuminuria and Nephropathy

Exercise can acutely increase urinary protein excretion. However, there is no evidence that exercise increases the rate of progression of diabetic kidney disease. Therefore, individuals with diabetic kidney disease should be encouraged to exercise.^{1,53}

Dyslipidemia

In diabetic patients, exercise combined with lifestyle-therapy interventions, including medical nutritional therapy—reduction of dietary trans fats, saturated fat, and cholesterol intake—and weight loss, improves lipid profile.¹ In many diabetic patients, lipid-lowering statin therapy is added to lifestyle therapy. Generally, the aforementioned exercise prescription guidelines may be applied to diabetic patients on lipid-lowering therapy, in the absence of other comorbid conditions requiring special considerations for exercise prescription (eg, hypertension).¹⁷ However, individuals on statin therapy may experience either myalgias, muscle weakness, or rhabdomyolysis,⁵⁸ and muscular problems occur more frequently both during and after exercise.⁵⁹ In professional athletes with familial hypercholesterolemia, 78% could not tolerate therapy with any statin secondary to myalgias and cramps.⁶⁰ Therefore, in dyslipidemic diabetic patients who engage in regular exercise, an alternative lipid-lowering therapy (eg, niacin) may be required.

SUMMARY

Regular exercise training is a pivotal intervention in the overall, multidisciplinary approach in the management of diabetes. ADA recommendations include a detailed

medical evaluation with appropriate diagnostic studies before increasing physical activity or beginning an exercise program. GXT is recommended before initiating a moderate- to vigorous-intensity exercise program and in individuals older than 35 years of age. In addition, individuals between 25 and 35 years of age with either T2D for more than 10 years, T1D for more than 15 years, risk factors for CAD, microvascular disease, macrovascular disease, or autonomic neuropathy should have a GXT before exercise prescription.

Prescribed exercise programs should include both aerobic and resistance exercises and should be optimally designed to improve both cardiorespiratory fitness (VO_2 max) and local muscle fitness (blood lactate response to exercise). Key elements of a thorough prescription include exercise duration, intensity, frequency, mode, rate of progression, and specificity. Additionally, training programs that use both upper-extremity and lower-extremity exercises should be included in exercise prescriptions.

Diabetics should be encouraged to formulate and balance exercise programs based on individualized insulin and nutritional needs. In T1D individuals with ketosis, vigorous physical activity is contraindicated; however, hyperglycemia without ketosis (urine and blood ketones negative) does not preclude exercise. Individuals with T2D who feel well, are adequately hydrated, and do not have either severe insulin deficiency or ketosis may perform light- or moderate-intensity exercise. The risk of exercise-induced hypoglycemia is increased by inadequate adjustment of insulin dosing or carbohydrate consumption, especially during prolonged exercise performed at peak exogenous insulin levels. Therefore, blood glucose levels should be monitored before exercise; carbohydrates should be ingested if glucose levels fall less than 100 mg/dL and as needed during exercise; and carbohydrates should be readily available both during and after physical activity. In diabetics with hypertension, exercise, as part of a lifestyle-therapy intervention program, is recommended for SBP less than 140 and DBP less than 90. Exercise is contraindicated if resting SBP is greater than 200 mm Hg or DBP is greater than 100 mm Hg, and diabetics with marked elevation or BP ($>160/100$) should not add exercise training until after the initiation of pharmacologic therapy. The risk for vitreous hemorrhage and retinal detachment is increased in individuals with proliferative or severe nonproliferative diabetic retinopathy, and, therefore, vigorous aerobic or resistance exercise should be avoided in this subset of individuals. Diabetic individuals with neuropathy should engage in non-weight-bearing exercise programs to reduce the risk of dermatologic and musculoskeletal complications.

Individuals with autonomic neuropathy should undergo a thorough cardiac evaluation before increasing the intensity of physical activity. Exercise does not seem to increase the rate of progression of diabetic kidney disease, and, therefore, individuals with diabetic kidney disease should be encouraged to exercise. Diabetics on statin therapy may experience myalgias, muscle weakness, cramps, or rhabdomyolysis. Therefore, dyslipidemic diabetic patients who engage in regular exercise may require alternative lipid-lowering therapy.

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