The Role of Physical Activity in Type 2 Diabetes Prevention: Physiological and Practical Perspectives

Jamie F. Burr, MSc; Chip P. Rowan, MSc; Veronica K. Jamnik, PhD; Michael C. Riddell, PhD

Abstract: Lifestyle changes that include a nutritionally balanced diet and increased physical activity (PA) are effective intervention options for persons with prediabetes who want to prevent progression to type 2 diabetes mellitus. Although nutritional counseling is standard practice for patients in a clinical setting, an individualized PA prescription, including recommendations on the type, frequency, duration, and intensity, is much less likely to occur. This is surprising because lifestyle modifications including a PA program are at least as effective in diabetes prevention as any single pharmacological agent. The success of regular PA in improving glycemic control in persons with either prediabetes or type 2 diabetes likely results from adaptations that occur in several organs and tissues, including adipose, skeletal muscle, liver, and pancreas. Increased insulin sensitivity is an important link between increased PA, body composition, and metabolic health, and it is at this link where increases in PA and energy expenditure exert much of their effect on preventing metabolic disorders and improving symptoms of existing disease. In addition to improving insulin sensitivity, regular PA has several cardioprotective effects, especially for persons with metabolic dysfunction, and has been shown to elicit minimal adverse events in these populations. Effective PA prescription is contingent on an understanding of the underlying physiological adaptations and the differing responses to diverse modes and intensities of PA. This article highlights recent findings on the beneficial role of regular PA for improving and/or maintaining insulin sensitivity in persons with prediabetes. We also provide an evidence-informed prescription for the type, intensity, and duration of both resistance and aerobic PA in persons with prediabetes.

Keywords: metabolic health; aerobic exercise; resistance exercise; physical activity prescription; prediabetes

Introduction

In the healthy functioning human body, the pancreas produces and releases the insulin needed to regulate the metabolism of ingested carbohydrates and fats in the body. Inadequate production of insulin by the pancreas or insufficient action of insulin in the main glucose disposal tissues (skeletal muscle, liver, and adipose tissue) leads to elevations in circulating blood glucose levels and can result in the development of type 2 diabetes mellitus.1 Prediabetes is a term used to classify persons with impaired fasting glucose (IFG), impaired glucose tolerance (IGT), or both, who have elevated risk of developing type 2 diabetes.1 Specific diagnostic criteria are provided in Table 1. Prediabetes affects many metabolic processes, tissues, and organs, typically resulting in an impairment of insulin sensitivity (or inversely, promotion of insulin resistance) and an increase in cardiovascular risk factors (Figure 1). The goal in treating prediabetes, therefore, is to prevent future development of type 2 diabetes and diabetes-related cardiovascular complications. A recent meta-analysis of randomized controlled trials of pharmacological and lifestyle interventions to prevent type 2 diabetes in people with IGT has shown that lifestyle changes that include increased physical activity (PA) are at least as effective as drug treatment in preventing the disease.2

Insulin resistance is often present years before IGT is observed or type 2 diabetes is manifested clinically3 and appears to be precipitated by lifestyle factors, such as a positive energy balance and physical inactivity.3,4 The presence of a positive caloric balance resulting from insufficient PA and a high energy intake appears to initiate the disease process with the accumulation of excess triglycerides and their associated products into specific body regions, including central (visceral) adipose tissue, liver, and skeletal muscle depots. This adipose accumulation into nonsubcutaneous adipocytes, which may affect only genetically predisposed individuals, causes reductions in insulin signaling in the main insulin target tissues (muscle, liver, and adipose) and a proinflammatory process within liver and adipose tissue that
increases the risk for metabolic dysfunction and cardiovascular disease. The development of type 2 diabetes starts with a progression from normal glucose tolerance with insulin resistance to IGT caused by deterioration in β-cell function with insulin resistance. The reasons for β-cell failure are unclear, but may be related to lipid and glucose toxicity of the β cells themselves. Because individuals with prediabetes and type 2 diabetes are characterized by defects in both insulin secretion and sensitivity, interventions that enhance β-cell function and counteract insulin resistance are effective in preventing the progression of IGT to type 2 diabetes. Given that excess adiposity strongly drives the underlying pathology of metabolic dysfunction, lifestyle interventions that combine caloric restriction with increased PA are thought to be the best nonpharmacological approach to diabetes prevention. Although diet alone has been shown to be more effective in decreasing body mass, the concurrent reductions in body fat (subcutaneous and visceral) and increases in lean mass that occur using PA interventions result in a higher resting metabolic rate and are likely more important to health. Sufficient PA offers additional benefits to metabolic function such as increased cardiorespiratory fitness (CRF), which has health benefits beyond those associated with weight loss.

This article highlights the potential mechanisms underlying the beneficial effects of regular PA on type 2 diabetes prevention in individuals with prediabetes. We also provide some perspectives on the selection and implementation of a PA program for persons at risk for developing type 2 diabetes. For the purposes of this review, we focus on the broad category of PA, which includes both structured and unstructured movement, and the more specific categories of exercise and sport.

It is important to note that PA, as opposed to the more narrowly focused classification of structured exercise, includes all activities of daily living.

### Insulin Sensitivity and CRF

Cardiorespiratory fitness is commonly used as a quantitative marker of habitual PA, based on the assumption that one's PA dictates their CRF; however, an individual's capacity for aerobic PA is also influenced by genetics. Experiments using rats specifically bred to express either high or low CRF have demonstrated a clear protective effect of CRF on insulin resistance and cardiovascular disease risk markers in the absence of significant PA. Given that individuals cannot alter their genetic makeup, modifying PA behaviors should be the primary goal from a treatment and preventive medicine perspective, with the understanding that sufficient PA should have the additional benefit of increased CRF.

### Insulin Sensitivity and Skeletal Muscle Mass and Composition

Skeletal muscle is the major site of glucose disposal in humans. Under hyperinsulinemic euglycemic conditions, approximately 80% of total body glucose uptake occurs in skeletal muscle. In persons with prediabetes or type 2 diabetes, glucose disposal into skeletal muscle is reduced by as much as 50%. Both aerobic and resistance PA are believed to improve insulin action primarily through effects on increasing/maintaining skeletal muscle mass and improving insulin sensitivity. Muscle strength is positively associated with insulin sensitivity, and whole-body glucose uptake is positively associated with a higher percentage of type 1 (aerobic, or

### Table 1. Prediabetes and Diabetes Diagnostic Criteria: Plasma Glucose Levels for Diagnosis of IFG and IGT

<table>
<thead>
<tr>
<th>Fasting Plasma Glucose (mmol/L)</th>
<th>2-h Plasma Glucose Using 75 g OGTT (mmol/L)</th>
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</thead>
<tbody>
<tr>
<td>Prediabetes</td>
<td></td>
</tr>
<tr>
<td>IFG 6.1–6.9</td>
<td>N/A</td>
</tr>
<tr>
<td>IFG (Isolated) 6.1–6.9</td>
<td>N/A</td>
</tr>
<tr>
<td>IGT (Isolated) &lt; 6.1</td>
<td>N/A</td>
</tr>
<tr>
<td>IFG and IGT 6.1–6.9</td>
<td>N/A</td>
</tr>
<tr>
<td>Diabetes &lt; 7</td>
<td>N/A</td>
</tr>
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</table>

The American Diabetes Association classifies IFG as having a fasting plasma glucose concentration between 100 and 125 mg/dL (5.6–6.9 mmol/L). Glycosylated hemoglobin between 5.6% and 6.4% may also be considered to be in the prediabetic range, but requires an OGTT for confirmation.

Adapted from Forouhi et al and the Canadian Diabetes Association Clinical Practice Guidelines.

Abbreviations: IFG, impaired fasting glucose; IGT, impaired glucose tolerance; OGTT, oral glucose tolerance test.
slow-twitch) fibers and thus increased oxidative capacity. Patients who present with insulin resistance and type 2 diabetes have been shown to have an increased proportion of type IIb (aerobic or slow-twitch) fibers, a decreased percentage of type I fibers, and a lower capillary density. These findings suggest that a decreased capacity to metabolize glucose and lipids using oxidative pathways is associated with diabetes development.

Both resistance and aerobic PA cause beneficial changes in insulin signaling within skeletal muscle that increase glucose disposal. Because resistance training increases muscle mass and glucose transporter protein 4 (GLUT4) content and glycogen synthase activity within the trained muscle, it should be considered an essential component of any PA regimen.

The metabolic effects of aerobic and resistance training are highlighted in the following sections.

**Aerobic Exercise Training**

For decades, aerobic PA has been recognized as a key component of diabetes management and prevention. However, in modern society, PA participation among both healthy and diseased populations has been replaced by sedentary living, as evidenced by the 2007 report on PA, which indicates that less than one-half (49.5%) of US adults meet recommended PA guidelines. For at least half of Americans, therefore, the benefits of PA for avoiding metabolic dysfunction and managing disease progression are clearly not being exploited. In general, PA partic-

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Figure 1. A summary comparison of the lean healthy individual with the obese, prediabetic individual and the effects of increased adiposity on metabolic regulation and insulin sensitivity.
ion levels are less in those with insulin resistance and prediabetes compared with age-matched controls.25 Moderate-intensity aerobic PA totaling at least 30 minutes per day performed in bouts of >10 minutes for ≥5 days per week is recognized to be of sufficient intensity, duration, and frequency to be associated with improvements in physical fitness in healthy persons.24 Moderate PA is characterized by a defined work rate (40%–59% heart rate reserve or 64%–76% heart rate max) and is subjectively perceived to cause increased breathing and an increase in body temperature while corresponding to a range between 4 and 6 on the Borg 10-point perceived exertion scale.25 For a patient with low-to-average CRF, moderate intensity activity would represent a range from 2.5 to 5 metabolic equivalents or 50% to 68% maximal oxygen uptake (VO$_2$ max).26 This intensity is also thought to be appropriate for those with metabolic diseases, such as diabetes, prediabetes, or the metabolic syndrome,27 although higher volumes (ie, 30–60 minutes per session) are likely to cause greater improvements in insulin sensitivity in the meals following exercise if glucose tolerance is poor. Recently, much attention has been paid to the time-efficient training strategy of high-intensity interval training, which focuses on brief bouts (15–240 seconds) at a high intensity (≥90% VO$_2$ max). This type of training has been shown to lead to beneficial effects on insulin action in healthy subjects.29 However, extremely high-intensity exercise may not be appealing or appropriate for all segments of the population, such as the elderly, those with underlying cardiovascular disease, or those with autonomic neuropathy.

Although improvements in insulin sensitivity are known to occur from a single bout of aerobic PA, much of this effect appears to be an acute response and is essentially transient.30,31 Based on evidence from healthy nondiabetic individuals, the acute effect of PA on improving basal whole-body insulin sensitivity after a single bout of activity requires a threshold intensity of about 60% VO$_2$ max for 60 to 90 minutes,32 which is likely an unfeasible initial amount for most untrained prediabetic individuals. Interestingly, improvements in insulin sensitivity also have been shown to occur at intensities below the level required for changes in CRF;31 however, longer duration, higher-intensity PA may provide more enduring benefits to insulin action because of a greater transient effect.30 Because the acute improvements in glucose tolerance and insulin sensitivity related to a single bout of endurance exercise appear to last somewhere between 12 and 48 hours, depending on the overall energy expenditure32 and because skeletal muscles require a recovery period following resistance exercise, current guidelines from the American College of Sports Medicine (ACSM) and the American Diabetes Association (ADA) suggest that PA frequency should be maintained so that “no more than 2 consecutive days” occur without aerobic PA4,5 to reverse this decline. Despite this evidence of an insulin-sensitizing effect following an acute bout of lower-intensity, longer-duration aerobic PA, there is little evidence to support the insulin-sensitizing effect of a single bout of short-duration, high-intensity training.33 Collectively, these results suggest that patients will realize the greatest insulin-sensitizing effects from PA when a balance between high-frequency, elevated intensity, and long-duration PA is reached so that PA volume is maximized.

**Aerobic PA: Mechanisms of Action**

Changes in insulin sensitivity from acute and long-term PA have been associated with changes in the cardiovascular delivery of insulin and substrates to muscle via improved endothelial function and capillarization,34,35 increased mitochondrial biogenesis and fiber ratios,36 improved muscular respiratory capacity and fatty acid oxidation,37 and increased expression and activity of key enzymes and signaling proteins, such as GLUT4 and glycogen synthase activity.38,39 It is these improvements in physical fitness that account for changes in the nongenetic component of CRF, and thus the association between elevations in CRF and improved metabolic health (ie, insulin sensitivity) can be attributed to the underlying physiological changes from aerobic training.

One of the major effects of increased aerobic PA is a decrease in adipose tissue mass, particularly in the visceral region, even if weight loss does not occur.40 This reduction in adipose mass, which can be accelerated by a caloric restriction, can also be accompanied by increased skeletal muscle mass, improvements in CRF, and reductions in various cardiometabolic risk factors, including insulin resistance.40 Although it is rare that changes in CRF would be realized in the absence of decreases in adiposity, research has shown that the insulin-sensitizing effect of PA training persists independently of the effects of weight loss and fat redistribution.41 Although evidence exists that certain adipokine levels may be affected by aerobic PA, at present, much of this effect appears to be solely the result of a decreased fat mass.42 Because the proinflammatory cytokine tumor necrosis factor-α (TNF-α) is overproduced by obese individuals compared with lean counterparts, it seems likely that a reduction in body mass through PA would be effective...
in reducing TNF-α expression and inflammation through this pathway, but this effect has yet to be conclusively demonstrated in humans. In the Finnish Diabetes Prevention Study, a diet and exercise lifestyle intervention effectively lowered circulating C-reactive protein (CRP) and interleukin-6 (IL-6) levels, although it was unclear what portion of the intervention program contributed to these changes. Resistin is another proinflammatory marker linked to type 2 diabetes and cardiovascular disease development. Aerobic PA does not appear to alter plasma resistin levels during or after moderate PA in middle-aged, overweight, individuals without diabetes, but may lower levels in overweight adolescents and in adults with diabetes if the PA program is sufficiently vigorous. In addition to the reductions in various proinflammatory adipokines caused by PA, increases in the insulin-sensitizing adipokines such as adiponectin and its associated receptor in skeletal muscle mass loss during caloric restriction, and an elevated resting metabolic rate. Apart from increased muscle mass, improvements in muscular insulin sensitivity as a result of resistance training appear to result from similar adaptations to those that occur with endurance training. Resistance training has been shown to increase GLUT4 protein content, hypertrophy, both type I and II muscle fibers, as well as upregulate insulin receptors and signal transduction in the muscle cell, and improve nonoxidative glucose metabolism through increased glycogen synthase. However, some of these effects, such as glycogen synthase activity, are known to occur to a much smaller extent as a result of resistance training compared with aerobic training.

Examination of the effects of resistance training on adipokines in the absence of an increase in VO₂max or reduced fat mass revealed no changes in adipokine levels (with the exception of a decrease in plasma leptin) despite an increase in insulin sensitivity. Other studies have shown resistance training to have no effect on proinflammatory markers; however, as mentioned previously, some markers of inflammation, including IL-6 and resistin, are affected by reductions in adipose mass, which can be stimulated/augmented using resistance training. As such, resistance training does not appear to exert much effect on adipokines apart from those stimulated by a decrease in overall adipose tissue mass.

The Exercise Prescription
Due to a higher than normal cardiovascular complication rate in those with metabolic disorders, appropriate screening should be performed before initiating new PA program, and patients should be monitored by a qualified exercise professional. The primary goal when first initiating a PA program for individuals with prediabetes should be to decrease adiposity, which will, in turn, improve body composition (% muscle mass) and decrease the effects of the proinflammatory and pathogenic adipokines. This can be accomplished using any combination of aerobic and resistance PA because both modes help increase caloric expenditure. Ideally, individuals with prediabetes should aim to expend at least 1000 kcal/week through increased PA, similar to what is recommended for the general population. Given their already compromised metabolic health, these individuals with prediabetes should be encouraged to work toward even greater caloric expenditures if they are willing and able. When considering that a lack of sufficient PA is commonly associated with a prediabetic state, a structured exercise program will be unfamiliar for many individuals with prediabetes.

Resistant Exercise Training
Resistance training is well known to be associated with increased muscle mass and strength as well as enhanced muscular endurance, improved body composition, attenuated muscle mass loss during caloric restriction, and an elevated
As such, individuals should be slowly accommodated to both aerobic and resistance exercises to avoid injury and dropout as a result of being overwhelmed. Patients should be educated that some of the characteristics for which they strive to improve with resistance training, such as decreased body fat and increased muscle mass, do not occur in the short term, and can require significant effort and dedication, but are worthwhile to improve health risks and quality of life. In an effort to encourage PA as part of an overall lifestyle change, it is important to emphasize that not all PA must be structured exercise. Participants should be encouraged to increase energy expenditure through sports, dance, games, and activities of daily living by choosing active alternatives to sedentary living. Examples include taking the stairs instead of the elevator or active commuting, such as riding a bicycle rather than driving.

The frequency of PA for those with metabolic dysfunction is of heightened importance. Bouts of PA should be performed with a high frequency on most, if not all, days of the week, with never more than 72 hours between workouts. This allows individuals to optimize the transient effects of PA on insulin sensitivity. A high frequency of weekly PA can be maintained by using a combination of workout intensities such that lower intensities are utilized on “recovery days” following higher-intensity workout days. If individuals with prediabetes are able to perform both aerobic and resistance PA, they should be encouraged to adopt both types of exercise.
to receive the overlapping and complementary effects on insulin sensitivity and glycemic control.66 A summary comparison of aerobic versus resistance training effects on glucose metabolism and insulin sensitivity in the prediabetic individual is included in Figure 2. Use of both aerobic and resistance modalities allows greater program variation from day to day to help avoid boredom. Specific aerobic and resistance exercise considerations for the individual with prediabetes are presented in Appendix 1 and Appendix 2, respectively. A carefully planned combination of PA modes and intensities, combined with participant education and personal program feedback, can boost adherence and decrease the likelihood of “burnout” in participants.67 Working with a qualified exercise professional and/or workout partner should also be encouraged to provide motivation and assist in program adherence and maintenance. Qualified exercise professionals who are experienced in working with moderate- and high-risk patients should have formal university training in exercise physiology, expertise in PA prescription/monitoring, and be backed by a reputable organization such as the ACSM professional Registered Clinical Exercise Physiologist or the Canadian Society for Exercise Physiology Certified Exercise Physiologist. Physicians seeking guidance for encouraging patients to increase PA are recommended to investigate the “Exercise Is Medicine” program launched by the ACSM and American Medical Association. This program aims to increase patient and clinician communication about healthy PA by offering education and tool kits for clinical practice.

It is important to follow the training principal of progression for both aerobic and resistance PA, wherein the demands of the PA are progressively increased as the body adapts to the PA stimulus. If PA is not progressively increased, when the body adapts, the initial stress will no longer be sufficient to cause further adaptation. This may lead to a plateau, in which calories are still effectively consumed during PA (and may aid in adipose tissue reduction) but continuing changes in CRF, strength, and muscle mass are unlikely. Once the individual is accommodated to PA, simple caloric expenditure should no longer be the main goal of the training and gains in aerobic and muscular fitness should be sought.

If a patient’s PA ability is limited because of disease or other physical limitations, he or she should be encouraged to adopt as much PA as possible, with the goal of increasing activity levels to the suggested targets over time. Patients can be reassured that some activity is still better than no activity and that improvements in metabolic health and insulin sensitivity can occur at intensities lower than those recommended for changes in fitness.31 A summary of specific evidence-based recommendations for aerobic and resistance training is found in Appendix 2.

Summary
Insulin sensitivity is controlled through complex mechanisms and interactions of vascular function, skeletal muscle, and adipose tissue in conjunction with the liver and pancreas. Insulin sensitivity within these major tissues and organs can be altered by changes in capillary density, endothelial function, inflammation, muscle mass, muscle strength, muscle fiber composition, muscle oxidative capacity, nonoxidative metabolism, membrane phospholipid content, total adipose tissue, location of adipose tissue, production of adipose derived cytokines, and many other factors. It is important to note that PA has been shown to be effective in altering insulin sensitivity through physiological changes in these organs and organ systems, although some of the effects of PA may only be transient. Both aerobic and resistance PA can independently drive positive changes in whole-body insulin sensitivity, but a combination of the 2 training stimuli would be expected to have the greatest effect, with associated fat loss playing an important mechanistic role.

Conflict of Interest Statement
Jamie F. Burr, MSc, Chip P. Rowan, MSc, Veronica K. Jamnik, PhD, and Michael C. Riddell, PhD disclose no conflicts of interest.

References
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and serine phosphorylation of IRS1 in the liver of ZDF rats. Am J Physiol Endocrinol Metab. Published ahead of print Dec 8 2009.


Appendix 1. Aerobic Exercise Considerations for a Program Design Tailored to the Prediabetic State

<table>
<thead>
<tr>
<th>Exercise Consideration</th>
<th>Explanation and Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Many prediabetic individuals are overweight or obese. Start with low impact or non-weight-bearing activity to avoid potential injury from repetitive impact.</td>
<td>Start with recumbent or regular cycling and slowly work toward jogging and other higher-impact aerobics. Swimming and other water exercises have the benefit of a cooling/calming effect, a lower heart rate perceived exertion, and reduced cardiovascular demand with virtually no impact.</td>
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<td>A goal of 60 minutes per session is considered optimal. However, sessions can be broken up into six 10-minute bouts.</td>
<td>If a 60-minute exercise session is impractical, especially when first initiating exercise, individuals can do six 10-minute sessions throughout the day when convenient. This could include 30 minutes of brisk walking with the dog or a brief exercise break during lunch at work.</td>
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<td>High-intensity interval training is time efficient and particularly suitable for prediabetic exercisers, but it should not be introduced until participants are physically and mentally ready to undertake this more demanding exercise. Higher intensities may allow for shorter bouts with equivalent caloric expenditures to long, lower-intensity workouts. Care should be taken not to consistently sacrifice exercise volume at the expense of intensity.</td>
<td>The transient effects of high-intensity interval training may be more enduring than those associated with moderate activity. Exercisers can work on incorporating shorter-duration, higher-intensity bursts of speed in their regular brisk walks or by increasing the elevation while treadmill walking. High-intensity interval training bouts may be included with continuous aerobic exercise (&gt; 75%) to increase aerobic capacity, not just calorie burning.</td>
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<td>High-intensity interval training should be interspersed with other regular workouts to avoid injury and/or dropout.</td>
<td>Too much high-intensity interval training can lead to immunosuppression, sickness, or burnout. Most of the exercise should be at a comfortable, sustainable pace, with very-high-intensity (sprint) workouts scheduled no more than 1–2 times week.</td>
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<tr>
<td>Vary activities to keep interest and use multiple muscle groups.</td>
<td>Lower body: cycling, running, aerobics/dance.</td>
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<td>The more muscle mass used, the higher the caloric cost and likely the greater the changes in local metabolic efficiency.</td>
<td>Upper body: swimming, rowing, arm-crank ergometer.</td>
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<td>Objective and subjective methods of measuring exertion should be explained to participants to maintain appropriate exercise intensity.</td>
<td>Whole-body activities that require both the arms and the legs (eg, cross-country skiing and swimming) are naturally more taxing on the cardiovascular system and engage more musculature and vasculature than those that only use isolated muscle groups (ie, stationary cycling).</td>
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</tbody>
</table>

Subjective measures: talk test or rating of perceived exertion. Objective measures: heart rate monitoring; a predefined speed (with a known associated metabolic demand).
Appendix 2. Resistance Exercise Considerations for a Program Design Tailored to the Prediabetic State

Resistance Exercise Specific

<table>
<thead>
<tr>
<th>Exercise Consideration</th>
<th>Explanation and Examples</th>
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<tbody>
<tr>
<td>The overall goal is to increase muscle mass, increase caloric expenditure, and simultaneously condition muscles toward a more aerobic state.</td>
<td>By increasing muscle mass and caloric expenditure, prediabetic individuals can improve body composition and insulin sensitivity. Resistance training directly increases caloric expenditure and also increases resting metabolic rate with increases in lean mass. Exercises should be directed toward muscle hypertrophy and circuit training (slight aerobic component to improve muscle fiber distribution) as opposed to strength and power lifting, which primarily promote nonoxidative fiber growth.</td>
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<tr>
<td>Begin by learning safe lifting techniques using light weights, then shift focus to work on increasing muscle mass with hypertrophy training.</td>
<td>Before working with heavy loads and fatiguing sets, participants should be accommodated to safe lifting techniques and movement patterns to avoid injury. Lighter weights with greater reps also promote greater use of aerobic energy pathways, helping the balance between resistance and aerobic exercise and easing the transition into exercise. Exercise should begin with 1–2 sets, 15–20 reps, and progress to 3 sets, 8–10 repetitions to failure (70%–80% 1RM).</td>
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<td>Maintain muscle balance and work multiple muscle groups (agonists and antagonists) to avoid injury.</td>
<td>A well-balanced program should involve exercises using all of the major muscle groups (both agonists and antagonists) to promote balance. For a typical workout, this typically requires 6–8 exercises. Working all major muscle groups will also promote greater whole-body muscle hypertrophy. More lean mass is associated with higher insulin sensitivity and better metabolic regulation.</td>
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<td>Single and multijoint exercises can be combined simultaneously or consecutively in a circuit for efficiency and workout variety.</td>
<td>By combining exercises (eg, curls and lunges), exercise time can be used more efficiently. This also increases the reliance on the aerobic energy system (recovery between sets) as well as combining exercises in a circuit with little rest between exercises. By appropriately varying the exercise combinations, new and challenging exercises can be created using the same basic lifting techniques to help prevent monotony and boredom.</td>
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<td>Exercise prescription should be done in consultation with a qualified exercise specialist trained in fitness assessment and program design. Although the end goal of each resistance training program is the same, the ideal program design requires careful consideration of the circumstance, constraints affecting individuals, and should include opportunities for both structured and unstructured physical activity. As suggested in the text, the American College of Sports Medicine and the Canadian Society of Exercise Physiology exercise physiologists possess high levels of expertise in this area of health-related fitness and exercise prescription.</td>
<td>General guidelines for structured resistance training include:</td>
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<td>- Hypertrophy training (gaining muscle mass) requires 3–5 sets, of 8–10 reps to failure, per muscle group and should be performed on alternating days. Intensity should be 70%–85% of 1RM max.</td>
<td>- Unstructured physical activity can be accumulated through simple alterations to activities of daily living, such as taking the stairs two at a time.</td>
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<tr>
<td>- Muscular endurance training, which has a greater aerobic component, should be performed with same frequency using 1–3 reps and 12–25 reps. This corresponds to 50%–70% 1RM. Rest intervals should range from 30–90 seconds and be adjusted to allow completion of sets as necessary.</td>
<td></td>
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<tr>
<td>- Unstructured physical activity can be accumulated through simple alterations to activities of daily living, such as taking the stairs two at a time.</td>
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