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PRONOUNCEMENT

Exercise/Physical Activity in Individuals with Type 2 Diabetes: A Consensus Statement from the American College of Sports Medicine

JILL A. KANALEY[1], SHERI R. COLBERG[2], MATTHEW H. CORCORAN[3], STEVEN K. MALIN[4], NANCY R. RODRIGUEZ[5], CARLOS J. CRESPO[6], JOHN P. KIRWAN[7], and JULEEN R. ZIERATH[8]

[1]Department of Nutrition and Exercise Physiology, University of Missouri, Columbia, MO; [2]Human Movement Sciences Department, Old Dominion University, Norfolk, VA; [3]Shore Physicians Group, Northfield, NJ; [4]Department of Kinesiology and Health, Rutgers University, New Brunswick, NJ; [5]Department of Nutritional Sciences, University of Connecticut, Storrs, CT; [6]Oregon Health and Science University–Portland State University School of Public Health, Portland, OR; [7]Pennington Biomedical Research Center, Baton Rouge, LA; and [8]Department of Molecular Medicine and Surgery, Karolinska Institute, Stockholm, SWEDEN

ABSTRACT

KANALEY, J. A., S. R. COLBERG, M. H. CORCORAN, S. K. MALIN, N. R. RODRIGUEZ, C. J. CRESPO, J. P. KIRWAN, and J. R. ZIERATH. Exercise/Physical Activity in Individuals with Type 2 Diabetes: A Consensus Statement from the American College of Sports Medicine. *Med. Sci. Sports Exerc.*, Vol. 54, No. 2, pp. 353–368, 2022. This consensus statement is an update of the 2010 American College of Sports Medicine position stand on exercise and type 2 diabetes. Since then, a substantial amount of research on select topics in exercise in individuals of various ages with type 2 diabetes has been published while diabetes prevalence has continued to expand worldwide. This consensus statement provides a brief summary of the current evidence and extends and updates the prior recommendations. The document has been expanded to include physical activity, a broader, more comprehensive definition of human movement than planned exercise, and reducing sedentary time. Various types of physical activity enhance health and glycemic management in people with type 2 diabetes, including flexibility and balance exercise, and the importance of each recommended type or mode are discussed. In general, the 2018 Physical Activity Guidelines for Americans apply to all individuals with type 2 diabetes, with a few exceptions and modifications. People with type 2 diabetes should engage in physical activity regularly and be encouraged to reduce sedentary time and break up sitting time with frequent activity breaks. Any activities undertaken with acute and chronic health complications related to diabetes may require accommodations to ensure safe and effective participation. Other topics addressed are exercise timing to maximize its glucose-lowering effects and barriers to and inequities in physical activity adoption and maintenance. **Key Words:** EXERCISE, PHYSICAL ACTIVITY, TYPE 2 DIABETES

SYNOPSIS

This consensus statement is an update of the 2010 position stand on exercise and type 2 diabetes (T2D) published jointly by the American College of Sports Medicine (ACSM) and the American Diabetes Association (ADA) (1,2). In the ensuing decade, a considerable amount of research on select topics in exercise in individuals of varying ages with T2D has been published while diabetes prevalence has continued to expand worldwide. The objective of this consensus statement is to provide readers with a summary of the current evidence and extend and update the prior recommendations from 2010.

Address for correspondence: Jill A. Kanaley, Ph.D., University of Missouri, 204 Gwynn Hall, Columbia, MO 65211; E-mail: kanaleyj@missouri.edu.
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BOX. Consensus Statements and Recommendations.

- Regular aerobic exercise training improves glycemic management in adults with type 2 diabetes, with less daily time in hyperglycemia and 0.5%–0.7% reductions in overall glycemia (as measured by A1C).
- High-intensity resistance exercise training has greater beneficial effects than low-to-moderate-intensity resistance training in terms of overall glucose management and attenuation of insulin levels.
- Greater energy expenditure postprandially reduces glucose levels regardless of exercise intensity or type, and durations ≥45 min provide the most consistent benefits.
- Small "doses" of PA throughout the day to break up sitting modestly attenuate postprandial glucose and insulin levels, particularly in individuals with insulin resistance and a higher body mass index.
- Weight loss (accomplished through lifestyle changes in diet and PA) of >5% seems to be necessary for beneficial effects on A1C, blood lipids, and blood pressure.
- For reductions in visceral fat in individuals with type 2 diabetes, a moderately high volume of exercise (~500 kcal) done 4–5 $d \cdot wk^{-1}$ is needed.
- In youth with type 2 diabetes, intensive lifestyle interventions plus metformin have not been superior to metformin alone in managing glycemia.
- Despite the limited data, it is still recommended that youth and adolescents with type 2 diabetes meet the same PA goals set for youth in the general population.
- Pregnant women with and without diabetes should participate in at least 20–30 min of moderate-intensity exercise most days of the week.
- Individuals with type 2 diabetes using insulin or insulin secretagogues are advised to supplement with carbohydrate (or reduce insulin, if possible) as needed to prevent hypoglycemia during and after exercise.
- Participation in an exercise program before bariatric surgery may enhance surgical outcomes, and after surgery, participation confers additional benefits.

The writing group used a consensus approach to synthesize available evidence from clinical trials and case reports, narrative and systematic reviews, and meta-analyses, and the recommendations represent the consensus of the writing panel and ACSM and incorporate guidance from other professional organizations with expertise in this area, such as the ADA (1,2). Current science, new topics for discussion, and clinical experience in making recommendations for participation by people with T2D of all ages are highlighted. In addition, the title of the consensus statement and the text itself have been expanded to include physical activity (PA), a broader, more comprehensive definition of human movement of which structured or planned exercise is a subset.

INTRODUCTION

Currently diabetes affects over 463 million people worldwide (3), and its prevalence in the United States is 10.5% (4). T2D accounts for 90%–95% of all cases (5). The goal of treatment for T2D is to facilitate an individualized treatment plan, one that may include education, glycemic management, reduction of cardiovascular disease (CVD) risk, and ongoing screening for microvascular complications, in order to achieve and maintain optimal blood glucose, lipid, and blood pressure levels that prevent or delay chronic complications. Lifestyle interventions and/or medications are usually prescribed for treatment of T2D, and more recently, bariatric surgery has also become part of a possible treatment plan.

During any type of PA, glucose uptake into active skeletal muscles increases via insulin-independent pathways. Blood glucose levels are maintained by glucoregulatory hormone–derived increases in hepatic glucose production and mobilization of free fatty acids (6,7), which may be impaired by insulin resistance or diabetes (7). Improvements in systemic, and possibly hepatic, insulin sensitivity after any PA can last from 2 to 72 h, with reductions in blood glucose closely associated with PA duration and intensity (8–10). In addition, regular PA enhances β-cell function (11), insulin sensitivity (12), vascular function (13,14), and gut microbiota (15), all of which may lead to better diabetes and health management as well as disease risk reduction.

IMPACT OF EXERCISE/PA ON DIABETES MANAGEMENT AND HEALTH RISKS

Multiple types of PA enhance health and glycemic management in people with T2D, although structured exercise training has been studied most frequently. Many of the proven benefits result from improved insulin sensitivity, postprandial hyperglycemia, and CVD risk.

Aerobic exercise. Short-term aerobic exercise training improves insulin sensitivity in adults with T2D, paralleling improved mitochondrial function (16). Vigorous aerobic exercise training for 7 d may improve glycemia without lowering body weight via increased insulin-stimulated glucose disposal and suppression of hepatic glucose production (12). Short-term aerobic exercise in individuals with obesity and T2D improves whole-body insulin action through gains in peripheral insulin sensitivity more so than hepatic insulin sensitivity (17). Meta-analyses and systematic reviews have confirmed that regular aerobic exercise training improves glycemia in adults with T2D, with fewer daily hyperglycemic excursions and 0.5%–0.7% reductions in hemoglobin A1C (A1C) (18–22). Regular training also improves insulin sensitivity, lipids, blood pressure, other metabolic parameters, and fitness levels, even without weight loss (23,24).

Resistance exercise. Resistance exercise training in adults with T2D typically results in 10%–15% improvements in strength, bone mineral density, blood pressure, lipid profiles, skeletal muscle mass, and insulin sensitivity (25). Combined with modest weight loss, resistance training may increase lean skeletal muscle mass and reduce A1C threefold more in older adults with T2D compared with a calorie-restricted, nonexercising group that lost skeletal muscle mass (26). A recent meta-analysis of resistance exercise suggests that high-intensity training is more beneficial than low-to-moderate-intensity training for overall glucose management and attenuation of insulin levels in adults with T2D (27).

Combined exercise. Interventions with combined aerobic and resistance exercise training may be superior to either mode alone. A greater reduction in A1C has been noted in adults with T2D undertaking a combined training program compared with either type alone (28); however, combined training group participants had a greater exercise volume. In another trial, combined training significantly improved A1C levels over nonexercising controls, although neither resistance nor aerobic training alone resulted in significant changes (29). Moreover, the combined group lost more weight and improved aerobic fitness more so than controls. A meta-analysis (21) showed that all three exercise modalities favorably impact glycemia and insulin sensitivity, and combined training may produce greater reductions in A1C than either training modality alone (30).

High-intensity interval exercise. Higher intensities of aerobic training are generally considered superior to low-intensity training (31). High-intensity interval exercise (HIIE) training is a regimen that involves aerobic training done between 65% and 90% $\dot{V}O_{2peak}$ or 75% and 95% heart rate peak for 10 s to 4 min with 12 s to 5 min of active or passive recovery. HIIE has gained attention as a potentially time-efficient modality that can elicit significant physiological and metabolic adaptations. One session of HIIE (10 × 60 s cycling at ~90% maximum heart rate) reduced postprandial hyperglycemia in adults with T2D (32). Two weeks of afternoon HIIE training was shown to improve continuous glucose monitor–monitored glycemia, whereas morning training may increase glucose levels on exercise days, particularly if undertaken fasted (33). HIIE training also significantly improves fitness levels and reduces A1C and body mass index (BMI) in adults with T2D. Compared with continuous walking matched for energy expenditure, HIIE training resulted in greater fitness, better body composition, and improved continuous glucose monitor–monitored glycemia (34), as well as enhanced insulin sensitivity and pancreatic β-cell function in adults with T2D (35). Individuals with T2D who seek to improve glycemia with HIIE should closely monitor their responses to training, as chronic intense training may have negative effects such as transient postexercise hyperglycemia.

The maximal activity of citrate synthase and skeletal muscle mitochondrial protein content in adults with T2D are improved after just six sessions of low-volume HIIE (36). Further changes observed with HIIE training include greater reduction in A1C and CVD risk factors with less exercise time (37), as well as enhanced diastolic function (38), increased left ventricular wall mass, greater end-diastolic blood volume due to increased stroke volume and left ventricular ejection fraction (39), and improved endothelial function (40).

Types of exercise training compared. Glycemia and insulin sensitivity in adults with overweight/obesity and with insulin resistance, prediabetes, or T2D are improved similarly with different modes of structured exercise training when energy expenditure is matched (41–44). Adverse events have been reported in 34% of studies included in a meta-analysis, with a majority attributable to musculoskeletal injuries during HIIE rather than moderate training (45). The benefits of other types of PA are less well established and have mixed glycemic outcomes. Yoga may improve A1C, blood lipids, and body composition in adults with T2D (46), whereas tai chi may improve glycemic management, balance, neuropathic symptoms, and some dimensions of quality of life (47). Further studies are required to fully establish the potential benefits of yoga and tai chi in populations with T2D.

EXERCISE/PA WITH AND WITHOUT WEIGHT LOSS

Dietary restriction and increased PA are the cornerstones of intensive lifestyle (ILS) interventions that are typically used to induce weight loss. Such interventions may prevent or delay onset of T2D in at-risk populations and reduce CVD risk in individuals with T2D. In many cases, PA has been shown to be as important as, if not more so than, weight loss.

T2D prevention. The US Diabetes Prevention Program (DPP) multicenter trial utilized ILS with a goal of achieving modest (5%–7%) weight loss and led to the important observation that for every 1 kg of body weight lost, T2D risk was reduced by 16% (48). Even among those failing to meet the weight loss goal of 7% during the first year, individuals meeting the PA goal had a 44% reduction in diabetes incidence, independent of the small weight loss (−2.9 kg) (48). The DPP outcomes study (DPPOS) has shown a higher incidence of T2D onset in those who gained weight at 10 and 15 yr after participating in the original ILS arm (49,50). More recent follow-up data from DPPOS show that cumulative T2D incidence remained lower in the ILS group, a finding not explained by differences in body weight among groups (51); rather, PA was inversely related to incident of T2D for all participants. Importantly, prevention of T2D was enhanced in active participants with lower baseline PA, and moderate-intensity walking (about 18.2 $km \cdot wk^{-1}$) improved oral glucose tolerance with only 2 kg of weight loss (52). Overall, individuals at high risk for developing T2D who have initially low PA levels benefit the most from moderate-intensity walking and other exercise with minimal weight loss.

CVD Risk Reduction. Most ILS interventions in adults with T2D have also led to a reduction in CVD risk factors. In the Look AHEAD trial (53), ILS participants with T2D lowered triglycerides and increased HDL-C levels. More weight loss led to greater improvements in A1C, systolic blood pressure, HDL-C, and triglyceride levels. Most ILS trials (focused primarily on dietary changes and increased PA) with weight reduction as a goal in adults with T2D have resulted in <5% weight loss and few beneficial metabolic outcomes (54,55). A weight loss of >5% seems to be necessary for beneficial effects on A1C, blood lipids, and blood pressure in most individuals (54,55). During the first year of the trial, ILS participants experienced greater reductions in A1C, initial improvements in fitness, and attenuation of all CVD risk factors except for LDL-C levels. Furthermore, ILS did not reduce the occurrence of a composite CVD outcome score over 9.6 yr despite the greater, sustained weight loss in participants (56), but the participants had fewer hospitalizations, medications, and health care costs over 10 yr (57). Thus, lifestyle interventions that include PA in recommended amounts and possible weight loss remain important approaches in the management of T2D and CVD risks.

Weight loss and regional fat distribution. Weight loss from PA alone is generally small, although possible with 1 or more hours of daily moderate- or high-intensity exercise (58–60). In men and women with obesity, 1 h of daily moderate-intensity aerobic exercise induced weight loss similar to dietary restrictions alone, with similar reductions in abdominal subcutaneous and visceral fat observed in both groups. Regular exercise without weight loss also reduced subcutaneous and visceral fat and prevented further weight gain (58). In postmenopausal women with T2D, modest weight loss with either dietary restriction alone or diet plus exercise similarly reduced total abdominal fat, subcutaneous adipose tissue, and glycemia, but the addition of exercise was necessary for visceral adipose tissue loss (61), which leads to lesser metabolic dysfunction and CVD risk. Thus, moderate- to high-intensity exercise (~500 kcal) done 4–5 $d \cdot wk^{-1}$ seems to reduce abdominal, but particularly visceral, fat in adults with T2D and may lower their metabolic risk.

Prevention of gestational diabetes. Women with gestational diabetes mellitus (GDM) may have a nearly 10-fold higher risk of developing T2D at some point (62). PA is a preventative tool for GDM and subsequent development of T2D (63,64). Prepregnancy exercise training has been consistently associated with a reduced risk of GDM (65–68). Moderate aerobic exercise performed 3 $d \cdot wk^{-1}$ (50–55 min per session) for 8–10 wk through the third trimester reduces the prevalence of GDM (2.6% vs 6.8% with standard care) and minimizes excessive weight gain during pregnancy (69). Cycling exercise (30 min, three times a week) initiated early in pregnancy has been shown to reduce the frequency of GDM in women with overweight/obesity and lowered gestational weight gain before the mid-second trimester (70). A recent meta-analysis concluded that prenatal exercise alone, including 140 min of moderate-intensity exercise weekly, results in a 25% reduction in risk of GDM, preeclampsia, and gestational hypertension (71). Regular PA of any type during pregnancy decreases the incidence of GDM and maternal weight gain without serious adverse events (72). It is widely recommended that pregnant women participate in ~20–30 min of moderate-intensity aerobic exercise most days of the week, but the total amount of PA needed to achieve these diabetes risk reductions may be greater (73,74).

MENTAL HEALTH AND COGNITION BENEFITS OF PA

Regular PA potentially has psychological and cognitive function benefits for people with T2D. Both are important for the long-term health of this population.

Mental health. Participation in both short- and long-term exercise training has been shown to substantially decrease symptoms of depression and anxiety in individuals across all age groups diagnosed with clinical depression (75). Exercise increases certain brain hormones that modulate hippocampal plasticity to improve both cognition and mental health (76). In the Look AHEAD trial, participants following ILS had improved health-related quality of life and reduced symptoms of depression after 12 months (77), and the benefit extended as long as 8 yr (78). In the U-TURN study (79), participants with T2D who undertook ILS experienced improvements in the physical component of quality-of-life scores but with no change in the mental component at 1 yr. Collectively, these studies suggest that regular exercise may improve psychological well-being, including health-related quality of life and depressive symptoms, in individuals with T2D.

Memory and cognitive function. T2D is associated with cognitive dysfunction, including poor attention and concentration, visual and verbal memory, processing speed, and executive function (80). Young and older adults have experienced increases in basal glucose uptake in brain regions critical to cognitive function after 12 wk of aerobic interval exercise (4×4 min >90% $\dot{V}O_{2peak}$ for 3 $d \cdot wk^{-1}$) combined with moderate-intensity treadmill walking (70% $\dot{V}O_{2peak}$ for 2 $d \cdot wk^{-1}$) (81). Similarly, 2 wk of sprint interval training lowered insulin-stimulated glucose uptake in the temporal cortex, cingulate gyrus, cerebellum, and global regions when compared with other moderate-intensity continuous exercise training in sedentary, middle-age adults with insulin resistance (82). When PA is combined with a low-fat diet, brain insulin sensitivity is increased in adults with obesity (83). Surprisingly, there is a paucity of research on the effects of exercise on memory and cognitive function in people with T2D (84–87). Although the Look AHEAD trial reported no cognitive benefit after 8–9 yr of lifestyle treatment in people with T2D (88), a recent meta-analysis suggested a favorable, albeit small to moderate, effect of exercise on executive function and memory (89), similar to reported associations between exercise and cognitive function in adults with T2D (90,91). There is a paucity of data on the physiological mechanisms related to memory, cognitive function, and cerebral blood flow.

PA RECOMMENDATIONS FOR INDIVIDUALS WITH T2D

The 2018 update of the Physical Activity Guidelines for Americans (Table 1) included recommendations for youth, adults, and older adults (92,93). In general, these recommendations apply to individuals with T2D as well, with a few exceptions and modifications (Table 2). In most instances, the recommendations for adults of all ages are the same unless comorbid health conditions or older age impacts their ability to be active and modifications are needed (92).

ADULTS AND OLDER ADULTS

Aerobic exercise. All adults with T2D should follow the same recommendations, with no more than 2 consecutive days between bouts due to the transient nature of exercise-induced improvements in insulin action (94,95). Adults with comorbid health conditions and compromised older adults with T2D should aim to get as much aerobic activity as their physical and mental health allows.

Resistance exercise. Resistance exercise training in older adults with T2D results in 10%–15% improvement in strength, bone mineral density, lean mass, blood pressure, blood lipids, and insulin sensitivity (25,96), along with threefold greater reductions in A1C (26). Notably, interventions that combine aerobic and resistance training may be superior to either one alone (21,29,30). Adults unable to meet current recommendations should focus on improving on functional fitness and balance.

Flexibility exercise. Exercises that enhance joint flexibility are highly beneficial for health and well-being in older adults with T2D. Limitations to joint mobility, resulting in part from glycation occurring with normal aging, may be accelerated by hyperglycemia (97). Although stretching exercises increase

TABLE 1. PA guidelines for all Americans (2018) (91,92).

Adults	Move more and sit less throughout the day. Some PA is better than none. For substantial health benefits, do at least 150 min (2 h, 30 min) to 300 min (5 h) a week of moderate-intensity, or 75 min (1 h, 15 min) to 150 min (2 h, 30 min) a week of vigorous-intensity aerobic PA, or an equivalent combination of moderate- and vigorous-intensity aerobic activity, preferably spread throughout the week. Additional health benefits are gained by engaging beyond the equivalent of 300 min (5 h) of moderate-intensity PA weekly. Perform muscle-strengthening activities of moderate or greater intensity and that involve all major muscle groups on 2 or more days per week.
Older adults	The guidelines for healthy older adults are the same as those for all adults. In addition, as part of weekly PA, do multicomponent PA that includes balance training as well as aerobic and muscle-strengthening activities. Determine level of effort for PA relative to the level of fitness. With chronic conditions, understand whether and how the conditions affect the ability to do regular PA safely. If an individual cannot do 150 min of moderate-intensity aerobic activity a week because of chronic conditions, engage in as much PA as abilities and conditions allow.
Children and adolescents	Preschool-age children (ages 3 through 5 yr) should be physically active throughout the day to enhance growth and development. Adult caregivers of preschool-age children should encourage active play that includes a variety of activity types. Provide young people opportunities and encouragement to participate in PA appropriate for their age that are enjoyable and that offer variety. Children and adolescents ages 6 through 17 yr should engage in 60 min (1 h) or more of moderate-to-vigorous PA daily: • Aerobic: Most of the 60 min or more per day should be either moderate- or vigorous-intensity aerobic PA and should include vigorous-intensity PA on at least 3 d·wk^{-1}. • Muscle-strengthening: As part of 60 min or more of daily PA, include muscle-strengthening activities on at least 3 d·wk^{-1}. • Bone strengthening: As part of 60 min or more of daily PA, include weight-bearing exercise to strengthen bones at least 3 d·wk^{-1}.

range of motion and flexibility (98), they generally do not impact glycemia unless undertaken as part of another PA such as yoga (99). Flexibility exercises, alone or in combination with resistance training, has been shown to improve joint range-of-motion in individuals with T2D and facilitates participation in activities that require flexibility (98). Moreover, flexibility training is generally low intensity and easier to perform, thereby providing one possible entry into a more physically active lifestyle for less fit and older adults (1).

Balance exercise. Many lower body and core resistance exercises double as balance training (100). Power training undertaken by adults with T2D can improve overall body balance (101). Balance exercises may reduce the risk of falls by improving balance and gait, even in adults with peripheral neuropathy (102,103). At-home balance exercises may reduce risk of falls even without significant changes in leg strength in older adults with T2D at increased risk for falls (103).

Other types of exercise and PA. Along with traditional static and dynamic stretching, yoga, tai chi, and other types of PA may also provide health and glycemic benefits. Inclusive of basic stretching and strengthening activities, yoga may improve overall glycemia, lipid levels, and body composition in adults with T2D (46,99,104,105). Tai chi training incorporates some balance, stretching, and resistance elements and may improve glycemia, reduce BMI and neuropathic symptoms, and increase balance and quality of life in adults with T2D and neuropathy (106,107). Various forms of qigong may improve A1C levels and other health and fitness parameters including balance (106,108,109). Pilates may improve blood glucose management, along with functional capacity, in older adults with T2D (110). Thus, many alternate types of exercise and PA may be appropriate and beneficial for adults with T2D, especially individuals with lower initial fitness and poorer balance.

Sedentary time and activity breaks. Physical inactivity (i.e., sitting or lying while awake) increases the risk of T2D across all racial and ethnic groups (111). In sedentary adults with 9 h of sedentary behavior per day, 1 h extra of sedentary time daily over an 8-d period is associated with a 22% increase in the odds of developing T2D (112). Furthermore, greater sedentary time is related to hyperglycemia independent of aerobic fitness (113), although high levels of fitness can attenuate CVD risk factor clustering (114).

TABLE 2. Recommended types of exercise training for all adults with T2D.

Type of Training	Type	Intensity	Frequency	Duration	Progression
Aerobic	Walking, jogging, cycling, swimming, aquatic activities, rowing, dancing, interval training	40%–59% of $\dot{V}O_2R$ or HRR (moderate), RPE 11–12; or 60%–89% of $\dot{V}O_2R$ or HRR (vigorous), RPE 14–17	3–7 d·wk^{-1}, with no more than 2 consecutive days between bouts of activity	Minimum of 150–300 min·wk^{-1} of moderate activity or 75–150 min of vigorous activity, or an equivalent combination thereof	Rate of progression depends on baseline fitness, age, weight, health status, and individual goals; gradual progression of both intensity and volume is recommended
Resistance	Free weights, machines, elastic bands, or body weight as resistance; undertake 8–10 exercises involving the major muscle groups	Moderate at 50%–69% of 1RM, or vigorous at 70%–85% of 1RM	2–3 d·wk^{-1}, but never on consecutive days	10–15 repetitions per set, 1–3 sets per type of specific exercise	As tolerated; increase resistance first, followed by a greater number of sets, and then increased training frequency
Flexibility	Static, dynamic, or PNF stretching; balance exercises; yoga and tai chi increase range of motion	Stretch to the point of tightness or slight discomfort	≥2–3 d·wk^{-1} or more; usually done with when muscles and joints are warmed up	10–30 s per stretch (static or dynamic)group; 2–4 repetitions of each	As tolerated; may increase range of stretch as long as not painful
Balance	Balance exercises: lower body and core resistance exercises, yoga, and tai chi also improve balance	No set intensity	≥2–3 d·wk^{-1} or more	No set duration	As tolerated; balance training should be done carefully to minimize the risk of falls

1RM, 1-repetition maximum; HRR, heart rate reserve; PNF, proprioceptive neuromotor facilitation; RPE, rating of perceived exertion; $\dot{V}O_2R$, $\dot{V}O_2$ reserve.

In adults with T2D, the interruption of prolonged sitting with activity breaks, such as light-intensity walking or simple resistance activities for 3 min every 30 min over 8 h, decreases postprandial glucose, insulin, C-peptide, and triglyceride levels (115). Replacing sitting time with standing (2.5 $h \cdot d^{-1}$) and light-intensity walking (totaling 2.2 $h \cdot d^{-1}$) every 30 min may improve 24-h glucose levels and insulin sensitivity more than structured exercise (116). Bouts of stair climbing also have been effective at reducing postprandial glycemia (117,118), but not necessarily A1C (119). Short 5-min breaks every h over 12 h more effectively lowered glucose and insulin levels than 1 h of moderate-intensity continuous exercise at the beginning of the day in people with impaired glucose tolerance (120), and short bouts of exercise (HIIE consisting of 6 × 1 min walking at 90% maximum heart rate) 30 min before meals reduces glucose levels more than a single 30-min bout of moderate walking (121). Small "doses" of PA to break up sitting moderately attenuate postprandial glucose and insulin levels, somewhat more than moderate continuous exercise, with greater effects in people with insulin resistance and a higher BMI (122). However, breaks from sitting have not been shown to lower hyperglycemia in free-living environments (123). Whether long-term use of breaks in sedentary time has clinically relevant glycemic benefits remains unclear.

ADOLESCENTS AND YOUTH

PA goals recommended for youth and adolescents with T2D are the same as for youth in the general population (92,93). Childhood obesity and T2D occur in complex psychosocial and cultural environments, making successful implementation of lifestyle interventions difficult (124). Youth with T2D manifest both insulin resistance and nonautoimmune β-cell failure similar to adults; however, youth onset is associated with a more rapid decline in β-cell function and acceleration of diabetes complications. The Bright Bodies Weight Management Program for Children, a year-long two times a week exercise and nutrition/behavior modification program in youth with obesity without diabetes, reduced insulin resistance and T2D risk (125). In a multicenter study in youth with T2D (the TODAY Study), metformin therapy managed glycemia in half of participants, and the addition of rosiglitazone, but not lifestyle changes including PA, was superior to metformin alone (126,127). A 12-wk gym-based, supervised program in adolescents with T2D improved endothelial function and health, independent of changes in insulin sensitivity (14). Thus, home-based and gym-based exercise and weight management programs should be encouraged for youth with T2D to enhance insulin sensitivity and cardiometabolic function and manage overweight and obesity.

PREEXERCISE EVALUATION AND TESTING

For most individuals planning to participate in a low- to moderate-intensity PA like brisk walking, no preexercise medical evaluation is needed unless symptoms of CVD or microvascular complications are present (1,96). In adults who are currently sedentary, medical clearance is recommended before participation in moderate- to high-intensity PA. Although suggested by practice guidelines (Table 3), preexercise stress testing in asymptomatic adults with T2D remains controversial. One study reported that all participants with T2D had lower rates of major CVD outcomes (<1%), with no differences between those who underwent stress testing (sedentary with one or more cardiac risk factors) and those who did not over 3.4 yr, and preexercise stress testing did not reduce CVD events (128). In the Look AHEAD trial, only older age was associated with an increased prevalence of all abnormalities during maximal exercise stress testing (129), and in the DIAD trial, more intensive testing did not alter event rates (130). Moreover, no evidence is available to determine whether preexercise evaluation involving stress testing is necessary or beneficial before participation in anaerobic or resistance training. Coronary ischemia is less likely to occur during resistance compared with aerobic exercise eliciting the same heart rate, and some doubt exists that resistance exercise induces ischemia (131–133).

TABLE 3. Indications for preparticipation exercise stress testing.

In general, maximal graded exercise stress testing may be indicated for adults matching one or more of these criteria:

- Age >40 yr, with or without CVD risk factors other than diabetes
- Age >30 yr and
  - Type 1 or T2D >10 yr duration
  - Hypertension
  - Cigarette smoking
  - Dyslipidemia
  - Proliferative or preproliferative retinopathy
  - Nephropathy including microalbuminuria
- Any of the following, regardless of age
  - Known of suspected cardiovascular, coronary artery, or peripheral artery disease
  - Autonomic neuropathy
  - Advanced nephropathy with renal failure

MANAGEMENT OF ACUTE AND CHRONIC HEALTH COMPLICATIONS WITH PA

Numerous acute and chronic health issues may arise around PA initiated by individuals with T2D. Of primary concern are exercise-related hypoglycemia and hyperglycemia. In addition, exercising with chronic health complications related to diabetes may require accommodations to ensure safe and effective PA participation.

Hypoglycemia. Individuals managing glycemia with lifestyle improvement alone have minimal risk for hypoglycemia (134). Use of select medications for T2D may increase the risk of exercise-related hypoglycemia, including insulin and insulin secretagogues (i.e., sulfonylureas and meglitinides) (7,135–137). For example, preexercise insulin administration increases the risk of hypoglycemia during exercise, and both insulin dosing and timing must be considered. Carbohydrates may be needed if preexercise blood glucose levels are likely to lead to hypoglycemia during or after activities, and medication doses are not lowered to compensate. No medication dose adjustments or carbohydrate intake is necessary for other oral diabetes medications or noninsulin injectables, such as glucagon-like peptide-1 (GLP-1) agonists (96). Later-onset hypoglycemia is a greater concern when carbohydrate stores (i.e., skeletal muscle and liver glycogen) are depleted, but usually is not an issue for most recreational exercisers who are noninsulin users. Although high-intensity exercise may be problematic for those taking insulin, finishing an exercise session with a short, high-intensity bout has been shown to be beneficial in preventing hypoglycemia in those not on insulin. Longer-duration, high-intensity PA increases the risk for postexercise hypoglycemia with use of insulin or its secretagogues (138).

Hyperglycemia. Clinical consensus recommendations state that if blood glucose is >300 mg·dL^{-1} (16.7 mmol·L^{-1}), caution should be advised when exercising without or with minimal levels of blood or urinary ketones, but ketones are seldom measured or excessively elevated in individuals with T2D. Regardless, if blood glucose is elevated, individuals are advised to only begin light activity if they are asymptomatic and properly hydrated (96,139). Activities that are short and intense (such as HIIE) may cause a transient increase in blood glucose that remains elevated afterward for a period of time (140,141). Extra insulin (in users) and/or a lower intensity cool-down after intense activities may be used to reduce postexercise glucose elevations, although no treatment is needed in most cases (140). Importantly, diabetic ketoacidosis, which normally is the result of hyperglycemia and elevated ketones, may occur with euglycemia or only moderate hyperglycemia in adults with T2D taking oral sodium-glucose-co-transporter-2 inhibitors to manage blood glucose (142). Given these potential confounders, PA should only be undertaken when individuals with elevated blood glucose, even without overt ketosis, are feeling well.

Heat stress. Aging alone negatively affects heat loss in both dry and humid environments (143), but T2D also seems to increase the risk of heat stress during PA, but not during passive rest (144). Impairments in whole-body heat loss are related to abnormal cutaneous vasodilation and decreased sweating (145), which can lead to increases in body temperature and heart rate. Consequently, many adults with T2D have a reduced ability to do PA, especially in warm environments, due to an impaired ability to thermoregulate, and with dehydration, their risk of chronic hyperglycemia increases (146). Moreover, certain diabetes-related comorbidities and medications may increase the risk of heat-related illness (147). Heat acclimation has been shown to be possible in adults with T2D engaging in aerobic or resistance training, though, with some improvements in exercise-generated heat dissipation and other factors after adaptation (148,149). Nevertheless, individuals with T2D should be cautious when exercising in hot environments, although they may acclimatize to hotter conditions with regular PA.

Chronic health complications. Recurrent hyperglycemia increases the risk for chronic complications of diabetes, including macrovascular complications (CVD, peripheral vascular disease, and lower limb amputations) and microvascular complications (e.g., retinopathy, nephropathy, and peripheral and autonomic neuropathy (150–152). Prolonged daily sedentary time also increases the risk of T2D, CVD, and premature mortality, even when adjusted for PA levels (153,154). Most individuals can engage in various types of PA safely and effectively despite having health complications. With regular training, they can anticipate significant and meaningful improvements when following general exercise training precautions (Table 4). Certain activities may be contraindicated because of existing health conditions, and special testing or preexercise preparation may be required (Table 5). In individuals with macrovascular diseases or cardiac autonomic neuropathy, preexercise screening should follow the guidelines set by the ACSM (155) and ADA (96).

TABLE 4. General exercise training considerations and precautions.

Medical clearance (and exercise testing) before starting activities more vigorous than brisk walking is recommended for adults with signs or symptoms of CVD, longer diabetes duration, older age, or other diabetes-related complications (95).
Individuals should not begin exercise with a blood glucose >250 mg·dL^{-1} (13.9 mmol·L^{-1}) if moderate or high levels of blood or urinary ketones are present. Use caution during PA with a blood glucose >300 mg·dL^{-1} (16.7 mmol·L^{-1}) without excessive ketones, stay hydrated, and only begin if feeling well (95,139).
Individuals are advised to hydrate properly by drinking adequate fluids before, during, and after exercise, as well as avoid exercising during the peak heat of the day or in direct sunlight to prevent overheating.
Particularly for anyone using insulin or taking sulfonylureas (and possibly meglitinides within 2–3 h of PA), it is important to carry rapid-acting carbohydrate sources during PA to treat hypoglycemia and have glucagon available to treat severe hypoglycemia (if prone to developing it).

EXERCISE TIMING AND DIETARY CONSIDERATIONS

Some studies have addressed optimal timing of exercise around meals and in general to maximize blood glucose management and other health benefits in T2D. In addition, although dietary eating patterns may be used to enhance blood glucose management, their impact on exercise remains equivocal.

Exercise timing. Most acute exercise studies have examined effects on glycemia around breakfast, demonstrating better management with light- or moderate-intensity aerobic exercise undertaken postprandially in individuals with T2D (156–158), but this glycemic benefit does not necessarily carry over to lunch (156,157). Only one study found better glycemic management with exercise before breakfast (159). A comparison of 2 wk of morning or afternoon HIIE (three times a week) training in men with T2D showed that afternoon sessions reduced blood glucose more than morning sessions, which actually increased glycemia (33). A 12-wk multimodal exercise training program found that either morning or afternoon sessions in men and women with T2D improved A1C, fasting glucose, and homeostatic model assessment-2 insulin resistance but not fructosamine, and postprandial glucose and insulin levels were similarly lowered after a mixed meal (160). When exercise was undertaken around dinner, better blood glucose responses occurred with self-selected pace walking after a meal (161), and blood glucose and triglyceride levels were attenuated by postmeal resistance exercise (162). Overall, most studies have shown that postprandial exercise provides better glucose control by attenuating acute glycemic spikes, and greater energy expenditure postprandially reduces glycemia regardless of exercise intensity or type, with a longer duration (≥45 min) providing the most consistent benefits (61).

Dietary intake and eating patterns. Prevention or delay of T2D can be achieved with regular PA and maintenance

TABLE 5. PA precautions for common comorbid health complications.

Health Complication	Precaution
Autonomic neuropathy	• Be aware of an increased likelihood of hypoglycemia, abnormal blood pressure responses, and impaired thermoregulation, as well as elevated resting and blunted maximal heart rate. • Use of ratings of perceived exertion (RPE) is suggested to monitor exercise intensity. • Take steps to prevent dehydration and hyperthermia or hypothermia.
Peripheral neuropathy	• Limit exercise participation that may cause foot trauma, such as prolonged hiking, jogging, or walking on uneven surfaces. • Non–weight-bearing exercises (e.g., cycling, chair exercises, swimming) may be more appropriate, but avoid aquatic exercise with unhealed plantar surface ulcers. • Check feet daily for signs of trauma and redness. • Choose shoes and socks carefully for proper fit and wear socks that keep feet dry. • Avoid activities requiring excessive balance ability.
Diabetic retinopathy	• With unstable proliferative and severe retinopathy, avoid vigorous, high-intensity activities that involve breath holding (e.g., weight lifting and isometrics) or overhead lifting. • Avoid activities that lower the head (e.g., yoga, gymnastics) or that jar the head. • In the absence of a stress test measured maximal heart rate, use RPE to monitor exercise intensity (10 to 12 on a 6–20 scale). • Exercise is contraindicated for anyone with unstable or untreated proliferative retinopathy, recent panretinal photocoagulation, or other recent surgical eye treatment. • Consult an ophthalmologist for specific restrictions and limitations.
Diabetic kidney disease	• Avoid exercise that causes excessive increases in blood pressure (e.g., weight lifting, high-intensity aerobic exercise) and refrain from breath holding during activities. • High blood pressure is common, and lower-intensity exercise may be necessary to manage blood pressure responses and fatigue. • Light to moderate exercise is possible during dialysis treatments if electrolytes are managed.
Hypertension	• Avoid heavy weight lifting or breath holding. • Perform dynamic exercises using large muscle groups, such as walking and cycling at a low to moderate intensity. • Follow blood pressure guidelines for activity levels. • In the absence of a measured maximal heart rate, use of RPE is recommended (10 to 12 on a 6–20 scale).

of a healthy body weight, and individuals with T2D should focus on sustainable eating plans that consider the amount and timing of carbohydrate intake in combination with an active lifestyle to manage glycemia, insulin sensitivity, body weight, and CVD risk. According to the 2020–2025 US Dietary Guidelines for Americans (163), a healthy eating plan provides appropriate daily calories; highlights fruits, vegetables, and whole grains; includes reduced or nonfat dairy products, lean meats, poultry, fish, beans, eggs, and nuts; and is low in saturated and trans fats, cholesterol, salt, and added sugar. Whole foods–based eating is micronutrient dense, antioxidant rich, and beneficial in preventing and managing T2D (164). Carbohydrate restriction reduces body weight and improves glycemia (165–168), and use of popular diet options (i.e., low carbohydrate, ketogenic diet) and other eating patterns (i.e., Mediterranean, vegan) are frequently followed for T2D management (169,170). Time-restricted feeding and intermittent fasting, which have multiple definitions, have become popular in recent years, but there are limited studies to date in individuals with T2D and the benefits to glycemic management are unknown. Caution is recommended when implementing a ketogenic diet that chronically restricts carbohydrate to $\leq 50\ g \cdot d^{-1}$ to induce ketosis (170), as insufficient trials in individuals with T2D support this approach (165,169,170) and its impact on PA participation and exercise performance remains equivocal (167,168,171–173).

MEDICAL INTERVENTIONS AND EXERCISE EFFECTIVENESS

Antidiabetes medications are often co-prescribed with exercise for management of T2D. Some of these, as well as others taken for comorbid conditions, may impact the effectiveness of exercise participation. In addition, adults undergoing bariatric surgery to manage obesity and T2D may also be impacted by presurgery and postsurgery exercise participation.

Diabetes medications. Somewhat surprisingly, pilot studies on adults with insulin resistance have found that metformin, the most commonly prescribed medication for prediabetes and diabetes, may attenuate exercise-enhanced peripheral insulin sensitivity benefits after acute (174) and chronic exercise (175) training. In adults with T2D, the normal reduction in postprandial glycemia with metformin use also may be somewhat attenuated by exercise (176). Although it augments skeletal muscle glucose uptake during any PA (177) and improves glycemia in individuals with T2D (178), metformin has been found to potentially blunt AMP-activated protein kinase activity (174) and mitochondrial adaptations to aerobic exercise (179) and attenuate skeletal muscle hypertrophy after weight lifting (180) in healthy adults. Thus, metformin may be contributing to the interindividual variability observed in exercise-induced improvements in insulin sensitivity and cardiometabolic health (181), but more research is needed in this area.

As for other medications, both GLP-1 agonists and sodium-glucose-co-transporter-2 inhibitors have glucose-lowering mechanisms and downstream metabolic impacts that may impact exercise-induced adaptations. GLP-1 agonists may improve A1C levels and fasting glycemia after aerobic exercise training in adults with T2D, but these findings have been confounded by significant weight loss (182). More research is needed on the interaction of all these medications and exercise. Insulin therapy is often a last option in T2D, but in men with T2D, similar reductions in time spent in hyperglycemia and reduced glycemic variations over 24 h were observed after a 45- to 60-min bout of exercise with and without insulin use (183). Individuals with T2D using insulin or insulin secretagogues are advised to supplement with carbohydrate (or reduce insulin, if possible) as needed to prevent hypoglycemia before and/or after exercise.

Nondiabetes medications. β-Blockers blunt the heart rate responses to exercise and lower maximal aerobic exercise capacity to ~87% of expected via negative inotropic and chronotropic effects (184). Although their use may increase the risk of hypoglycemia unawareness with PA by blunting adrenergic responses, β-blockers can increase exercise capacity in people with T2D and CVD by reducing ischemia during PA (185). In adults using β-blockers, ratings of perceived exertion should be utilized to monitor exercise intensity rather than heart rate (186). In a small number of individuals, statin use has been associated with an elevated risk of myopathies (myalgia and myositis), particularly when combined with fibrates and niacin and hyperglycemia (187).

Bariatric surgery. Bariatric surgery is now considered the most effective way to improve glycemic management and achieve diabetes remission over the long term (188,189); however, less than 10% of adults undergoing bariatric procedures meet PA recommendations before surgery, despite the nearly 40% of adults saying they feel ready to exercise 14 d before surgery (190). Preoperative exercise may benefit these individuals by lowering surgical risk and enhancing recovery, as well as reducing the length of hospital stays (191). Increases in $\dot{V}O_{2peak}$ are also associated with reduced operating time and improved quality of life despite no additional effect on blood glucose levels or insulin sensitivity (192,193). Others have suggested increased exercise before surgery increases the propensity for being active afterward (194). Aerobic exercise training after surgery may further enhance weight maintenance, glycemic management, and insulin sensitivity (195–197); lower the risk of CVD; enhance endothelial function (198); and improve cardiac autonomic regulation (199). Resistance exercise training may reverse muscle strength deficits frequently observed after bariatric surgery (200). Exercise training is also effective in ameliorating surgery-related bone loss (201,202), which is common after bariatric surgery (203–205).

BARRIERS TO ADOPTION OF PA AND INEQUITIES

Barriers to PA participation are similar among people with and without diabetes and include lower self-efficacy (206), inappropriate goal setting (207), lack of access to facilities (208), lack of supervision or social support (209–211), and inattention to cultural nuances (212). Health issues like obesity and knee and hip osteoarthritis may also be barriers as they negatively impact self-efficacy related to PA participation (213). The built environment, or human-made surroundings, may also impact the ability and willingness to be regularly active (208) and may include availability of facilities, having pleasant and safe places to walk, and access to green spaces (214,215). Focusing on creating more exercise-friendly environments is likely to promote greater participation. Setting realistic goals with appropriate activities, slower progression, and supportive feedback can increase success and confidence (216–218). Counseling by health care professionals may also be a meaningful and effective source of support (219). Likewise, supervision of exercise sessions improves compliance and glycemia (220).

The prevalence of physical inactivity, obesity, and T2D is significantly higher among non-Hispanic Blacks, American Indian/Alaskan Natives, and Hispanics than among non-Hispanic Whites (4,221–224). The disproportionate burden of these conditions is likely more attributable to social and environmental determinants in these racial and ethnic minorities than biological differences (225,226). Physical education in schools, limited open spaces for outdoor activities, inadequate infrastructure for active transportation, unsafe environments, and hypercaloric diets are dominant environmental factors that contribute to T2D development (225–232). Community environments that promote PA are associated with a lower incidence of T2D (227,233–235); therefore, efforts that promote long-term health outcomes and target environmental factors may reduce T2D (235,236). Neighborhood walkability, PA resources, and access to green spaces may reduce T2D risk (215,235), whereas living in urban settings may raise it.

EXPERT INTERPRETATION AND KEY FUTURE DIRECTIONS

- Large-scale clinical trials in T2D are needed to understand optimal treatment regimens and importance of PA and exercise, other lifestyle changes, and medications on glycemia.
- Further work is warranted to elucidate the cognitive domains that are most responsive to PA and dietary improvements in adults with T2D, as well as exercise effects on memory and cognitive function related to glycemic management.
- More research on the effect of exercise training on vascular function and the microbiome needs to be conducted in individuals with obesity and with and without T2D.
- Longer-duration training is needed to establish whether exercise timing modifies the glycemic response to meals as well as overnight levels and if specific time of day of planned exercise should be prescribed.
- Although prolonged sitting has been found deleterious in research settings, studies on PA breaks in daily life are necessary to determine whether long-term use has clinically relevant glycemic benefits in populations with T2D.
- Potential interactions between diabetes medications like metformin and exercise training need to be further investigated with respect to their impact on glycemic management.
- Social and environmental factors have also been associated with physical inactivity and the incidence of T2D, and these factors need to be explored further.
- Targeted research is needed to better define the health disparities that exist across racial, ethnic, and potentially socioeconomic populations and how their impact on PA participation for T2D and prediabetes prevention and management can be mitigated.
- Larger clinical trials examining the impact of chronic high-intensity exercise on mitochondrial function and glucose tolerance in a population with obesity and with and without T2D are needed.

CONCLUSIONS

Various types of PA, inclusive of but not limited to planned exercise, can greatly enhance the health and glycemic management of individuals of all ages with T2D, including flexibility and balance exercise in adults. The latest Physical Activity Guidelines for Americans are applicable to most individuals with diabetes, including youth, with a few exceptions and modifications. All individuals should engage in regular PA, reduce sedentary time, and break up sitting time with frequent activity breaks. PA undertaken with health complications can be made safe and efficacious, and exercise training undertaken before and after bariatric surgery is warranted and may enhance its health benefits. Finally, barriers to, and inequities in, PA and exercise adoption and maintenance need to be addressed to maximize participation.

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Click here (http://links.lww.com/MSS/C442) to download a slide deck that summarizes this American College of Sports Medicine Expert Consensus Statement on Exercise/Physical Activity and Type 2 Diabetes.

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