Minimizing Negative Effects on Glycemia of Pre- and Post-Meal Exercise for People With Diabetes: A Personal Case Report and Review of the Literature

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Despite extensive efforts to prevent diabetes through healthful eating patterns, exercise, and medications, the prevalence of diabetes is on the rise (1). Healthy lifestyles can help with the management (2), prevention (2–4), and remission (5) of type 2 diabetes. However, data indicate that few people practice healthy lifestyles (6–10).

Healthy lifestyle habits typically include eating a well-balanced diet, getting regular physical activity, controlling body weight and blood pressure, not smoking, and consuming little or no alcohol (1,2,6). Aerobic exercise (AE) and resistance exercise (RE) have consistently shown glycemia benefits for people with diabetes (2,11). AE consists of continuous, rhythmic movement of large muscle groups, such as what occurs during walking, jogging, and cycling (2,11). RE involves movements using free weights, weight machines, body weight exercises, or elastic resistance bands (2,11). Anaerobic exercise is short-length, high-intensity activity such as high-intensity interval exercise (HIIE), sprinting, and jumping that breaks down glucose for energy without using oxygen. American Diabetes Association (ADA) guidelines recommend 150 minutes/week of moderate to vigorous activity for adults and 60 minutes/week for children and adolescents (2). It also recommends RE at least three times per week for all people with diabetes (2). These forms of physical activity, along with healthful eating patterns, are expected to help people with overweight or obesity reach a recommended weight reduction goal of >5% body weight (2).

New research results also show the benefits of paying attention to meal timing and exercise timing (12,13). However, of five evidence-based healthy practices (healthful meal composition, meal timing, nutrient sequencing, and safe pre- and post-meal exercises), only meal composition is included in ADA guidelines (2,14). Although a consensus statement from the American College of Sports Medicine includes one paragraph about exercise timing, it does not address the negative effects on glycemia of post-meal exercises (14); it does, however, mention post-exertion glucose elevations from pre-meal exercise.

Unlike meal-related habits with fairly straightforward glycemic effects (2,15–24), the effects of exercise on glycemia are quite complex; hyperglycemia or hypoglycemia can occur with certain types of physical activity. Decades of studies in various populations have shown the negative and positive effects on glycemia of pre-meal (25–45) and post-meal exercises (46–76) (Tables 1 and 2). Minimizing the negative effects on glycemia of any exercise is a desirable goal for people with diabetes, but many may not know how to accomplish this goal. This case report describes how evidence-based, safe exercise helped a person with type 2 diabetes (the author) improve her diabetes management.

Case Presentation

I was a 50-year-old practicing physician when I saw my primary care physician (PCP) with a complaint of excessive hunger and dizziness before lunch at work.

I grew up in South India, in a community where white rice was the main carbohydrate at almost every meal and coconut oil was the main oil used for cooking. Late supper (around 9:00 p.m.) was the norm. My medical history was positive for gestational diabetes during my first pregnancy that was managed through healthful eating and exercise. My family history was negative for diabetes, although the prevalence of the disease is quite high in South India.

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TABLE 1 Pre- Versus Post-Meal Training in Type 2 Diabetes (39)

Training Three Times Per Week for 12 Weeks*	A1C, %	C-Reactive Protein, mg/dL	HOMA-IR	LDL Cholesterol, mg/dL	HDL Cholesterol, mg/dL	Total Cholesterol, mg/dL	Triglycerides, mg/dL
Pre-meal	From 7.4 to 7.7	From 1.2 to 1.5	From 4.5 to 4.0	From 84 to 82	From 39 to 40	From 147 to 145	From 141 to 122
60 minutes post-meal	From 6.6 to 6.3	From 1.6 to 0.9	From 7.7 to 7.9	From 65 to 68	From 45 to 46	From 137 to 138	From 105 to 94

*Training included 60 minutes of exercise per bout at 65% VO_{2peak}.

My social history was negative for smoking or excessive alcohol consumption. My physical examination was normal, with normal vital signs except for a BMI of 27 kg/m^2. I was not taking any medication at that time. My A1C was 8.4%, and my lipid profile included a total cholesterol of 181 mg/dL, HDL cholesterol of 31 mg/dL, LDL cholesterol of 118 mg/dL, and triglyceride level of 118 mg/dL. Other laboratory results, including microalbumin in the urine, were normal.

TABLE 2 Data on Pre- Versus Post-Meal Exercise

Consideration	Pre-Meal Exercise	Post-Meal Exercise
Hormonal activity	Counterregulation (79)	Incretin-insulin system (80)
Fuel	Free fatty acids, liver glucose, and muscle glycogen (26,33)	Glucose arriving from food, muscle glycogen, and liver glycogen (40,48,52,53)
Duration	The longer the better for insulin sensitivity and fasting glucose (40)	Too long a duration may cause hypoglycemia (46)
Intensity	High-intensity exercise may cause higher PPG and delayed hypoglycemia (26,27,32–34)	High-intensity exercise may cause hyper- or hypoglycemia (72–75); supply of meal-derived glucose should match the demand of the exercise (55)
Hypoglycemia during activity?	No (36–38)	May occur with long duration (46) and with high intensity (75)
Insulin sensitivity improvement?	Yes (25,26,39)	Usually short-lived with endurance exercise (53,39,81)
Fasting glucose improvement?	Yes (40)	No significant improvement with endurance exercise (40)
Net immediate benefits	No hypoglycemia during activity (36–38), improves insulin sensitivity (25,26,39), and improves fasting glucose (40)	Improves post-meal glucose with appropriate timing and energy expenditure (46–66) and with short-duration (6–10 minutes) of high-intensity exercise (62–64)
Net negative effects	Glucose dysregulation for up to 3 hours (26,28–35); delayed hypoglycemia in people taking insulin (27)	Hyperglycemia or hypoglycemia when timing or energy expenditure are not appropriate (46,71–75,83,84)
Effects after 3 months of training	Improves muscle glycogen content, GLUT-4 protein, AMPK activity (42–44), and HOMA-IR (39)	Improves A1C and CRP when timing, intensity, and duration are right, but HOMA-IR does not improve (39)
Effects of type of exercise	One hour-long HIIE bout while fasting is better than while fed (45).	45 minutes of RE post-dinner is better than pre-dinner (61) for glucose and triglyceride levels.

My PCP diagnosed me with type 2 diabetes, initiated metformin 500 mg twice a day, and sent me to a certified diabetes care and education specialist (CDCES). I was also started on simvastatin 20 mg daily and losartan 50 mg daily. The CDCES gave me the proper training and told me to include 6–9 15-g carbohydrate (carb) servings per day in my meals and to increase my physical activity. My A1C decreased to the range of 6.4–7.9% during the next 4 years.

In 2002, 4 years after my diagnosis, I started my first weight reduction program, for which I chose to have a pre-breakfast walk followed by a regular breakfast daily. I settled on pre-meal exercise because a 3-mile walk after breakfast gave me frequent hypoglycemia (neuroglycopenia). My meals at that time included 5–6 carb servings (75–90 g) daily. After following this routine for 4 months, my weight had decreased by 14% (because of decreased carb intake), but neither by A1C nor by HDL cholesterol levels improved (Table 3) (77). My BMI decreased from 27 to 23 kg/m^2.

I decided to discontinue the pre-meal exercise. For the next 10 years, life got busy, and I managed by diabetes passively. By 2011, my BMI was back up to 27 kg/m^2, and my medications included metformin 1,000 mg twice daily and insulin glargine 36 units daily. My A1C was 8.8%, and my HDL cholesterol was 36 mg/dL.

In 2012, I started another weight reduction program, incorporating a 30-minute post-breakfast walk starting 30 minutes after the start of the meal every day for 4 months, as had been done in a 1982 Canadian study (46). My meals included 5–6 carb servings per day, as before. This new lifestyle routine was successful; my A1C, HDL cholesterol, and weight all improved (Table 3).

A training study in 2020 that compared exercise while fasting to exercise in a fed state three times per week for 3 months in people with type 2 diabetes showed an A1C improvement similar to mine (Table 1) (39); training in a fasted state yielded worsened A1C (from 7.4 to 7.7%) and C-reactive protein (from 1.2 to 1.5 mg/dL), but the homeostatic model assessment of insulin resistance (HOMA-IR) improved (from 4.5 to 4.0). Exercising in the fed state improved A1C (from 6.6 to 6.3%) and C-reactive protein (from 1.6 to 0.9 mg/dL) but HOMA-IR worsened (from 7.7 to 7.9). This study gave me incentive to keep improving my physical activity.

I also developed impaired awareness of hypoglycemia (IAH) and almost died twice as a result of severe hypoglycemia (blood glucose levels of 25 and 15 mg/dL), causing seizures. My endocrinologist suggested that I wear a diabetes medical alert bracelet and prescribed a continuous glucose monitoring (CGM) system for me in 2017. I realized that managing diabetes was an uphill battle for most people, and especially for hypoglycemia-prone individuals. The barriers people must overcome include busy lives, resistance to change, feelings of deprivation, easy availability of good-tasting processed foods, unhealthy cultural practices, lack of appropriate referral to a CDCES (7–9), food and medication insecurity, fear of exercise because of the attendant risk (or perceived risk) of hypoglycemia, and glycemic dysregulation resulting from inappropriate exercise choices.

Through the years, I have continually tested research findings in my own diabetes self-management mode using blood glucose monitoring (BGM) with a glucose meter and, more recently, CGM to monitor results. I perform these self-tests because glucose levels are sensitive to numerous variables, and inconsistent results can be seen if multiple variables are present in a study design. Applying new research findings as they were reported (25–89) and watching my own A1C levels and BGM and CGM data, it took 16 years for me to learn how to minimize the negative effects of exercise on my own glucose levels.

By this time, I had a steady meal plan; I followed meal composition recommendations based on the ADA's Diabetes Plate Method approach (12,13,90), filling half of my plate with nonstarchy vegetables, healthy fats, and nuts; one-fourth with a serving of lean protein (i.e., fish, legumes, or, occasionally, chicken); and one-fourth with high-fiber carbohydrates. For meal timing, I followed early eating (circadian-friendly) recommendations and included a morning snack (12,13,15–24). My meals included the following: a morning snack containing half of a carb serving (e.g., coffee with 1/2 cup milk and 1 egg), breakfast containing 2–3 carb servings (e.g., 1/2 cup bran cereal, 1 cup 2% milk, and 1/2 cup berries), lunch containing 3–4 carb servings (e.g., smoothie with 1 cup milk, 1 banana, and 1 Tbsp peanut butter), an afternoon snack containing half of a carb serving (e.g., a mini nut bar), and an early supper (before 6:00 p.m.) containing 2 carb servings (e.g., barley or quinoa, fish, and vegetables).

As my lifestyle improved, I found that I could taper down my insulin dose to one-third of my previous dose. When my physician added semaglutide to my diabetes treatment regimen, I stopped insulin completely. My

TABLE 3 Different Meal-Exercise Combinations and Resulting A1C Levels in a Person With Type 2 Diabetes

Meal-Exercise Combination	Date of Laboratory Testing	Medications	A1C, %	HDL Cholesterol, mg/dL	Comments
Pre-breakfast walk for 60 minutes, followed by a regular breakfast every day for 4 months	16 May 2002	Metformin 1,000 mg twice daily	6.4	36	A1C did not change; HDL decreased from 39 to 36 mg/dL
Post-breakfast walk 30 minutes after the start of the meal for 30 minutes every day for 4 months	17 March 2012	Metformin 1,000 mg twice daily and insulin glargine 36 units daily	6.0	51	A1C decreased from 7.2 to 6.0%; HDL increased from 36 to 51 mg/dL
Morning walk every other day plus a morning snack and post-breakfast walk	17 October 2018	Metformin 1,000 mg twice daily and insulin glargine 18 units daily	5.8	50	
Morning walk every other day plus morning snack and post-meal exercise after bigger meals	7 June 2019 to 26 October 2020	Metformin 1,000 mg twice daily and semaglutide 1 mg once weekly	6.0–6.2	44–53	
Morning walk for 30 minutes plus morning snack every day and post-meal exercise after bigger meals	18 January 2022	Metformin 1,000 mg twice daily and semaglutide 1 mg once weekly	6.4	46	
Morning walk for 30 minutes plus morning snack every other day and post-meal exercise after bigger meals (with new medication regimen)	21 April 2022	Metformin 500 mg twice daily, semaglutide 1 mg once weekly, and empagliflozin 10 mg once daily	6.0	50	

BMI then declined and stabilized at 19.6 kg/m^2; following a healthy lifestyle, stopping insulin, and starting a glucagon-like peptide 1 receptor agonist all helped. My random urine microalbumin level remained in the low range throughout the 23 years (3–10 µg/mL [reference range 30–300]).

Question

How can a person with type 2 diabetes and a history of IAH exercise safely?

Literature Review

Data on Pre-Meal Exercise and Its Role in Diabetes

Pre-meal exercise has two negative effects on glycemia. First, it causes a post-exertion glucose elevation, which leads to glucose dysregulation for 1–3 hours (26,28–34) after the physical activity. HIIE is also associated with post-exertion glucose elevations (35). The second problem is delayed hypoglycemia after high-intensity pre-meal exercise in people on insulin (27). On the other hand, pre-meal exercise has many positive effects on glycemia (Tables 1 and 2); these include the absence of hypoglycemia during the activity (36–38), insulin sensitivity improvement (in the liver) that may last 24 hours or longer (25,26,39), and improved fasting glucose levels (40). One hour of HIIE (high-intensity exercise for 16 minutes and walking for 44 minutes) was found to be more beneficial in the fasted state than in the fed state for overall glucose control (45).

Training during a fasting condition also offers improved glycogen content, GLUT-4 protein levels, and activity of AMPK, a protein that promotes mitochondrial biogenesis (42–44).

However, my CGM data have repeatedly shown that the negative effects of pre-meal exercise can be minimized by keeping the intensity of the activity moderate and opting for a relatively light meal after the exercise (12,13,77). I have been taking 30-minute morning walks, followed by a morning snack (15–17), every other day for >3 years. My A1C has ranged from 5.8 to 6.2% during this period with different medication regimens. It was 5.8% with metformin 1,000 mg twice daily and 18 units of insulin glargine and 6.0–6.2% with either metformin 1,000 mg twice daily and semaglutide 1 mg weekly or metformin 500 mg twice daily, semaglutide 1 mg weekly, and empagliflozin 10 mg daily. My A1C was slightly higher (6.4%) when the pre-meal walks occurred every day instead of every other day (Table 3). That is why my choice is to continue with these morning walks every other day.

Data on Post-Meal Exercise and Its Role in Diabetes

Timely moderate-endurance post-meal exercise can readily blunt the post-meal glucose surge from bigger meals in real time (14,46–70). However, post-meal exercise also has many negative effects on glycemia (49,71–75,83,84), and minimizing these negative effects can be challenging (Table 2). Both the timing of the exercise and the energy expenditure have to be just right for desired results (46–66).

Post-Meal Exercise Timing

Sufficient glucose should be in the blood when the post-meal exercise is started. If exercise is started too early, the activity may be less effective in blunting the peak (49,50), and a large secondary glucose peak can be seen after the exercise. Gonzalez (83) and Haxhi et al. (84) noticed glucose elevations that may have been related to late exercise timing.

Gonzalez found a marked post-lunch glucose elevation after 60 minutes of endurance exercise at 61% VO_{2peak} performed ~2 hours after breakfast in physically active males (83). The authors referred to this occurrence as a "paradoxical second-meal phenomenon." This phenomenon is thought to be caused by increased splanchnic blood flow, leading to the arrival of extra glucose from the gut, and also by increased hepatic glucose output. However, the glucose elevation is much milder when similar exercise was done 30 minutes post-breakfast in a study by Nygaard et al. (51).

Haxhi et al. (84) also noticed a delayed glucose elevation for several hours after exercise was performed around lunchtime for 20 minutes before the meal and 20 minutes starting 40 minutes after the meal. Continuous endurance exercise for 40 minutes starting 40 minutes post-lunch did not show any such glucose elevation. If the pre-lunch exercise is viewed as a 2- to 3-hour post-breakfast exercise session, the delayed timing of the exercise might have contributed to the late glucose elevation. HIIE performed 2 hours after breakfast also shows glycemic dysregulation, with glucose-lowering seen at dinner and at breakfast the next morning (71).

One problem with post-meal exercise is that the glucose peak can occur at different times depending on the glycemic load of the meal. Glucose levels after a high-glycemic liquid breakfast may peak in 40 minutes (82), whereas glycemia after a well-balanced supper may take 90–120 minutes to peak (29,61). Exercise should be started as soon as the meal is eaten in the former case (82) and 45–60 minutes after the start of the meal in the latter case (29,61). When to start the exercise is easy to determine for people who use CGM. Others can get an idea of when to expect the glucose peak for a specific meal through blood glucose monitoring with a traditional glucose meter. For a typical breakfast, exercise may be started 30–45 minutes after the start of the meal (46,47,51–54,65), and for lunch and supper, exercise may be started 45–60 minutes after the start of the meal or 30 minutes before the anticipated peak (29,61,66).

Post-Meal Energy Expenditure

When energy expenditure (intensity, duration, or both) is high, hyperglycemia or hypoglycemia may occur with post-meal exercise (Table 2), depending on the status of the liver (71–75). If hepatic glucose production is triggered as glucose levels decrease during the exercise, hyperglycemia results; otherwise, hypoglycemia may be the outcome. When Achten and Jeukendrup (74) tried post-meal exercise at 80% intensity, hyperglycemia occurred within 5 minutes. Praet et al. (75) noticed mild hypoglycemia in six of 11 subjects with type 2 diabetes who were taking insulin when moderate-intensity circuit training was done. Nelson et al. (46) reported hypoglycemia in participants when the duration of the post-meal activity was >35 minutes. Erickson et al. (55) demonstrated that "the effectiveness of an exercise bout for lowering glucose will be dependent upon the size (peak and duration) of the postprandial glucose excursions." In other words, supply and demand should match.

Post-dinner RE for 45 minutes occurring 45 minutes post-meal was better than pre-dinner exercise for glucose and triglyceride levels (61). Moderate, short-duration RE plus a short walk post-meal gave me consistent results with glucose control (86–89). However, I have had glucose elevations after lifting weights if I performed >10 repetitions.

Insulin Sensitivity Improvement

Many studies have shown that the improvement in insulin sensitivity from post-meal endurance exercise is short-lived (14,39,53,81). Fasting glucose did not improve when post-meal long-duration endurance exercise was conducted by Borer et al. (40). Also, in a post-meal training study by Verboven et al. (39), HOMA-IR did not improve (Tables 1 and 2). On the other hand, when AE combined with RE was used in a similar training study by Teo et al. (66), HOMA-IR improved (from 1.74 to 1.28 in the a.m. exercise group and from 1.94 to 1.35 in the p.m. exercise group), as did A1C (from 7.91 to 7.34% in the a.m. group and from 8.04 to 7.64% in the p.m. group) and fasting glucose (from 9.02 to 7.76 mmol/L in the a.m. group and from 10.32 to 8.52 mmol/L in the p.m. group).

Numerous studies have shown that combined exercise is better than RE or AE alone (2,14,86–89). Short-duration, post-meal HIIE/stair-climbing exercise also seems promising for glucose control (61–63,76).

Morning Versus Afternoon Exercise

Studies of the glycemic effects of morning versus afternoon exercise have yielded mixed results; some data indicate that afternoon exercise provides better metabolic benefits (14,85). Teo et al. (66) did not find a difference between morning and afternoon exercise when timing, intensity, and duration were appropriate in a 3-month training study using AE plus RE three times per week. In this study, exercise started 60 minutes post-meal. It was not clear when the exercise was started with respect to the meal in a study by Mancilla et al. (85), which found an advantage for afternoon exercise. Also, the exercise was slightly different in the latter study, involving 2 days of AE and 1 day of RE (85). More studies may be needed in this area.

I have been doing short-duration RE plus short-duration AE after bigger meals with good results (77).

In summary, exercise timing and energy expenditure for post-meal exercise should be appropriate for the meal size and composition (46,53).

Commentary

As seen in Tables 1 and 2, pre-meal and post-meal exercise are quite different. A morning walk during hormonal counterregulation is safe (no hypoglycemia during the activity) (36–38) and improves insulin sensitivity in the liver via liver glycogen depletion (25,26), leading to improved fasting glucose (40). Improving fasting glucose is important for people with diabetes because it influences both postprandial glucose (PPG) levels and A1C.

My own A1C levels after training in the fasted state or in the fed state have agreed with the data in the literature; in 2002, taking a pre-breakfast walk every morning, followed by a regular breakfast, did not improve my A1C, which remained 6.4%, as in the study by Verboven et al. (39). But 16 years later, a morning walk followed by a morning snack every other day improved my A1C (from 6.0 to 5.8%). My A1C was slightly worse (6.4%) when the morning walk happened every day, indicating that glucose dysregulation may be worse when such exercise is performed daily (Table 3).

Timely, moderate, post-meal AE is effective in blunting the glucose peak via contraction-mediated glucose uptake (70). In this setting, the insulin-to-glucagon ratio is high, hepatic glucose output is suppressed, and free fatty acid levels are low. Thus, the main fuel for moderate post-meal exercise is exogenous glucose from food; in using up this glucose, exercise improves PPG levels. The improvement in insulin sensitivity from post-meal exercise is short-lived (14,39,53,81) and does not improve fasting glucose (40). This is because there is very little glycogen depletion (liver/muscle) during moderate post-meal exercise. On the other hand, when moderate RE is added to AE, there is muscle glycogen depletion leading to improvement in insulin sensitivity in the muscle and adipose tissue and some improvement in fasting glucose (66).

People with diabetes have poor glucose tolerance in the morning and evening (78). A morning walk, followed by a morning snack (15–17), every other day and combined short-duration RE and AE after bigger meals (65,86–89) would be ideal for diabetes self-management. I have been practicing these two exercise modalities, along with a healthy eating pattern, for >3 years with excellent results. I have found it to be easy to do as a retired person who uses CGM.

Coordinating meals and exercise as described here has many influences on glycemia and lipid levels (91). Delaying or skipping breakfast increases diabetes risk (21). It is important to eat breakfast (18–21) because breakfast switches hormonal counterregulation to the more favorable incretin-insulin system and moderates PPG after lunch via the second-meal phenomenon

(15–17); thus, breakfast is the body's primer. Evidence supports the attainment of good metabolic benefits from two larger meals, at breakfast and lunch (18,19). These benefits are even greater when a high-protein morning snack is added 90 minutes before breakfast to moderate breakfast PPG via the second-meal effect (15–17). In this case, the morning snack is the primer, helping to counter the poor glucose tolerance common in the morning. Having an early light supper is also a diabetes-friendly practice. Going to bed during a large glucose peak has been found to increase liver fat, leading to high fasting glucose in the morning (22–24). Thus, eating early (circadian-friendly) meals and morning snacks is a valuable habit for diabetes management.

Timely post-breakfast exercise would be complementary to this meal plan. Short-duration (10-minute) RE plus a short walk after breakfast can directly moderate the PPG level after breakfast further through contraction-mediated glucose uptake (70). The RE can improve insulin sensitivity through muscle glycogen depletion and may offer some improvement in fasting glucose (66,86–89). Progressive moderate RE or strength training performed every other day is especially valuable for elderly people to counter sarcopenia (muscle wasting) and osteoporosis (92).

Exercise may not be necessary after lunch, which can be the biggest meal of the day. This is because glucose tolerance is the best at midday, and earlier meals are helping through the second-meal effect. Moderate pre-meal exercise goes well with this meal plan and is an excellent insulin sensitizer; liver glycogen repletion after glycogen depletion offers glucose control throughout the day (as well as the day after) and improves fasting glucose (40). Pre- and post-meal exercises improve lipids, too (39,61,77,91). Hypoglycemia risk is also minimal with this lifestyle. There is no hypoglycemia risk during pre-meal activity (36–38). Because the exercise intensity is moderate, the risk of delayed hypoglycemia is also low (27). RE after breakfast is safer than after supper with respect to hypoglycemia because there are meals and snacks after the exercise during the daytime that do not occur in the evening or nighttime.

Other safe exercise options include frequent physical activity breaks to interrupt prolonged sitting (14,60), brief periodic exercise as demonstrated by Hatamoto et al. (93), and getting 10,000 steps per day (94), as long as the energy expenditure is moderate. These three approaches and post-meal exercises after bigger meals may be more practical for working people who cannot fit morning walks into their schedule.

Clinical Pearls

- Decades of data have shown that pre- and post-meal exercise have both negative and positive effects on glycemia for people with diabetes. Minimizing the negative effects on glycemia of any exercise is an important part of diabetes self-management.
- Based on research and the author's personal experience, taking a 30- to 60-minute morning walk followed by a morning snack every other day can be beneficial in three ways: the absence of hypoglycemia during the activity, improvement in liver insulin sensitivity that may last for 24 hours or longer, and improvement in fasting glucose.
- Moderate post-meal exercise starting ~30 minutes before the anticipated glucose peak and lasting for 20–30 minutes is a safe way to lower post-meal glucose surges from larger meals. Performing RE, taking a 20-minute brisk walk (AE), or combining the two can be helpful, and the combination of RE and AE yields better glycemic results that either type of exercise alone.
- To prevent hyperglycemia or hypoglycemia from post-meal exercise, people with diabetes should avoid delayed timing ($\geq$2 hours after the start of the meal), high intensity (>65% VO_{2max}), and long duration (>30 minutes) of exercise.
- Although moderate pre-meal exercise is a safe way to improve glucose tolerance and fasting glucose via liver glycogen depletion, timely, moderate post-meal exercise is helpful for moderating PPG. Retired people with flexible schedules can often benefit from both. Working people and those without CGM may be better off with a morning walk followed by a morning snack every other day (less glucose dysregulation) as their primary exercise and performing post-meal RE plus a short walk after breakfast.
- Lunch can be the biggest meal of the day, and exercise after lunch may not be necessary for two reasons: glucose tolerance is high midday (circadian effect) and the second meal effect is helping from prior meals.

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DUALITY OF INTEREST

No potential conflicts of interest relevant to this article were reported.

AUTHOR CONTRIBUTIONS

As the sole author, E.C. is the guarantor of this work and, as such, had full access to all the data reported and takes responsibility for the integrity of the data and the accuracy of the data analysis.

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