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Stair climbing–descending exercise following meals improves 24-hour glucose excursions in people with type 2 diabetes

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Abstract We aimed at evaluating the effect of short-duration stair climbing–descending exercise (ST-EX) on 24-hour blood glucose (BG) response in people with type 2 diabetes (T2D). Seven men (age, 70.1 ± 1.3 years) with uncomplicated T2D consumed three meals per day according to a meal plan for patients with diabetes. Participants completed one session of ST-EX 60 and 120 min after each meal on the first day (ST-EX day), and did not perform ST-EX on the following day (REST day). Each ST-EX session comprised two 3-min bouts of brisk climbing to the second floor, followed by walking down to the first floor. The BG levels on the experimental days were recorded using a continuous glucose monitoring device. The mean BG level and the area under the curve for BG in the 24-hour period on the ST-EX day were significantly lower than those in the same period on the REST day (both $p < 0.05$). The duration of hyperglycemia (BG > 10 mmol/L) on the ST-EX day was significantly shorter than that on the REST day ($p < 0.05$). Repeated 3-min ST-EX after each meal might be an effective strategy to improve 24-hour glucose excursions in people with T2D.

Keywords : exercise, hyperglycemia, 24-hour glucose excursions, glucose metabolism, type 2 diabetes

Introduction

Aerobic exercise (AE) contributes to the reduction of blood glucose (BG) level in people with type 2 diabetes (T2D). Generally, AE should be of at least moderate intensity and a minimum of 10 min per bout, 30 min per day and 150 min per week[1)]. On the other hand, individuals who have sufficient physical fitness may gain benefits even from shorter duration. A minimum of 75 min per week of vigorous exercise or interval training has been recommended for younger and more physically fit individuals[1)]. In particular, repeated bouts of short-duration high-intensity AE, such as 6 bouts of 1-min high-intensity incline walking before each meal using treadmill[2)] and 10 bouts of 1-min high-intensity cycle ergometer exercise[3)], has been reported as an effective method for reducing postprandial and 24-hour BG levels.

Stair climbing–descending exercise (ST-EX) is our original exercise regimen of short-duration high-intensity AE[4-9)]. ST-EX typically comprises 3–6 min of repeated brisk climbing up a flight of stairs (80–110 steps/min) followed by slow walking down to the starting point at a free step rate[9)]. When multiple sets of ST-EX were applied, a rest period of 1–2 min was provided between the sets. The overall intensity of ST-EX is self-regulated in the range of 11–13 on the Borg rating of perceived exertion (RPE) scale[10)].

There are clinically important advantages to ST-EX. First, individuals can immediately perform high-intensity AE, regardless of weather conditions, using indoor stairs and without the need for special exercise implements or training clothes. In fact, lack of time and exercise facilities as well as perceived difficulties taking part in exercise are the major reasons for inactivity in people with diabe-

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tes[11]. Second, ST-EX is a nonstrenuous method for performing high-intensity AE, since dyspnea and fatigue can be substantially alleviated during the descending phase, thereby, increasing overall exercise intensity without excessive perceived exertion. Third, contractile activity, an acute and strong stimulator of glucose uptake and insulin sensitivity in skeletal muscle[12-14], continuously occurs in the lower extremity muscles, not only during the ascending phase, but also during the descending phase.

We have been conducting a series of studies to demonstrate the BG-lowering effect of ST-EX[4-8]. Takaishi et al. showed that in people with impaired glucose tolerance (IGT)[8] and T2D[6], a 6–6.5 min bout of ST-EX after a meal decreased the postprandial BG level more promptly than a bout of level walking for the same duration. Honda et al.[4] found that as little as a 3-min bout of ST-EX 60 and 120 min after a meal reduced the area under the curve for BG (0–180 min after a meal) by 18% in people with T2D even when they took oral hypoglycemic agents. More recently, Takaishi et al.[7] reported that an 8-min bout of ST-EX decreased the postprandial BG level more rapidly than bicycle exercise at the same heart rate in people with T2D or IGT. Additionally, Honda et al.[5] found that two 3-min bouts of ST-EX 60 and 120 min after each meal for 2 weeks increased the serum1,5-anhydroglucitol level in people with T2D.

Collectively, we consider that ST-EX is an effective and efficient way of high intensity AE having a substantial BG-lowering effect. However, we have never tested, and therefore it is still unknown, whether ST-EX after each meal improves 24-hour overall glucose excursions in people with T2D. To address this issue, we added two 3-min bouts of ST-EX 60 and 120 min after each meal to the usual activities at home of people with T2D, and evaluated the BG level by a continuous glucose monitoring (CGM) device for 24 hours.

Materials and Methods

Participants. Seven men with T2D (age 65–75 years) who regularly visited Toyooka Hospital Hidaka Medical Center (Toyooka, Japan) were recruited (Table 1). They had no macrovascular or microvascular complications, or motor dysfunction. They were under nutritional therapy (energy intake: 25–30 kcal/kg body weight/day), exercise therapy (low to moderate-intensity aerobic exercise for 20–60 min/day, at least 2 days/week) and taking oral agents (glimepiride, metformin, and anagliptin [n = 2]; glimepiride, metformin, and voglibose [n = 1]; voglibose and vildagliptin [n = 1]; miglitol and alogliptin [n = 1]; metformin [n = 1]; alogliptin [n = 1]). On the experimental days, the nutrition and exercise therapies were discontinued, but the participants continued to take medications as usual. All participants provided written informed consent. The institutional review board of Toyooka Hospital Hidaka Medical Center approved the study (approval number: 26, 2016) in accordance with the Declaration of Helsinki.

Table 1. Characteristics of the study participants.

Variable	
Age (years)	70.1 ± 1.3
Duration of T2D (years)	14.1 ± 2.8
Height (cm)	163.2 ± 1.8
Weight (kg)	63.0 ± 3.3
Body mass index (kg/m^2)	23.7 ± 0.5
Hemoglobin A1c (%)	7.0 ± 0.1
Low-density lipoprotein cholesterol (mmol/L)	3.0 ± 0.2
High-density lipoprotein cholesterol (mmol/L)	1.5 ± 0.1
Triglycerides (mmol/L)	1.3 ± 0.2
Systolic blood pressure (mmHg)	128.1 ± 2.2
Diastolic blood pressure (mmHg)	73.3 ± 2.4

Values are presented as mean ± standard error. N = 7. Formula to calculate mg/dL from mmol/L: low-density lipoprotein cholesterol and high-density lipoprotein cholesterol, mg/dL = 38.7 × mmol/L; triglycerides, mg/dL = 88.6 × mmol/L. T2D: type 2 diabetes.

Experimental design. We set two consecutive experimental days in this study. One day prior to the experimental day, the participants were given pre-packaged Japanese-style test meals (total, 1,570 kcal/day; breakfast: 522 kcal, 86.5 g carbohydrate, 17.4 g protein, 13.5 g fat; lunch: 526 kcal, 71.7 g carbohydrate, 26.6 g protein, 14.3 g fat; dinner: 522 kcal, 82.4 g carbohydrate, 22.6 g protein, 10.3 g fat). The participants consumed the test meal for dinner at their homes. During the experimental days, there was no change in quantity and type of medications.

On the first experimental day (ST-EX day), the participants consumed the test meal for breakfast, lunch, and dinner in approximately 15 min, and performed one session of ST-EX 60 and 120 min after each meal at their homes. They performed their usual activities, except during ST-EX sessions. On the second experimental day (REST day), the participants consumed the same meals at the same time as that on the ST-EX day, and performed their usual activities with no ST-EX at their homes.

During the experimental days, the number of steps was estimated using an activity recorder (Welsupport; Nipro, Osaka, Japan). The device is equipped with real-time triaxial accelerometry and barometric pressure measurement, and the accuracy of step count was validated for Japanese people[15]. We asked the participants to wear the recorders throughout the experimental days except during their bath and bedtimes. After collecting them, we confirmed that the recording was registered for more than 10 h on each day.

ST-EX protocol. One session of ST-EX comprised two bouts of 3-min repetitions (8–10 times) of climbing and descending the stairs between the first and second floor of their homes (13–15 steps; each 16–22 cm in height). The speed of climbing was set at a rate of 80–110 steps/min, and that of descending was self-selected by the participants. The interval between the first and second ST-EX bout was 1–2 min. Thus, 7–8 min was needed to complete one session of ST-EX. The overall extent of physical effort of ST-EX was self-controlled within the range of 11–13 (modest intensity) on the Borg RPE scale[10]. We have previously shown that during this exercise, heart rate reaches approximately 80% of age-predicted maximum heart rate[4], which is within the range of high intensity[16].

Glycemic profile analysis. BG levels were recorded every 5 min during the experimental days by a CGM device (Ipro2; Medtronic Minimed, Northridge, CA, USA). This was calibrated 4 times/day by self-monitoring BG independently, according to the manufacturer's instructions. We calculated the mean BG levels, the area under the curve (AUC) for BG and the duration of hyperglycemia (>10 mmol/L)[17] for 24 hours on the experimental days. AUC was calculated using the trapezoid method as follows: [BG (00:00) + BG (00:05)] × 5 min × 0.5 + … + [BG (23:55) + BG (24:00)] × 5 min × 0.5. The BG (hh:mm) result expressed BG levels at each time point from the start of breakfast.

Statistical analysis. All values are reported as the mean ± standard error or median (quartiles 25–75). Pairs of medians of glycemic profiles on experimental days were analyzed using the Wilcoxon signed-rank test. Additionally, post hoc sample size (set at 5% alpha-error and 80% power), effect size ($r = Z/\sqrt{n}$), and power (1-β) calculations were performed for each variable. Power calculation was conducted using G*Power (version 3.1.9.4., Heinrich-Heine University, Düsseldorf, Germany), and other statistical calculations were performed using IBM SPSS statistics software (version 20.0, IBM, Tokyo, Japan). Significance was set at $p < 0.05$ (two-tailed p-value).

Results

Glycemic profiles on the ST-EX day and REST day are shown in Fig. 1 and Table 2. Fasting BG levels before breakfast did not differ between the ST-EX and REST days [7.3 (7.1–8.3) mmol/L and 7.2 (6.4–7.9) mmol/L, respectively]. The median value of the mean BG level and that of AUC for 24 hours on the ST-EX day were 16% and 16% lower than, respectively, those on the REST day (both $p < 0.05$). The median duration of hyperglycemia (> 10 mmol/L) on the ST-EX day was 57% lower than that on the REST day ($p < 0.05$). All these variables achieved large effect sizes (> 0.5), and mean BG and AUC showed high powers (> 0.8)[18] (Table 2), although the post hoc analysis for sample size indicated that at least 9 participants are required.

Daily step count on the ST-EX day was higher than that on the REST day [step: ST-EX 6630.0 (6379.0–7050.0) vs. REST 3529.0 (2837.0–3861.5), $p < 0.05$].

Discussion

A novel and clinically important finding of the present study was that two 3-min bouts of ST-EX conducted 60 and 120 min after each meal maintained the BG-lowering effect for 24 hours, and the duration of hyperglycemia (>10 mmol/L) on the ST-EX day was significantly shorter than that on the REST day. It is notable that hyperglycemia (>10 mmol/L) is highly prevalent in people with T2D, and even well-controlled T2D patients with an HbA1c level below 7.0% experience hyperglycemia for nearly 350 min per day[19].

We consider that the decrease in BG level on the ST-EX day is induced by performing ST-EX, but no other physical activities, because the difference in daily step number between the ST-EX day and the REST day (approximately 3,100 steps) was within the expected range [2,496–3600 steps: 13–15 steps × 2 (both ways) × 8–10 times × 2 bouts × 2 sessions × 3 times (after each meal)].

Contraction is a strong stimulator of glucose uptake

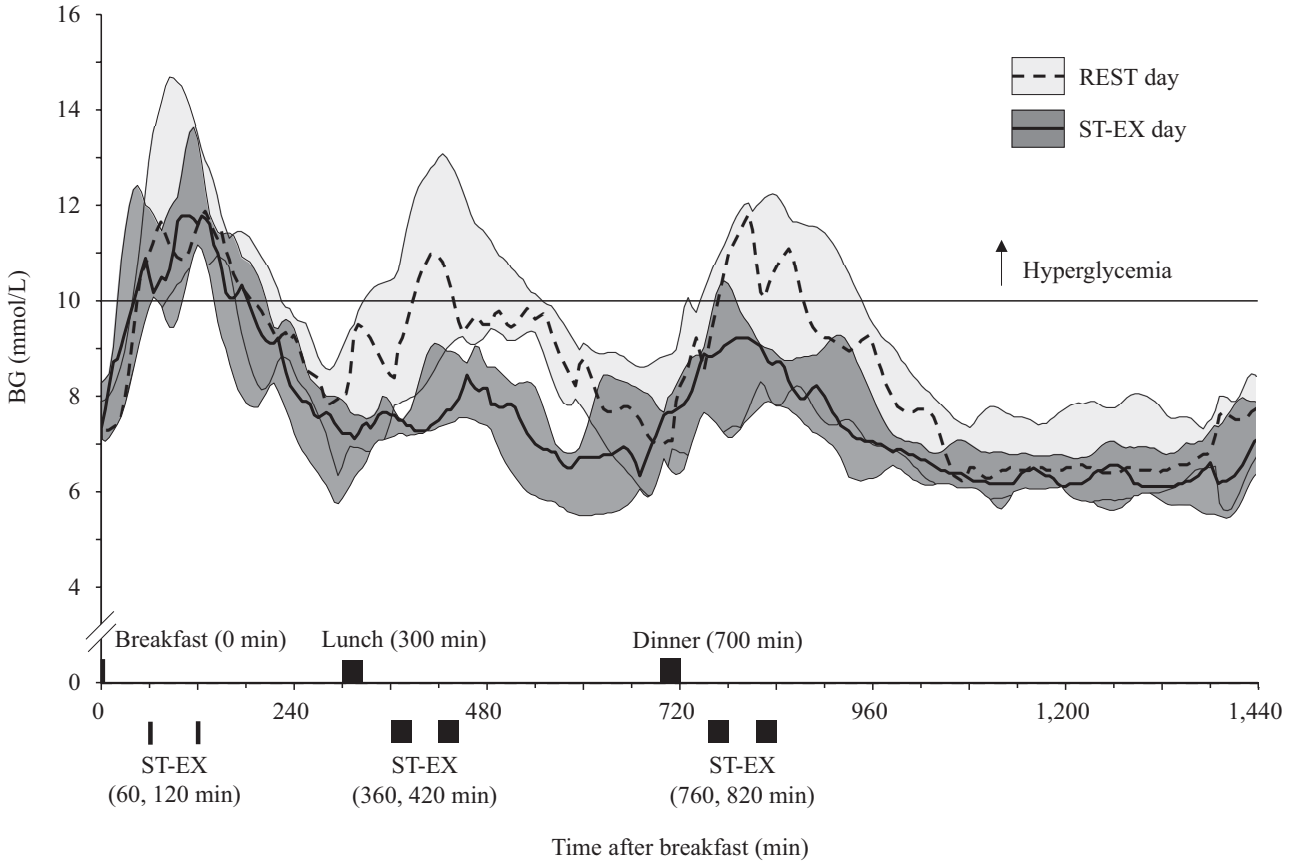

Fig. 1 Time-course changes in blood glucose (BG) levels.
Values are presented as median and range (25th–75th quartile). N = 7. Dotted line: REST day. Thick solid line: ST-EX (stair climbing-descending exercise) day. Black bars indicate the range of starting time of meals or ST-EX. Participants had breakfast, lunch, and dinner around 7, 12 and 19 o'clock, respectively. One session of ST-EX was performed 60 and 120 min after each meal.

Table 2. Glycemic profiles for 24 hours on experimental days.

Variable	ST-EX day	REST day	Effect size (r)	Power (1-β)
Mean BG (mmol/L)	7.7 (7.2–8.1) †	9.2 (8.3–9.3)	0.89	0.98
AUC (×10^3 mmol/L*min)	11.1 (10.3–11.6) †	13.2 (12.0–13.4)	0.89	0.98
Duration of hyperglycemia (min)	175 (130–195) †	405 (295–460)	0.83	0.65

Values are presented as median (quartiles 25–75). N = 7. Formula to calculate mg/dL from mmol/L: mg/dL = 18 × mmol/L. ST-EX: stair climbing-descending exercise; BG: blood glucose; AUC: area under the curve. †$p < 0.05$ vs. corresponding REST day, the Wilcoxon signed-rank test.

in skeletal muscles by inducing translocation of GLUT4 glucose transporter to the cell surface of muscle cells, independently of insulin (contraction-stimulated glucose transport)[12,14]. In humans, contraction causes the rate of glucose uptake to increase within 5 min[20], rising to approximately 80% of the maximum level within 10 min after the start of exercise[21]. Importantly, contraction-stimulated glucose uptake remains intact in insulin-resistant conditions such as T2D[22,23]. Furthermore, contraction enhances muscle insulin sensitivity in the post-exercise period, and leads to an increase in insulin-stimulated glucose transport for many hours[13,24]. These insulin-independent and -dependent mechanisms might be responsible for the substantial and prolonged BG-lowering effect of ST-EX in people with T2D.

The rate of glucose uptake in skeletal muscle during exercise depends on the intensity of exercise represented by oxygen consumption ($\dot{V}O_2$)[20,25]. In this regard, we have

previously measured $\dot{V}O_2$ during the last 8 repetitions (~4 min in duration) of 16 repetitions of ST-EX using the Douglas bag method. We have found that $\dot{V}O_2$ increased to a mean value of 18.7 mL/kg/min, without a feeling of strenuous effort (Borg rating 13–14) in 11 people with T2D or impaired glucose tolerance[7]. Although the perceived exercise intensity in the present study (Borg rating 11–13) was lower than that in the previous study, augmented glucose uptake in contracting muscles may be responsible for the BG-lowering effect of the ST-EX regimen used in the present study.

We chose the timing for the first ST-EX (60 min after a meal) to lessen the effect of rebound increase in BG level after exercise[4]. It has been shown that moderate- to high-intensity exercise during the rapid rising phase of BG after a meal (<60 min after a meal) acutely decreases BG level during exercise, but results in a rebound increase after exercise[26,27]. We chose the timing of the second ST-EX (120 min after the meal) to boost the decrease during the declining phase in BG level[4]. Recently, Dempsey et al.[28] examined the effect of interrupting 7-hour sitting with 3-min light-intensity walking or simple resistance activities every 30 min after breakfast. They found that the glycemic improvement persisted until the next morning for 22 hours in people with T2D. Similar to their findings, the addition of ST-EX during the rapid rising phase (e.g., at <60 min), after the first ST-EX (e.g., at >60 min) and/or after the second ST-EX (e.g., at >120 min) may improve 24-hour BG excursions more prominently than the current protocol.

As an important note for clinicians, ST-EX may increase the risk of falls, particularly in people with diabetic complications and/or locomotor diseases[29]. Unexpected cardiopulmonary response may also occur in people with obesity and/or low physical fitness. Although ST-EX is an easy-to-perform high-intensity exercise in daily life, these cautions should be considered when incorporating this type of exercise into activity regimens.

This is a preliminary study and had some major limitations. First, the sample size was small. However, the post hoc analyses showed that there were enough effect sizes to be of practical significance. Second, the effect of ST-EX was not compared with other exercises. Regarding this point, we have previously demonstrated that ST-EX was more effective in decreasing BG levels than level walking[6,8] and cycling exercise[7] in people with IGT or T2D. The effect of ST-EX should also be compared with dietary modifications such as low-calory and/or low-carbohydrate diet. Third, this study did not use a randomized crossover design, and we set the ST-EX day as the first experimental day, followed by the REST day. Since exercise increases whole-body insulin sensitivity for up to 72 hours[24], the BG level on the REST day might be affected by increased insulin sensitivity caused by ST-EX performed on the previous day. This means that the BG-lowering effect of ST-EX might even be underestimated in our study population, and thus more than 72 hours between experiments would have been preferable. Additional well-controlled studies are clearly warranted, especially those on the long-term effects and the safety of ST-EX to clarify the clinical relevance in diverse patient populations.

In summary, an ST-EX program comprising two 3-min bouts of ST-EX 60 and 120 min after each meal improved the 24-hour glucose excursions in people with T2D. Our exercise protocol might be potentially applicable to people with T2D, for instance when they cannot perform the recommended AE, such as 10 min per bout, 30 min per day and 150 min per week[1], owing to time restrictions.

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Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this article.

Author Contributions

Experiment conception and design: HH, TT, TH. Experiment implementation: HH, MI, MK, ST. Data analysis: HH and TH. Paper composition: HH. Analyzing and writing advisory: HH and TH. All authors approved the final version of the manuscript.

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