Stair climbing/descending exercise for a short time decreases blood glucose levels after a meal in people with type 2 diabetes

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ABSTRACT

Objective: We examined whether stair climbing–descending exercise (ST-EX), a convenient method to increase physical activity in daily life, for a short period would acutely improve the postprandial blood glucose (BG) response in people with type 2 diabetes (T2D).

Methods: 16 people with T2D (age 65.4±1.1 years) participated in 2 separate sessions. After an overnight fast, each participant consumed a test meal and then kept resting for 180 min, except when performing each 3 min bout of ST-EX at 60 and 120 min after the meal (ST-EX session), or kept resting for 180 min (REST session). ST-EX comprised 6 continuous repetitions of climbing to the second floor (21 steps) at a rate of 80–110 steps/min followed by walking down slowly to the first floor at a free step rate.

Results: The BG at 60 min after the meal during the ST-EX session (immediately before the first ST-EX) did not differ from that during the REST session, but analysis of variance revealed a significant interaction between time and treatment (p<0.01). The BG at 150 min after the meal (30 min after the second ST-EX) was significantly lower than that during the REST session (p<0.01). The area under the curve was also 18% lower during the ST-EX session than during the REST session (p<0.05). The heart rate and blood lactate levels indicated that the actual intensity of ST-EX was 'hard'. In contrast, the rating of perceived exertion (RPE) indicated that the overall intensity of ST-EX was 'moderate' because of decreased RPE scores during descent.

Conclusions: The present findings suggest that performing 3 min ST-EX 60 and 120 min after a meal may be a useful strategy to accelerate the decrease in postprandial BG levels in people with T2D.

INTRODUCTION

Postprandial hyperglycemia is recognized as an independent risk factor for cardiovascular events,¹–³ and is highly prevalent throughout the day in people with type 2 diabetes (T2D), even among those with apparently good glycemic control according to their glycated hemoglobin (HbA1c) level.⁴ Physical exercise has been widely prescribed as part of the treatment of hyperglycemia, and recent studies have shown that high-intensity exercise (HIE) effectively improves postprandial glucose metabolism in people with T2D. Gillen et al⁵ demonstrated that 10 bouts of 60 s high-intensity cycling exercise after a meal reduced the postprandial peak of blood glucose (BG) level and the area under the curve (AUC) of BG in people with T2D. Karstoft et al⁶ demonstrated that premeal 1-hour interval walking in people with T2D (repeated cycles of 3 min of slow and fast walking) decreased the postmeal incremental BG levels. François et al⁷ examined the effect of six bouts of 1 min high-intensity incline walking (90% of maximal heart rate) before each meal in individuals with insulin resistance, and found that the postdinner and subsequent 24-hour BG levels were significantly improved. These studies have clearly shown the clinical benefits of HIE for the management of T2D.

On the other hand, the lack of time, the lack of access to an exercise facility and the perceived difficulty in performing exercise are important barriers to regular participation in physical activity in people with T2D.⁸ Thus, it would be desirable to develop a time-saving and non-strenuous way of HIE
that assures substantial improvements in glycemic control regardless of weather conditions without the need for dedicated exercise equipment. To address this issue, we examined the acute hypoglycemic effect of two separate 3 min bouts of stair climbing–descending exercise (ST-EX), an easy-to-perform HIE in daily life. One can increase the overall exercise intensity without much effort by alternately climbing and descending stairs on a flight of stairs, because the subjective intensity is alleviated when descending the stairs.9–11

**METHODS**

**Participants**

Sixteen Japanese people with T2D but no macrovascular or microvascular complications (13 men and 3 women, under the age of 75), who regularly visited Toyooka Hospital Hidaka Medical Center (Toyooka, Japan), volunteered for this study. Their clinical characteristics were determined in the outpatient clinic within 4 weeks prior to the experiment (table 1). All participants were under medical nutritional therapy (energy intake: 25–30 kcal/kg body weight/day) and exercise therapy (low-intensity to moderate-intensity aerobic exercise including walking, cycling and/or calisthenics for 20–60 min/day), which were discontinued on the experimental days. No participants regularly climbed stairs in their daily life. They were taking oral hypoglycemic agents (glimepiride, metformin, and voglibose (n=2); glimepiride and metformin (n=2); voglibose (n=2); alogliptin (n=2); glimepiride, miglitol, and vildagliptin (n=1); voglibose, nateglinide, and vildagliptin (n=1); metformin and voglibose (n=1); metformin and miglitol (n=1); voglibose and nateglinide (n=1); miglitol and alogliptin (n=1); metformin (n=1); sitagliptin (n=1)). No participant was taking β-blockers or antihypertensive drugs that affect heart rate responses to exercise. Written informed consent was obtained from all participants before the experiments. The Institutional Review Board of Toyooka Hospital Hidaka Medical Center approved the study protocol.

**Statistics**

All values are reported as the mean ± SE. The time-course changes of BG, C peptide, and NEFA were analyzed with two-way repeated measures analysis of variance (ANOVA). For BG and C peptide levels, post hoc analysis was then performed with Tukey’s test to assess differences between each data point. Differences in the AUCs between the two sessions and parameters in table 2 were analyzed using paired Student’s t-test. The AUCs were calculated using the trapezoid method as follows: 0.5×δ(60)+0.5×δ(90)+0.5×δ(120)+0.5×δ(150)+0.5×δ(180)×30 min, where δ(n) is the increase from the premeal value (time=0) at the time point of n min. Significance was set at p<0.05.

**Table 1** Characteristics of study participants

<table>
<thead>
<tr>
<th>Age (years)</th>
<th>65.4±1.1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Body mass index (kg/m²)</td>
<td>23.6±0.7</td>
</tr>
<tr>
<td>Duration of diabetes (years)</td>
<td>11.3±1.5</td>
</tr>
<tr>
<td>HbA1c (%)</td>
<td>6.9±0.1</td>
</tr>
<tr>
<td>HbA1c (mmol/mol)</td>
<td>52±1</td>
</tr>
<tr>
<td>Serum total cholesterol (mmol/L)</td>
<td>5.0±0.1</td>
</tr>
<tr>
<td>Serum triglycerides (mmol/L)</td>
<td>1.6±0.2</td>
</tr>
<tr>
<td>Serum HDL-cholesterol (mmol/L)</td>
<td>1.6±0.1</td>
</tr>
<tr>
<td>Serum LDL-cholesterol (mmol/L)</td>
<td>3.1±0.1</td>
</tr>
</tbody>
</table>

Values are the mean±SE. N=16.

HbA1c, glycated hemoglobin; HDL, high-density lipoprotein; LDL, low-density lipoprotein.
RESULTS

The BG at 60 min after the meal during the ST-EX session (immediately before the first ST-EX) did not differ from that during the REST session; however, it decreased more rapidly during the ST-EX session than during the REST session. The ANOVA revealed a significant interaction between time and treatment on BG ($p<0.01$; figure 1A). The BG at 150 min during the ST-EX session (30 min after the second ST-EX) was significantly lower than that during the REST session ($p<0.01$; figure 1A). The decreases in BG were also greater during the ST-EX session than during the REST session at any sampling period ($p<0.05$; figure 2).

Furthermore, the AUC for BG (0–180 min) during the ST-EX session was 18% lower than during the REST session (ST-EX 428.1±67.0 mmol/L×min vs REST 521.0±50.6 mmol/L×min, $p<0.05$).

The ANOVA showed a significant interaction between time and treatment on C peptide ($p<0.01$), but there was no significant difference between sessions at any sampling time (figure 1B). The interaction was not significant in NEFA (figure 1C). The AUCs for C peptide and NEFA (0–180 min) were not different between sessions (C peptide: ST-EX 64.5±7.7 mmol/L×min vs REST 64.8±6.1 mmol/L×min, NEFA: ST-EX −28.1±2.2 mmol/L×min vs REST −29.9±6.9 mmol/L×min).

All the participants completed the ST-EX session without adverse clinical manifestations indicating cardiovascular, respiratory, or orthopedic complications. The percentage of age-predicted maximal heart rate (% HRmax; table 2) indicated that ST-EX was indeed an HIE, because activity is classified as ‘hard’ when the heart rate is between 70% and 89% HRmax. $^{13}$ Moreover, the blood lactate level was robustly increased at the end of ST-EX (table 2). Nevertheless, the participants performed ST-EX without serious symptoms such as dyspnea or leg exhaustion, and the overall extent of physical effort estimated by the RPE for ST-EX was at the ‘moderate’ level. $^{13}$

DISCUSSION

We reported previously that a continuous 6 min bout of ST-EX starting 90 min after a meal accelerated the decrease in postprandial BG levels in people with impaired glucose tolerance (IGT). $^{9}$ We also demonstrated that a continuous 6.5 min bout of ST-EX starting 90 min after ingestion of a carbohydrate solution hastened the decrease in BG levels in people with T2D. $^{11}$ However, we have realised that even the 6–6.5 min bout of ST-EX is too strenuous for some unfit people to perform regularly in daily life. Therefore, we conducted this study to clarify whether ST-EX for a shorter duration...
ST-EX had a limited effect on BG levels (data not shown). As shown in figure 1C), suggesting strongly that it does not elicit a clinically unfavorable counter-regulatory effect, and that insulin secretion might have been slightly reduced as a secondary response to the decreased BG levels induced by ST-EX (figure 1A, B).

It is notable that falls on stairs are common among older and/or obese people, particularly those with orthopedic disorders, and that stair descent seems to be more hazardous than stair ascent despite the low exercise intensity during descent. A survey of falls in community-living older people at least 75 years of age demonstrated that 80% (20/25) of falls on stairs occurred during descent.27 Aging is accompanied by deteriorations in musculoskeletal capacity for safe stair descent, such as decreased eccentric strength at the knee and ankle. In people with diabetes, visual dysfunction due to retinopathy may also increase the risk of accident. Furthermore, neuropathy is often accompanied by deterioration in sensory, motor, and autonomic nervous systems that may be critical to safe locomotion on stairs. Thus, the use of ST-EX in practice should be individualised with careful consideration of the risk of falling, particularly during descent.

There were some limitations to this study. First, the study participants were lean, maintained optimal HbA1c values, and already under exercise therapy, so the results might not be directly applicable to obese, poorly controlled, or sedentary patients. In particular, physical fitness and body mass index are closely linked in people with T2D: the heaviest people are the least fit,28 and thus the decrease in exercise intensity during the descending phase of ST-EX might not be generalised to severely obese patients. Second, no comparison of the exercise intensity between ST-EX and other exercise modalities such as level walking was made. In this regard, we reported previously that a single bout of ST-EX for 6–6.5 min was more effective than level

T2D.21-23 Thus, it seems reasonable to speculate that a 3 min bout of ST-EX is sufficient to substantially increase glucose uptake in working muscles. In addition, the postexercise period has been characterised by enhanced insulin sensitivity in skeletal muscle, which leads to a prolonged increase in insulin-stimulated glucose uptake.24 These insulin-dependent and insulin-independent mechanisms might contribute to the acute hypoglycemic effect of ST-EX in people with T2D.

C peptide and NEFA levels often reflect the intensity and/or duration of exercise. Larsen et al demonstrated that moderate-intensity to high-intensity cycling exercise for 45 min after a meal acutely blunted the postprandial increases in insulin and C peptide levels and postprandial decreases in NEFA levels in people with T2D. The reduction in insulin secretion might occur in response to the decreased BG level induced by exercise, as well as from the induction of a counter-regulatory response such as increased sympathetic nervous activity during exercise,25 which also causes NEFA release.26 In this study, our exercise protocol did not change NEFA levels (figure 1C), suggesting strongly that it does not elicit a clinically unfavorable counter-regulatory effect, and that insulin secretion might have been slightly reduced as a secondary response to the decreased BG levels induced by ST-EX (figure 1A, B).

Figure 2 Changes in BG levels from 60 min (immediately before the first stair climbing–descending exercise (ST-EX) to 180 min postmeal. Participants kept resting for 180 min except when performing each 3 min bout of ST-EX at 60 and 120 min postmeal (ST-EX session), or kept resting for 180 min (REST session). Values are the mean±SE. *p<0.05, **p<0.01 versus corresponding REST. N=16.
walking for the same duration in decreasing postprandial BG in people with IGT and T2D. Third, an ST-EX protocol that could attenuate the increase in BG starting 60 and 120 min after a meal and blunt the peak postprandial BG, which should be lower than 10 mmol/L, remains to be determined. Thus, further studies are needed prior to clinical applications of this regimen to a variety of patient populations.

CONCLUSIONS

In lean, moderately active older people with T2D, 3 min ST-EX starting 60 and 120 min after a meal hastened the decrease in postprandial BG levels without the need for excessive effort. Although further research is required, ST-EX may be a potentially useful method for increasing physical activity in daily life, with efficient and acute postprandial BG reduction in people with T2D.

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Contributors

HH contributed to the study conception and design, acquisition of data, analysis and interpretation of data, and drafting of the manuscript. MI, YH, MK, ST, TM, and TS contributed to the acquisition of data. TT contributed to the study conception and design, analysis and interpretation of data, and drafting of the manuscript as the guarantor of this work and takes responsibility for the integrity of the data analysis and interpretation of data, and drafting of the manuscript.

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Competing interests

None declared.

Ethics approval

Toyooka Hospital Hidakagakuen Medical Center.

Provenance and peer review

Not commissioned; externally peer reviewed.

Data sharing statement

No additional data are available.

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REFERENCES


Correction


Some instances of ‘Participants’ has been changed to ‘people’ throughout, including the title. The correct title is now ‘Stair climbing/descending exercise for a short time decreases blood glucose levels after a meal in people with type 2 diabetes’.

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