Clinical effect of real time pulse rate monitoring with a portable pulsimeter on physical exercise therapy for male patients with type 2 diabetes

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Abstract In patients with type 2 diabetes, it is recommended that exercise therapy is performed using heart rate as an index of exercise intensity. This study was designed to clinically evaluate whether continuous exercise therapy with a portable pulsimeter for self-monitoring of the pulse rate influences glycemic control in patients with type 2 diabetes. We randomly assigned 23 male patients to a pulse displayed group (in which the portable pulsimeter displayed a pulse rate) or a pulse non-displayed group (in which the portable pulsimeter only recorded the data and did not display a pulse rate). The patients then received

exercise therapy for 1 month. Patients in the pulse displayed group were instructed to regulate their walking speed by maintaining their portable pulsimeter in the target pulse rate zone, whereas patients in the pulse non-displayed group were instructed to regulate their walking speed while taking their pulse rate and using the Borg scale to maintain the target pulse rate zone using the conventional method. We found the mean walking time within the target pulse rate zone during exercise therapy was significantly increased in the pulse displayed group ($p < 0.01$). Similarly, glycoalbumin and 1,5-anhydro-D-glucitol improved significantly in the pulse displayed group after 1 month of exercise therapy ($p < 0.01$, respectively). Our results suggest that this therapeutic device might be useful for improving glycemic control in patients with type 2 diabetes.

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Introduction

Physical exercise in patients with type 2 diabetes has been shown to improve insulin sensitivity, glycemic control and cardiovascular risk factors [1–3]. Furthermore, studies have indicated that exercise contributes to reductions in cardiovascular events and mortality risk [4, 5]. Diabetic patients are recommended to exercise aerobically for 150 min per week with a moderate intensity corresponding to 50–70 % of the maximal heart rate [6]. However, with daily exercise therapy for diabetes mellitus, it can be difficult to perform self-monitoring of the pulse during exercise. Furthermore, when the Borg scale, which reflects the subjective intensity of exercise, is not estimated correctly,

the exercise intensity might be outside the optimal range. Therefore, when recommending and managing diabetic exercise therapy, a tool which provides the pulse rate needed to maintain optimal intensity during exercise is required in the clinical setting. This study was designed to evaluate whether continuous exercise therapy with a portable pulsometer for self-monitoring of the pulse rate in patients with type 2 diabetes influences glycemic control.

Subjects and methods

This was an open-label randomized controlled trial conducted at a single institution. The protocol was approved by the Hospital Ethics Committee affiliated with Kyorin University School of Medicine and informed consent was obtained from all subjects. This study was registered under the UMIN protocol registration system (ID UMIN 000012142).

Study subjects

Twenty-three male patients with type 2 diabetes participated in this study. All patients had been followed at our hospital for at least 3 months and were treated with dietary modification alone or diet therapy plus oral hypoglycemic agents (pulse non-displayed group—sulfonylurea [2 subjects], DPP-4 inhibitor [2 subjects]; pulse displayed group—sulfonylurea [2 subjects], DPP-4 inhibitor [6 subjects], biguanide [6 subjects]). We excluded patients on insulin therapy. Other exclusion criteria were advanced microangiopathy (diabetic peripheral neuropathy CVR-R <2.0 %), diabetic retinopathy (both preproliferative and proliferative retinopathy) and diabetic nephropathy (>stage 3), renal failure (estimated glomerular filtration rate [eGFR] ≤ 60 mL/min/1.73 m²), liver disease (serum AST or serum ALT >100 IU/L), tobacco use, alcohol abuse and any history of cardiovascular disease. All subjects underwent medical examinations to judge whether they were appropriate candidates for exercise therapy. We fully explained the protocol and the risks of this study and all subjects provided written consent to participate.

Study design

The subjects underwent cardiopulmonary exercise testing after the preliminary medical examinations. We then assigned patients to the pulse displayed group ($n = 15$, the group in which the portable pulsometer displayed their pulse rates) or the pulse non-displayed group ($n = 8$, the group in which the portable pulsometer only recorded data

and did not display a pulse rate) at a ratio of 2:1, in the order that the subjects had been registered. The patients performed exercise therapy for 1 month after physical therapists had instructed them how to walk. We examined blood samples before and after the 1-month exercise program. Furthermore, in patients with a displayed pulse rate, we examined the relationships between glycemic control parameters and the exercise time recorded on the portable pulsometer.

Cardiopulmonary exercise test

We performed a multi-stage exercise test using an ergometer (Aero monitor AE300S; Minato Medical Science, Osaka, Japan), and measured maximum oxygen intake and the aerobic threshold (AT) at 1 week before the beginning of the study.

Instructions for exercise therapy

We instructed the patients before exercise that, although the target pulse rate used as a general guideline for exertion was the pulse rate at the AT, they were to avoid over-exertion in the interests of safety.

Furthermore, the maximum for the target pulse rate zone was set as the pulse rate derived by adding 20 % of the AT pulse rate to that at the AT (i.e., the ‘the target pulse rate zone’ was the pulse rate at AT + ~20 % of the pulse rate at AT).

We instructed all subjects to attach a portable pulsometer whenever they went out. Physical therapists instructed patients who were assigned to the pulse displayed group to regulate their walking speeds by remaining aware of the portable pulsometer in order to maintain a pace that kept their heart rates within the target pulse rate zone. The physical therapists also instructed patients who were assigned to the pulse non-displayed group to regulate walking speed by taking their pulse rate and applying the Borg scale of subjective intensity in order to maintain their pulse rates within the target pulse rate zone. This method is conventionally applied for exercise therapy in diabetic patients. The physical therapists instructed both groups to maintain the target pulse rate zone for >30 min a day by walking as part of their daily routines.

Portable pulsometer

We used a wristwatch-type photoplethysmographic pulse meter (model E200; Seiko Epson Corporation, Suwa, Nagano, Japan) because of its ability to measure pulse rates accurately even when walking. The heart beats are

calculated, displayed and stored with the dedicated algorithm which eliminates the effects of body artifacts by using motion signals. Furthermore, by analyzing the signals, several subject movements, such as resting, walking, running, etc., can be discriminated, thereby providing accurate measurements of walking times.

Two types of wrist pulsometer were used for this study. The first was the original type, which was used in the pulse displayed group. The second, used in the pulse non-displayed group, was similar to the original except for the pulse rate display being disabled. After a 1-month test period, the following exercise characteristics of each subject, on the day of measurement, were calculated.

(1) Mean wearing time: the period between the initiation and completion of the recording, (2) mean activity time: the time excluding resting periods from the mean wearing time, (3) mean walking time: the time spent walking, (4) mean walking time within the prescribed pulse rate zone: the duration of walking within the prescribed pulse rate range, (5) mean walking intensity: the walking intensity described in metabolic equivalents (mets) calculated by mean pulse rates during the walking periods, (6) mean energy expenditure was calculated by walking time (h), estimated walking intensity (mets) and body weight (kg) during the walking periods, and (7) mean steps: the number of steps calculated from daily pulsometer data.

Blood sampling

Blood samples were collected in the early morning, after a fasting period of at least 12 h starting after dinner on the previous day. We measured the blood glucose (HK-6-PDH method; Shino-Test Corporation, Tokyo, Japan), glycoalbumin (enzymatic method; Asahi Kasei Pharma, Tokyo, Japan), 1,5-anhydro-D-glucitol (1,5-AG) (PROD-HRP method, Kainos Laboratories, Inc., Tokyo, Japan), serum adiponectin (CLEIA, Fujirebio, Inc., Tokyo, Japan), serum LDL-C (enzymatic assay; Sekisui Medical, Japan), serum HDL-C (selective inhibition method; Sekisui Medical, Japan), serum triacylglycerol (POD method; Kyowa Medical, Japan) and high sensitivity C-reactive protein (CRP) (CLEIA, Fujirebio Inc.) levels.

Statistical analysis

All data are shown as mean $\pm$ standard deviation. Intra-group comparisons with differences after versus before exercise therapy were analyzed using the paired *t* test for data with a normal distribution or the Wilcoxon signed-rank test for non-parametric data. Comparisons between the two exercise groups were performed using Student's

t test for parametric data or the Mann–Whitney *U* test for non-parametric data. Relationships between glycemic parameters and portable pulsometer data were evaluated using the Spearman rank correlation coefficient.

Statistical comparisons were considered significant at $p < 0.05$.

All analyses were performed using R software version 3.10.0 (R Foundation for Statistical Computing, Vienna, Austria).

Results

None of our subjects experienced hypoglycemia during the exercise therapy period.

Table 1 shows each parameter 1 month before the initiation of exercise therapy, allowing comparisons between the two groups. The glycoalbumin level was significantly lower in the pulse non-displayed than in the pulse displayed group, but this was the only parameter that differed significantly between the two groups.

The effects obtained with 1 month of exercise therapy are presented in Table 2. The changes in body mass index (BMI), blood pressure, fasting blood glucose, 1,5-AG, high-sensitivity CRP and lipid profile were not statistically significant. However, glycoalbumin levels were significantly decreased and adiponectin levels were significantly increased after 1 month of exercise therapy in both groups.

Table 2 also shows the effects of exercise for 1 month in each group. In the pulse displayed group, the glycoalbumin level decreased significantly, and the 1,5-AG levels increased significantly. In the pulse non-displayed group, BMI, blood pressure, fasting blood glucose, glycoalbumin, 1,5-AG, and high sensitivity CRP values were not significantly different after the exercise intervention, with only adiponectin being significantly increased.

Table 3 shows an analysis of the recorded data obtained from the portable pulsimeters. There were no significant differences in mean wearing time or mean activity time between the two groups. However, the mean walking time was significantly greater in the pulse displayed group. Furthermore, the mean walking time within the set target pulse rate zone during exercise was significantly greater in the pulse displayed group. Furthermore, the mean estimated mets and the mean walking time (min/day) $\times$ estimated mets were significantly greater in the pulse displayed group.

Table 4 and Fig. 1a–d show the simple correlation results for pre-exercise versus post-exercise changes in glycoalbumin/1,5-AG and the portable pulsometer data. The change in glycoalbumin correlated significantly with exercise time $\times$ estimated mets. Moreover, the change in 1,5-AG correlated significantly with estimated mets, exercise time $\times$ estimated mets and mean energy expenditure.

Table 1 Clinical characteristics

	Pulse non-displayed group (<i>n</i> = 8)	Pulse displayed group (<i>n</i> = 15)
Age (years)	56.4 ± 12.1	55.1 ± 10.4
Weight (kg)	79.9 ± 14.1	74.9 ± 9.7
BMI (kg/m ²)	27.4 ± 4.7	25.5 ± 2.8
SBP (mmHg)	124.8 ± 6.2	124.9 ± 6.8
DBP (mmHg)	73.0 ± 6.2	78.7 ± 6.2
FPG (mg/dL)	119.4 ± 23.5	134.7 ± 33.3
LDL cholesterol (mg/dL)	101.0 ± 29.9	115.7 ± 18.7
HDL cholesterol (mg/dL)	45.9 ± 8.7	49.7 ± 11.7
Triglycerides (mg/dL)	135.0 ± 69.6	131.3 ± 51.0
High-sensitivity CRP (mg/dL)	0.05 ± 0.05	0.10 ± 0.01
eGFR (mL/min/1.73 m ²)	83.7 ± 18.5	86.6 ± 18.9
Glycoalbumin (%)	14.7 ± 2.3	17.9 ± 2.9 [†]
1,5-AG (μg/mL)	12.04 ± 6.9	10.2 ± 6.9
Adiponectin (μg/mL)	1.6 ± 0.8	1.4 ± 0.6
Heart rate at AT (bpm)	111.8 ± 15.1	100 ± 9.4
VO ₂ at AT (mL/kg/min)	11.6 ± 1.6	13.2 ± 3.0
Peak heart rate (bpm)	140.0 ± 21.4	131.3 ± 13.3
Peak VO ₂ (mL/kg/min)	18.3 ± 2.1	21.4 ± 3.4

Data are mean ± SD

[†] *p* < 0.05 for pulse non-displayed group versus pulse displayed group**Table 2** Clinical values before and after exercise therapy in each group

	Before ET (<i>n</i> = 23)	After ET (<i>n</i> = 23)	Pulse non-displayed group (<i>n</i> = 8)		Pulse displayed group (<i>n</i> = 15)	
			Before	After	Before	After
Weight (kg)	76.6 ± 11.7	76.5 ± 11.5	79.9 ± 14.1	79.5 ± 14.0	74.9 ± 9.7	74.8 ± 9.5
SBP (mmHg)	124.9 ± 6.6	126.4 ± 7.2	124.8 ± 6.2	123.3 ± 9.5	124.9 ± 6.8	128.0 ± 4.8 [†]
DBP (mmHg)	76.7 ± 6.7	76.6 ± 7.4	73.0 ± 6.2	71.5 ± 8.5	78.7 ± 6.2	79.3 ± 4.9
FPG (mg/dL)	129.4 ± 31.1	123.6 ± 22.8	119.4 ± 23.5	113.8 ± 19.6	134.7 ± 33.3	128.9 ± 22.7
LDL cholesterol (mg/dL)	110.6 ± 24.2	112.9 ± 22.6	101.0 ± 29.9	107.3 ± 27.4	115.7 ± 18.7	115.9 ± 18.9
HDL cholesterol (mg/dL)	43.4 ± 10.9	53.3 ± 20.7	45.9 ± 8.7	47.1 ± 9.6	49.7 ± 11.7	56.6 ± 24.0
Triglycerides (mg/dL)	132.6 ± 58.2	115.2 ± 43.9	135.0 ± 69.6	117.5 ± 55.9	131.3 ± 51.0	113.9 ± 35.8
High-sensitivity CRP (mg/dL)	0.08 ± 0.11	0.05 ± 0.04	0.05 ± 0.05	0.05 ± 0.04	0.10 ± 0.01	0.05 ± 0.04
eGFR (mL/min/1.73 m ²)	84.2 ± 17.9	82.0 ± 19.2	83.7 ± 18.5	78.9 ± 20.1	86.6 ± 18.9	76.9 ± 14.7
Glycoalbumin (%)	16.78 ± 3.10	16.26 ± 2.68 [†]	14.7 ± 2.3	15.0 ± 2.5	17.9 ± 2.9	16.9 ± 2.5 ^{††}
1,5-AG (μg/mL)	10.82 ± 6.93	10.96 ± 6.80	12.04 ± 6.9	10.6 ± 6.4	10.2 ± 6.9	11.1 ± 7.0 ^{††}
Adiponectin (μg/mL)	1.43 ± 0.71	1.63 ± 0.89 [†]	1.6 ± 0.8	1.9 ± 1.1 [†]	1.4 ± 0.6	1.5 ± 0.8

Data are mean ± SD

[†] *p* < 0.05 before versus after exercise therapy in each group^{††} *p* < 0.01 before versus after exercise therapy in each group

Discussion

To the best of our knowledge, this is the first study to scientifically evaluate whether exercise therapy for diabetes with a portable pulsimeter for 1 month influences glycemic control in patients already diagnosed with type 2 diabetes and to demonstrate that self-monitoring of the

pulse as an index of exercise intensity can be reliably and continuously performed.

We demonstrated that the mean walking time achieving the target pulse rate zone was significantly increased in the pulse displayed group compared with the pulse non-displayed group, that glycoalbumin and 1,5-AG as indices of glycemic control were significantly improved only in the

Table 3 Portable pulse rate monitor records

	Pulse non-displayed group (<i>n</i> = 8)	Pulse displayed group (<i>n</i> = 15)
Mean wearing time (min/day)	440.7 ± 201.6	501.8 ± 243.8
Mean activity time (min/day)	189.1 ± 79.3	193.3 ± 116.0
Mean walking time (min/day)	34.8 ± 16.5	54.1 ± 17.9 [†]
Mean walking time within target pulse rate zone (min/day)	8.2 ± 4.7	28.0 ± 16.1 ^{††}
Mean pulse rate (bpm/day)	99.9 ± 6.3	100.0 ± 5.7
Mean estimated mets (mets)	2.4 ± 0.7	3.7 ± 1.0 ^{††}
Mean energy expenditure (kcal/day)	154.6 ± 60.1	314.0 ± 119.3 ^{††}
Mean steps (/day)	3,666.7 ± 1,660.5	6,072.4 ± 1,907.9 ^{††}

Data are mean ± SD

[†] *p* < 0.05 for pulse non-displayed group versus pulse displayed group

^{††} *p* < 0.01 for pulse non-displayed group versus pulse displayed group

Table 4 Relationship changes in glycemic parameters and portable pulsimeter data

	Delta of glycoalbumin (%)		Delta 1,5-AG (μg/mL)	
	<i>r</i>	<i>p</i> value	<i>r</i>	<i>p</i> value
Mean walking time (min/day)	−0.28	0.200	0.27	0.200
Estimated mets (mets)	−0.32	0.139	0.52	0.010
Mean walking time (h/day) × estimated mets (mets)	−0.42	0.046	0.46	0.027
Mean energy expenditure (kcal/day)	−0.34	0.109	0.43	0.039

Delta represents changes after versus before exercise therapy

r Spearman rank correlation coefficient

former, and that the change in glycoalbumin correlated significantly with exercise time × estimated mets.

Therefore, the results of the present study suggest that exercise therapy for diabetes which keeps subjects aware of their pulse rate as displayed on a portable pulsimeter, as an index of exercise intensity, may be useful for the achievement of at least 150 min per week of moderate-intensity aerobic exercise, which is in accord with public health recommendation, and for the improvement of glycemic control in patients with type 2 diabetes.

It is recommended that the heart rate be used as an index of exercise intensity for patients with diabetes mellitus [5]. However, in actual clinical settings, exercise instruction relies on the Borg scale (rating of perceived exertion) and self-monitoring of the pulse during exercise. Exercise based on these indices is often insufficient owing to low intensity, and the blood glucose level might even be temporarily reduced to hypoglycemic levels due to excessive exercise intensity [7]. Therefore, when prescribing exercise therapy for patients with diabetes, it is important that these patients continuously perform this therapy while always remaining aware of maintaining optimal target pulse rates.

Pedometers and accelerometers have been widely used in exercise therapy for diabetes and studies have shown that the use of such devices is effective for increasing physical

activity [6, 7]. Exercise therapy in which pedometers and heart rate monitors are utilized has also been shown to improve glycometabolism [8]. The use of portable pulsimeters allowed the subjects to remain aware of their pulse rate as a measure of exercise intensity during exercise, which we believe allowed them to adjust their walking speed and motivated them to increase the amount of time during which they were within the target pulse rate zone.

The results of our present study suggest that the use of portable pulsimeters significantly increased 1,5-AG and may have reduced postprandial hyperglycemia. A previous study showed that exercise therapy which maintains appropriate intensity under supervised conditions was effective in significantly reducing the duration of postprandial hyperglycemia without affecting the fasting glucose level due to the action of continuous glucose monitoring devices [9]. We consider that using portable pulsimeters could possibly result in maintaining appropriate intensity, even without supervision, as well as reducing postprandial hyperglycemia and improving 1,5-AG. Moreover, exercise therapy using portable pulsimeters yields results in accordance with exercise time and intensity, both being associated with improvement of glycemic control. Therefore, our results raise the possibility that exercise therapy for diabetes using this portable pulsimeter

Fig. 1 Relationship changes in 1,5-AG with **a** mean walking time, **b** estimated mets, **c** mean walking time $\times$ estimated mets, and **d** mean energy expenditure $\times$ 1,5-AG

on a daily basis would be extremely useful for performing exercise therapy according to the recommendations for managing diabetes.

This study has several limitations. First, since the number of subjects was too small to allow analysis of the various factors that can affect glycoalbumin and 1,5-AG, further study with a larger number of subjects is required. Second, although individual dietary instruction was provided prior to the study, we cannot rule out dietary influences during the study period as we did not investigate the daily food intake of the subjects.

Conclusion

Our study clearly demonstrated that exercise therapy for diabetes with awareness of the pulse rate displayed by a portable pulsometer increased the time spent within the target pulse rate zone and significantly reduced glycoalbumin and 1,5-AG levels.

We believe that the major advantage of wearing a portable pulsometer is that exercise intensity can be appropriately maintained with self-monitoring of the pulse rate during exercise therapy.

Although pedometers and accelerometers are already widely used in exercise therapy for diabetes, we anticipate that the portable pulsometer will become a third device used in clinical practice in the near future.

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Human rights statement and informed consent All procedures followed were in accordance with the ethical standards of the responsible committee on human experimentation (institutional and national) and with the Helsinki Declaration of 1964 and later revision. Informed consent or an acceptable substitute was obtained from all patients prior to inclusion in the study. Additional informed consent was obtained from all patients for whom identifying information is included in this article.

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