Original Article

Improvement of pulmonary function with arm swing exercise in patients with type 2 diabetes

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Abstract. [Purpose] Obesity and hyperglycemia play roles in the impairment of pulmonary function in type 2 diabetes mellitus (T2DM) patients. Low-intensity exercise is known to reduce body fat and improve hyperglycemia. The arm swing exercise (ASE), a low-intensity exercise, is easy and convenient to perform without any equipment and is suitable for daily practice. Therefore, we aimed to investigate the effects of ASE on lung function and obesity in overweight T2DM patients. [Subjects and Methods] Twenty-four subjects continued their daily life routines for 8 weeks (control period), and then performed ASE for 8 weeks (30 minutes per day, 3 days per week) (ASE period). Pulmonary function tests were performed, and fasting blood glucose, haemoglobin A1c (HbA1c), lipid profiles, high-sensitive C-reactive protein (HSCRP), insulin concentration, and anthropometric parameters were measured before and after each period. [Results] After the ASE period, the forced vital capacity, forced expiratory volume in the first second of expiration, and maximal voluntary ventilation were increased when compared with after the control period. HbA1c, a low-density lipoprotein, malondialdehyde, oxidized glutathione, and the percent body fat were significantly decreased when compared with after the control period. However, other parameters, such as lung volume, anthropometric parameters, and fasting blood glucose, insulin, high-density lipoprotein, triglycerides, total cholesterol and glutathione concentrations, showed no differences between the two periods. [Conclusion] These data suggest that there is improvement of pulmonary functions in T2DM patients after ASE training.
Key words: Physical activity, Pulmonary functions, Fatness

INTRODUCTION

Diabetes mellitus type 2 (T2DM) is a chronic disease that has been increasing globally over the past 2 decades including in Thailand[1]. It is a significant health problem with microangiopathy and macroangiopathy resulting in many complications, i.e, neuropathy[2], retinopathy[3], nephropathy[4], and coronary artery disease[5]. In addition, hyperglycemia-induced microangiopathy via increased oxidative stress has also been shown to impair pulmonary function[5]. Lung impairment due to microangiopathy is indicated by a decrease in spirometric parameters, forced vital capacity (FVC), and the forced expiratory volume in the first second of expiration (FEV1)[6–8]. Human autopsy[9, 10] and transbronchial biopsy studies[11] of diabetic patients have revealed an increase in alveolar-capillary basement membrane thickness, which may contribute to the limitation of lung expansion caused by

an enlarged interstitium and decreased diffusion because of the thickening and fibrotic changes in the alveolar-capillary and pulmonary arteriole basement membranes[6, 12]. In fact, glycemic status was negatively correlated with the dynamic lung functions in T2DM patients[13].

In addition, impaired lipid metabolism indicated by an increase of body fat mass[14] and chronic low-grade tissue inflammation[14], autonomic neuropathy involving the respiratory muscles[15], and loss of elastic recoil according to collagen glycosylation of lung parenchyma[16] are considered to contribute to respiratory impairments in T2DM patients. Therefore, the modalities that improve glycemic status and control lipid metabolism, e.g, exercise, diet restriction, and intake of medicinal herbs, may be useful in improving the pulmonary functions of T2DM patients.

Low-intensity exercise is known to effectively reduce body mass and fat mass[17, 18], glucose and triglyceride levels[19], and blood pressure and waist and hip circumferences[18]. In addition, it is known to increase lipid oxidation and insulin sensitivity in patients with metabolic syndrome[20], provide an anti-inflammation effect[21], decrease HbA1c[22] and oxidative stress[23], and increase lipid oxidation in patients with T2DM[24].

The arm swing exercise (ASE), a low-intensity exercise, is easy and convenient to perform without any equipment.

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The ASE is, therefore, suitable for daily practice. We previously demonstrated that performance of the ASE for 8 weeks conclusively improved hyperglycemia via improvement of oxidative stress in T2DM[23]. We also demonstrated that, in untrained men and women, fat was used as a major source of energy for low-intensity exercise more than in the case of higher-intensity exercise[25]. The ASE may thus increase fat usage, leading to improvement of the lipid profile and a reduction in fat mass. We hypothesized that the ASE may have beneficial effects on pulmonary functions via improvement of hyperglycemia, antioxidant activity, and fat metabolism in the T2DM patients. In this study, we aimed to investigate the effects of the ASE on dynamic pulmonary function of overweight T2DM patients. In relation to the effects of the ASE on the pulmonary functions, the effects of the ASE on oxidative stress, lipid profiles, obesity, and glycemia of T2DM patients were investigated.

SUBJECTS AND METHODS

Twenty-four Thai patients with T2DM (20 women and 4 men) were recruited in Khon Kaen Province, Thailand. Their mean age (± SE) was 59.5 ± 1.46 years, and they had no cardiovascular and/or respiratory complications. They were informed verbally and in writing before signing a consent form approved by the Ethical Committee of Khon Kaen University in accordance with the 1964 Declaration of Helsinki. If the subjects could not attend 90% of the total exercise sessions or could not maintain their usual therapy for at least 80% of all interventions throughout the experiment, they were excluded from the study.

All subjects maintained their sedentary daily lives for the first 8 weeks (control period), and then they performed the ASE for 8 weeks (30 minutes per day, 3 days per week) (ASE period). On the first day of the ASE period, the participants learned how to perform the ASE correctly in our laboratory. They then performed it with video tape recorder monitoring at home for the following 8 weeks. Once a week, all subjects were telephoned to check on their ASE training. Anthropometric parameters and body composition were measured before and after each period. At the same points of time, blood samples were collected from the antecubital vein to determine glucose, lipid, HbA1c, malondialdehyde (MDA), reduced glutathione (GSH), oxidized glutathione (GSSG), and insulin concentrations.

The ASE is a traditional Chinese exercise with an intensity of approximately 23% of the maximal oxygen consumption (unpublished data). In starting position of the ASE, each subject stood with his/her head erect, but relaxed, with the mouth naturally closed and the tip of the tongue placed against the hard palate and with the trunk of the body straight. They gazed forward with their eyes focused on a point while they concentrated their minds on swinging their arms. The arms initially hung naturally at the sides with the palms of both hands facing backward and with the fingers spreading naturally. The buttock and quadriceps muscles were contracted firmly. The feet were firmly placed on the ground, at shoulder width apart. Then both arms were swung forward about 30 degrees with a smooth and even force and then backward to about 60 degrees. The speed of swinging was 50 times/min. However, during the first week of the training, the speed of swinging was actually 30 times/minute.

Body weight and height were measured without shoes using a balance beam scale. The body mass index (BMI) was calculated from the body weight (kg) and height (m^2). Waist circumference was measured at the midpoint between the lower margin of the last palpable rib and the top of the iliac crest. Hip circumference was measured at the widest portion of the hip. Body fat was determined by measuring the skinfold thickness at 4 points on the right side of the body including the biceps, triceps, supra-iliac crest, and the subscapular area.

To assess pulmonary functions, forced expiratory volume in the first second (FEV_1) and forced vital capacity (FVC) were measured using a Vitalograph 2120 according to the ATS (American Thoracic Society) criteria. FEV_1 and FVC were measured before and after each study period. Maximal voluntary ventilation (MVV) was calculated from FEV_1 by the following equation: $MVV = FEV_1 (L) \times 40$[26].

At each visit, 7-ml blood samples were collected from the antecubital vein. One milliliter of blood was collected into tubes containing fluoride-oxalate for subsequent determination of whole blood glucose by using glucose oxidase and L-lactate oxidase methods (Yellow Springs Instrument Analyzer, YSI, 2300 STAT Plus). After placing 4 ml into EDTA and 2 ml into clotting tubes, all samples were placed immediately on ice. The tubes were then centrifuged at 3,000 g for 15 min to remove red blood cells, and the serum and plasma were separated. The serum obtained was used to analyze TC, HDL, LDL, TG, and hsCRP levels using standard automated laboratory methods (Roche Integra 800, Roche, Basel, Switzerland) and to analyze insulin by using the radioimmunoassay technique. These methods are routinely used in Srinagarind Hospital, Faculty of Medicine, Khon Kaen University. Two milliliters of residual plasma was used for analysis of MDA by the authors.

Insulin sensitivity was examined using Homeostatic Model Assessment-Insulin Resistance (HOMA-IR)[27].

The plasma MDA was measured using the thiobarbituric acid (TBA) test[28]. The basis of the TBA method is the reaction of MDA with 0.6% of TBA at low pH and 95 °C (boiled for 30 min) to form a colored complex. Acid hydrolysis and heat are necessary to release MDA bound to the amino groups of proteins and other amino compounds. The MDA-TBA complex, with an absorption at 532 nm, was measured using a spectrophotometer (Genesys 20, SN:35 gk 130009; Thermo Fisher Scientific, Waltham, MA, USA).

The serum hsCRP concentration was determined using a Roche/Hitachi cobas c system (Cobas c 501, Roche). The HSCRP level was determined using a particle-enhanced immunoturbidimetric method, in which formation agglutinates of human CRP with latex particles coated with monoclonal anti-CRP antibody was determined turbidimetrically.

Ongoing diabetes therapies that patients had been receiving, such as pharmacotherapy, dietary control, and exercise, were not modified during the study period. The data from 3 days of records (2 days during the week and 1 day on the weekend) for dietary intake and physical activity were averaged to estimate daily energy intake and expenditure.

Table 1. Anthropometric parameters and body composition of the subjects during the control and ASE periods

	Control (n=24)		ASE (n=24)	
	Before	After	Before	After
Age (yrs)	59.5±7.1	59.7±7.2	59.7±7.2	59.7±7.2
Height (cm)	156.5±7.3	156.5±7.3	156.5±7.3	156.5±7.3
Body mass (kg)	63.6±7.6	64.1±12.1	64.1±12.1	64.3±11.8
BMI	25.9±3.8	26.1±10.0	26.1±4.0	25.8±4.5
Waist (cm)	92.6±10.7	93.8±10.8	93.8±10.8	92.8±11.3
Hip (cm)	98.0±8.5	97.4±8.4	97.4±8.4	96.8±8.8
Waist to hip ratio	0.9±0.1	1.0±0.1	1.0±0.1	1.0±0.1
% Body fat	41.7±6.1	41.8±6.0	41.8±6.0	40.8±6.0[#]
Fat mass (kg)	27.3±6.6	26.8±6.2	26.8±6.2	26.8±6.6
Fat free mass (kg)	37.9±6.3	37.7±5.8	37.7±5.8	38.6±5.9
Rest HR (/min)	71.1±9.6	70.8±10.4	70.8±10.4	71.8±8.3

Data are expressed as means ± SE (n = 20 women and 4 men). Analysis was performed using the paired t-test for within groups and analysis of covariance between groups. Significant difference after exercise (adjusted by its baseline) between groups: [#] $p<0.05$
ASE: arm swing exercise; BMI: body mass index

Table 2. Daily dietary intake and total energy expenditure during the control and ASE periods

	Control (n=24)		ASE (n=24)	
	Before	After	Before	After
Dietary intake (MJ/day)	6.88±0.4	6.98±0.4	6.76±0.3	6.77±0.5
Total energy expenditure (MJ/day)	6.54±0.3	6.74±0.3	6.88±0.5	9.88±0.5[#]

Data are expressed as means ± SE (n = 20 women and 4 men).
Significant difference after exercise (adjusted by its baseline) between groups: [#] $p<0.05$
ASE: arm swing exercise

A two-way ANOVA with repeated measures (within subject factors of exercise and time) was used to analyze all dependent variables with the SigmaStat version 2 software. The Bonferroni method was used to adjust the multiple comparisons. Backward stepwise regression was used to analyze correlation between parameters at each time point. A p value of < 0.05 was considered statistically significant. Results are presented as means ± SE, except as stated elsewhere.

RESULTS

The percentage of body fat was found to be significantly reduced after the ASE compared with that before the ASE (p<0.05). All other anthropometric parameters were not significantly changed by the ASE (Table 1). The changes in mean daily dietary intakes were similar after both periods (Table 2). The mean total energy expenditure after the exercise period was significantly higher than that after the control period after adjustment with the pre-exercise values (p<0.05, Table 2). Drug therapies, eating situations, and momentum did not change throughout the study period of 8 weeks.

HbA1c, LDL, MDA, and GSSG were significantly lowered after 8 weeks of the ASE (p<0.05). However, there were no significant differences in FBG, insulin, lipid profiles, and HSCRP concentrations. Also, HOMA-IR was not altered after the ASE (Table 3). In all the participants, glycemic control was poor throughout the examined period.

All dynamic lung parameters were within normal ranges (Table 4). FEV_1, FVC, and MVV were significantly increased at the end of the ASE period (p<0.05) (Table 4). However, %FEV_1/FVC did not change significantly after the ASE period.

DISCUSSION

The present results showed that ASE training slightly improved the dynamic lung volumes including FEV_1, FVC, and MVV of overweight T2DM patients. This may have been due to a reduction of hyperglycemia and fat metabolism and a decrease in obesity.

The results support our hypothesis that ASE training may have beneficial effects on pulmonary function via reduced hyperglycemia, fat metabolism, and oxidative stress in overweight T2DM patients. Moreover, due to the movement of both arms and rhythmic breathing during the ASE, the ASE training may mobilize the chest wall and stimulate all the respiratory muscles (intercostals, diaphragm, abdominals, and scalenii) to do more work during the period of exercise. This is supported by a previous study that demonstrated that exercise at low levels of intensity increased expiratory muscle activity in healthy men[29]. In addition, although the expired gas composition was not measured, ventilatory efficiency (increased ventilation ($\dot{V}E$)/carbon dioxide output ($\dot{V}_{CO2}$) slope) may be improved by ASE training. This is supported by a previous study demonstrating that weight reduction resulting from ASE training may improve ventila-

Table 3. Blood parameters in the control and ASE periods

	Control (n=24)		ASE (n=24)	
	Before	After	Before	After
HbA1c (%)	9.5±0.4	9.1±0.4	8.8±0.4	8.4±0.5[#]
FBG (mg/dL)	156±12	150±10	154±10	144±10
Insulin (pmol/L)	28.2±3.8	27.0±3.8	24.9±5.1	29.3±5.8*
HOMA-IR	11.4±2.4	10.4±2.1	10.4±2.7	10.4±2.1
HDL (mg/dL)	48±3	48±3	51±4	48±3
LDL (mg/dL)	113±6	125±8	114±6	107±5[#]
TG (mg/dL)	195±24	185±17	192±23	207±25
TC (mg/dL)	200±7	206±10	199±9	197±7
hsCRP (mg/dL)	8.3±2.0	11.0±5.5	6.1±0.9	5.1±0.7
MDA (μM)	1.8±0.2	1.8±0.1	1.8±0.2	1.3±0.1*[#]
GSH (μM)	538.7±24.1	581.9±15.2	524.7±19.3	566.2±17.7***
GSSG (μM)	21.3±1.9	19.0±1.2	20.9±1.3	14.7±0.8***[##]
GSSG/GSH	0.04±0.01	0.03±0.01	0.04±0.00	0.03±0.00**

Data are expressed as means ± SE (n = 20 women and 4 men). Analysis was performed using the paired t-test for within groups and analysis of covariance between groups. Significantly different from before exercise within group: *$p<0.05$; **$p<0.01$; ***$p<0.001$. Significant difference after exercise (adjusted by its baseline) between groups: [#]$p<0.05$; [##]$p<0.01$. ASE: arm swing exercise; HbA1c: haemoglobin A1c; FBG: fasting blood glucose; HOMA-IR: Homeostatic Model Assessment-Insulin Resistance; HDL: high-density lipoprotein; LDL: low-density lipoprotein; TG: triglycerides; TC: total cholesterol; HSCRP: high-sensitive C-reactive protein; MDA: malondialdehyde; GSSG: oxidized glutathione; GSH: reduced glutathione

Table 4. Pulmonary function tests and predicted values in the control and ASE periods

	Control (n=24)		ASE (n=24)	
	Before	After	Before	After
FEV$_1$ (L)	1.91±0.1	1.84±0.09	1.84±0.09	2.0±0.10[#]
FVC (L)	2.21±0.14	2.08±0.12	2.08±0.12	2.29±0.13[#]
FEV$_1$/FVC (%)	89.0±1.23	88.5±1.25	88.5±1.25	88.5±0.91
MVV (L/min)	76.2±3.83	73.5±3.70	73.5±3.70	79.8±4.05[#]

Values are expressed as means ± SE (n = 20 women and 4 men).
Significant difference after exercise (adjusted by its baseline) between groups: [#]$p<0.05$
FEV$_1$: forced expiratory volume in first second; FVC: forced vital capacity; MVV: maximal voluntary ventilation

tory efficiency during graded exercise in obese children[30].

The reductions in hyperglycemia (decreased HbA1c) and oxidative stress (after the ASE) are supported by our previous study[23] in that the hypoglycemic effect of the ASE might be attributed to a reduction in oxidative stress or exercise per se. This may result in decreased nonenzymatic glycosylation of tissue proteins and the formation of advanced glycosylation end products, resulting in microvascular complications[31, 32] in various organ systems including the alveolar-capillary network in the lung[33, 34]. Moreover, it may attenuate reduced pulmonary elastic recoil. Thus, the decrease in HbA1c may have improved the lung function of the subjects after the ASE training in this study.

It is known that normal lung mechanics and gas exchange are affected by the integrity of pulmonary connective tissue and microvasculature. Abnormalities in either of these two structural components of the lung may result in the development of pulmonary dysfunction[34]. In a previous report, it was reported that a 10% decrease in FEV$_1$ was related to a 12% increase in all-cause mortality[8]. The measured airflow limitation is expected to increase all-cause mortality in patients with diabetes. Rigorous blood management may reduce the risk of death through improved ventilatory function independent of other beneficial effects.

The ASE decreased obesity and increased the dynamic lung volumes. The fact that a reduction in body fat or obesity improved the pulmonary functions after the ASE training in this study is consistent with many previous studies investigating low-intensity exercise training in patients with diabetes[24], patients with metabolic syndrome[20], and obese subjects[35]. Moreover, Miyatake, et al.[36] reported that reduction of body fat by low-intensity exercise in obesity leads to increased lung elasticity, which is reflected in improvements in FEV$_1$, FVC, and MVV. The presence of extensive microvascular circulation and abundant connective tissue in the lungs raises the possibility that lung tissue may be

affected by a microangiopathy process and nonenzymatic glycosylation of tissue proteins.

The decrease in body fat in this study may be due to increased fat oxidation during the exercise. Although we did not measure fat oxidation during the exercise, previous studies support this finding[25, 37]. Van Aggel-Leijssen, et al. (2002) demonstrated that low-intensity exercise contributed to increased fat oxidation during exercise in obese subjects. Our previous study showed that fat was mostly used as an energy source during low-intensity exercise compared with higher-intensity exercise in young lean Thai individuals[25]. The reason for this result could be due to a lower rate of glycolysis resulting in lower malonyl CoA production from a low level of muscle contraction during low-intensity exercise. Malonyl CoA inhibits carnitine palmitoyl transferase (CPT), which carries free fatty acid into mitochondria for fat oxidation[38]. Therefore, with a lower level of malonyl CoA, more fat is taken up and oxidized during the exercise. However, we did not measure the amount of fat oxidation or the fat source that was used during the exercise. Instead, we used lipid profiles from routine clinical investigation to indicate the source of fat in the blood stream during rest in this study, and it was found that it was unchanged by the ASE. Free fatty acids from either adipocytes or intramuscular triglycerides may be the source of fat involved in the increased fat oxidation during exercise in this study. Thus, further research investigating fat oxidation and the fat source during the ASE needs to be performed.

In summary, the present results indicate that the ASE can be an alternative mode of exercise to reduce pulmonary function impairment of T2DM patients, especially pulmonary function impairment. This reduction of pulmonary function impairment as a result of the ASE may be due to the improvement of hyperglycemia and fat metabolism and the decrease in percent body fat.

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