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ORIGINAL ARTICLE

Blood glucose response to aerobic exercise training program among patients with type 2 diabetes mellitus at the University of Nigeria Teaching Hospital, Enugu South-East, Nigeria

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Abstract Control of all types of diabetes involves maintaining normal or near-normal blood glucose levels through the appropriate therapy: insulin, oral hypoglycemic agents, diet, and exercise. The aim of this study was to investigate the blood glucose response to aerobic exercise training among subjects with type 2 diabetes mellitus at University of Nigeria Teaching Hospital (UNTH), Enugu. Age-matched randomized controlled trial design was used; subjects with diagnosis of type 2 diabetes mellitus attending the diabetes clinic of the UNTH participated in the study. Fifty-four subjects (N=54) with type 2 diabetes mellitus (fasting blood sugar (FBS) of between 110 and 225 mg/dl) were age-matched and randomized into two groups: exercise (n=30) and control (n=24) groups. The exercise group was involved in an 8-week continuous training (60–79 % heart rate (HR) max) of between 45 and 60 min, three times per week, while the control group remained sedentary. Systolic blood pressure (SBP), diastolic blood pressure (DBP), VO_2 max, and FBS were assessed. Analysis of co-variance and Pearson correlation tests were used in data analysis. Findings of the study revealed significant effect of exercise training program on SBP, DBP, FBS, and VO_2 max. Changes in VO_2 max significantly and negatively correlated with changes in FBS ($r=-.220$) at $p<0.05$. It was concluded that aerobic exercise program is an effective adjunct therapy in controlling blood glucose level among type 2 diabetic subjects.

Keywords Type 2 diabetes mellitus · Blood glucose · Aerobic exercise

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Introduction

The etiology of type 2 diabetes mellitus (T2DM) is unknown, but several studies indicate that the disease results from a combination of genetic susceptibility and external risk factors [1, 2]. According to this multifactorial model, genetically predisposed subjects will not necessarily develop overt disease unless they are also exposed to particular environmental factors [1, 3]. Important risk factors for the development of type 2 diabetes mellitus, apart from obesity, include a family history of diabetes, increased age, hypertension, lack of physical exercise, and ethnic background [1, 2].

It has been reported that diabetes mellitus occurs throughout the world but is more common (especially type 2) in the more developed countries. The greatest increase in prevalence is, however, expected to occur in Asia and Africa, where most patients will probably be found by 2030. The increase in incidence of diabetes in developing countries follows the trend of urbanization and lifestyle changes, perhaps most importantly a "Western-style" diet. This has suggested an environmental (i.e., dietary) effect, but there is little understanding of the mechanism(s) at present, although there is much speculation, some of it most compellingly presented [4]. Treatment of diabetes includes a combination of exercise, proper diet, medication, and daily self-care [5]. Aerobic exercise has consistently been shown to improve glucose control, enhance insulin sensitivity, and improve cardiovascular risk factors such as visceral adiposity, lipid profile, arterial stiffness, and endothelial function [6].

Consistent with all the evidences on the benefits of aerobic exercise, the American Diabetes Association (ADA) recommends that individuals with type 2 DM (T2DM) perform at least 150 min of moderate-intensity aerobic exercise and/or at least 90 min of vigorous aerobic exercise per week [7]. Although, a lifestyle modification of exercise training could have substantial impact on the metabolic and cardiovascular health of this population, it is often difficult for those who have been habitually sedentary to adhere to these guidelines [6].

Most of these studies investigating diabetes and associated factors are conducted using white, Caucasian and other non-pure black African subjects. However, studies [2, 8–10] have shown interracial, interpersonal, and ethnic variation in susceptibility of T2DM. It has also been reported that genetics plays a major role in a person's VO_2 max and that heredity accounts for up to 25–50 % of the variance seen between individuals [11]. It is also unclear whether genetic and associated factors could affect response to exercise in T2DM subjects of pure black (Nigeria) African origin. Therefore, the purpose of the present study was to investigate the effect of continuous training program on blood pressure and fasting blood sugar (FBS) of pure black African subjects with T2DM.

Materials and methods

Subjects

The subjects are composed of 54 (27 male and 27 female) adults with diagnosis of type 2 diabetes mellitus who were attending at the diabetes clinic of University of Nigeria Teaching Hospital (UNTH), Enugu. Their age ranged between 40 and 55 years. Subjects were fully informed about the experimental procedures, risk, and protocol, after which they gave their informed consent in accordance with the American College of Sports Medicine guidelines (ACSM) [12], regarding the use of human subjects as recommended by the human subject protocol. Ethical approval was granted by the Research and Ethics Committee of the UNTH, Enugu.

Research design

In the present study, age-matched randomized independent groups design was used to determine the influence of the continuous training program on cardiovascular parameters and FBS. All procedures were conducted at the Medical Rehabilitation Department of University of Nigeria, Enugu Campus (UNEC), Enugu, Nigeria. Subjects' ages were arranged in ascending order (50 to 70 years) and then assigned to exercise and control groups in an alternating pattern (age-matched randomized). The exercise group engaged in a continuous training program for 8 weeks, while the control group remained sedentary during the period. At the end of the training and sedentary period, a post-test procedure was administered to all subjects.

Inclusion criteria

Only those who volunteered to participate in the study were recruited; they were all stable, without any cardiac complications. Their blood pressure (BP, <140/90) was within normal range. Only those treated with or on diet and/or oral agents were recruited. They were sedentary and have no history of psychiatry or psychological disorders or abnormalities.

Exclusion criteria

Obese or underweight (BMI below 20 or above 30 kg/m^2), smokers, alcoholic; those with uncontrolled hyperglycemia (>250 mg/dl) and hypertension (Resting BP > 200/115), and other cardiac, renal, and respiratory diseases; and subjects on insulin therapy were excluded. Those involved in vigorous physical activities and above averagely physically fit were also excluded.

A total of 61 type 2 DM subjects satisfied the necessary study criteria. Subjects were aged-matched and randomly grouped into experimental (31) and control (30) groups.

Diet and drug characteristics of the subjects

All subjects were on oral hypoglycemic (sulfonylureas) agents (tolbutamide, tolazamide, acetohexamide, and chlorpropamide) in various dosages. Dietary advice was a well-balanced nutritious (diabetes exchange diet) diet that provides approximately 50–60 % of calories from carbohydrates (low glycemic index), approximately 10–20 % of calories from protein, and less than 30 % of calories from fat.

Pre-training procedure

Physiological measurement Subjects' resting heart rate (HR), Systolic blood pressure (SBP), and diastolic blood pressure (DBP) were monitored from the right arm as described by Musa et al. [13] using an automated digital electronic BP monitor (Omron digital BP monitor, Model 11 EM 403c, Tokyo Japan).

Anthropometric measurement Subjects' physical characteristic (weight (kg) and height (m)) and body composition (body mass index (BMI, kg/m2)) assessment was done in accordance with standardized anthropometric protocol [14].

Blood sample collection (venipuncture method) Both pre- and post-treatment venous blood samples were obtained between 8:00 am and 10:00 pm after about a 12-h overnight fast (fasting blood sample). Five-milliliter syringes were used for blood sample collection. About 5 ml of blood was drawn from the antecubital vein of each subject under strict antiseptic condition. Blood samples were allowed to coagulate (clot) at room temperature for 1 h and centrifuged for serum. Serum samples were transferred into plastic containers (vials), sealed, and labeled. All samples were stored in a refrigerator at −80 °C until analysis.

Fasting plasma blood glucose Subject's pre- and post-training fasting plasma glucose level was measured using the Accucheck glucometer before the exercise training and after the 8-week exercise training under the supervision of a medical laboratory scientist from the Medical Laboratory Science Department of UNTH, Enugu.

Stress test The Young Men Christian Association (YMCA) sub-maximal cycle ergometry test protocol was used to assess subjects' aerobic power as described by ACSM [15], Golding et al. [16]. The YMCA protocol uses two to four 3-min stages of continuous exercise. Two HR power output data points were needed (two steady state HR) of between 110 and 150 beats/min. The bicycle seat height was adjusted and the subjects' knee slightly flexed when the pedal was in the down position. Exercise test started with a 2- to 3-min warm-up at zero resistance in order to acquaint the subjects with the cycle ergometer. According to Brook et al. [17] and Pollock and Wilmore [18], middle aged, less fit, cardiac patients generally begin at 100 or 150 to 300 kg·m min^{-1} (17 or 25 to 50 W, respectively) with power increments of 5–25 W per stage.

The first 3-min work rate was set between 100 and 150 kg·m (17–25 W) (1 W=6 kg·m min^{-1}). The pedal speed was set at 50 rpm (revolutions per minute) by setting the metronome at 100 bpm (beats per minute); HR was measured within the last minute of each stage. When an HR of above 110 bpm was obtained in the first 3 min, then only one additional 3-min stage was performed by increasing the workload by either 30 or 150 kg·m. If the second-stage HR was less than 110 bpm, then third- or fourth-stage 3 min was performed at additional workload of 30 or 150 kg·m up to 300 kg·m in order to obtain two HRs between 110 and 150 bpm. These two HR should not differ by more than 5 bpm; when they did, the test was extended by another minute or until a stable value was obtained. At the end of the test, another 2- to 3-min recovery period (cool down) at zero resistance pedaling was administered.

The two steady state HRs were plotted against the respective workload on the YMCA graph sheet. A straight line was drawn through the two points and extended to the subjects' predicted maximum HR (220-Age). The point at which the diagonal line intersects the horizontal (predicted HR max) line represents the maximal working capacity for the subject (HR max). A perpendicular line was dropped from this point to the baseline where the maximal physical workload capacity was read in kg·m min^{-1}, which was used to predict the subjects' VO_2 max. This procedure was done for both pre- and post-test stress test [19].

Training procedure

Exercise group (group 1) After a 10-min warm-up (pedaling at zero resistance), subjects in the exercise group exercised on a bicycle ergometer at a moderate intensity of between 60 and 79 % of their HR max [19, 20]. The starting workload was 100 kg·m (17 W) which was increased at a pedal speed of 50 rpm to obtain a HR max 60 % was increased in the first 2 weeks to and level up at 79 % HR max throughout the remaining part of the training period. The initial of exercise session was increased from 45 min in the first 2 weeks of training to, and leveled up at, 60 min throughout the remaining part of the training. After each training session, 10-min cool-down was established by pedaling at zero resistance. Exercise session of three times per week was also maintained throughout the 8-week training period.

The control group (group 2) Subjects in the control group were instructed not to undertake any organized/structured physical activity apart from the activity of daily living during the 8-week period of study.

Post-training procedure

Post-training SBP, DBP, VO_2 max, stress test, and FBS were measured as earlier described in the pre-test procedures using standardized protocols, techniques, and methods. All pre- and post-test measurements were recorded on a data sheet.

Fifty-four subjects (30 from continuous, and 24 from control group) completed the 8-week training program. Seven subjects (one from exercise, and six from control group) had dropped out because of non-compliance and incomplete data; therefore, the data of 54 subjects were used in the statistical analysis (Fig. 1).

Statistical analysis Following data collection, the measured variables were statistically analyzed. The descriptive statistics (means and standard deviations) of the subjects' physical characteristics, blood pressure, VO_2 max, and FBS were

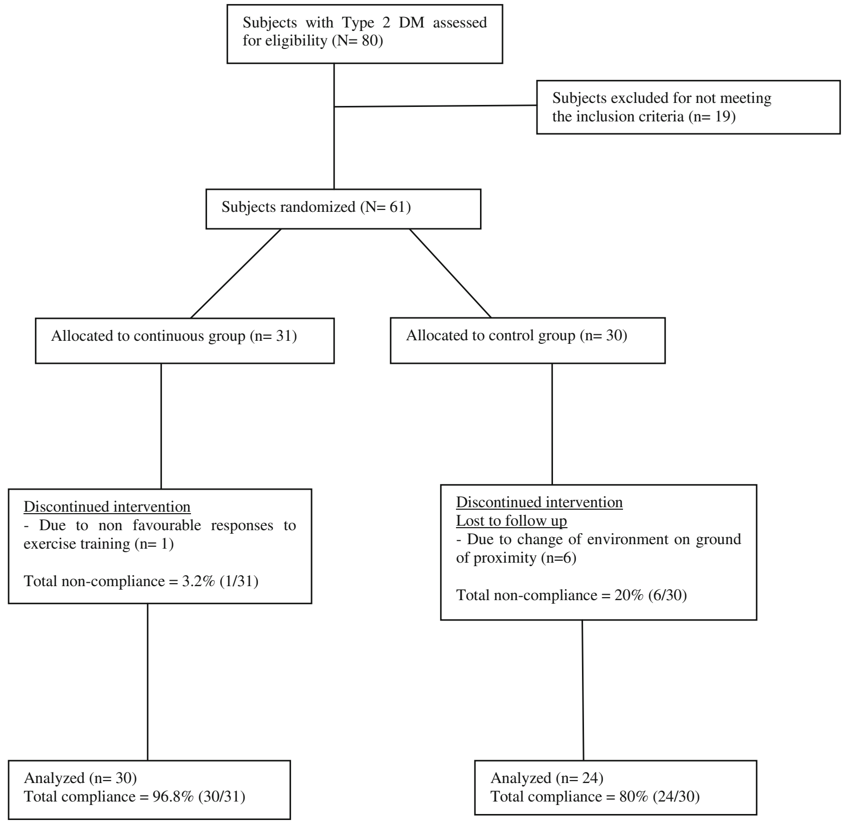

Fig. 1 Study design flow chart

determined. Analysis of covariance (ANCOVA) was used to assess treatment outcomes. In the ANCOVA, the post-test values were the outcome variables and baseline characteristics were as covariates. Pearson product moment correlation test was used to determine the relationship between the estimated changes in VO_2 max (changed score) and FBS. All statistical analyses were performed using the statistical package for the social science (SPSS, version 16.0, Chicago, IL, USA). The probability level for all the above tests was set at 0.05 to indicate significance.

Results

The subject's mean±SD was 47.35±4.55; age ranged between 40 and 55 years. Mean (SD) age and body mass index (BMI) of subjects in exercise group were (47.53 (4.68) years, and 22.48 (2.89) kg m^{-2}), respectively, while for the control group, mean (SD) age was 47.13 (4.48) years and 23.37 (5.31) kg m^{-2}, respectively. Detailed physical characteristics' of subjects are depicted in Table 1.

ANCOVA tests and groups' pre- and post-treatment mean BP (SD; mmHg), FBS (mg/dl), and VO_2 max (ml kg^{-1} min^{-1}) are depicted in Table 2. ANCOVA analysis indicated significant difference in groups' pre- and post-treatment SBP (F=31.377, p=.000), DBP (F=9.004, p=.007), FBS (F=26.597, p=.000), and VO_2 max (F=6.643, p=.013).

There was a significant negative correlation between changes in VO_2 max and changes in FBS (r=−0.252) at p<0.01 (Fig. 2).

Discussion

Findings from the present study revealed a significant decrease in SBP, DBP, and FBS and increase in VO_2 max in the exercise group over control group. Also, the result of the present study indicated a significant negative correlation between changes in VO_2 max and changes in FBS. The

Table 1 Group mean±SD values for baseline and physical characteristics (N=54)

Variables	Exercise group X±SD	Control group X±SD
Age (years)	47.53±4.48	47.13±4.48
BMI (kg/m2)	22.48±2.89	23.37±5.31
SBP (mmHg)	126.37±6.85	115.46±8.82
DBP (mmHg)	79.80±5.97	76.76±5.97
FBS (mg/dl)	192.37±32.65	190.54±35.24
VO_2 max (ml/kg/min)	21.85±12.84	21.45±6.28

Table 2 ANCOVA test and group mean±SD for pre-training and post-training values (N=54)

Variables	Exercise pre-training X±SD	Exercise post-training X±SD	Control pre-training X±SD	Control post-training X±SD	p-values
SBP (mmHg)	170.45±15.57	157.82±23.91	160.87±13.23	163.47±14.88	0.000*
DBP (mmHg)	97.56±7.53	94.83±7.21	97.17±1.43	96.10±2.61	0.007*
VO_2 max (ml/kg/min)	20.69±12.49	28.68±13.60	21.23±5.76	22.82±7.44	0.013*
FBS (mg/dl)	192.27±32.65	160.30±29.95	190.58±35.24	193.50±34.45	0.000*

The asterisk means that the p values less than 0.05 were considered significant ($p < 0.05$).

favorable changes resulting from aerobic training in both SBP and DBP demonstrated in the present study are consistent with those of several other studies [20–23].

A similar study was conducted by Kadoglou et al. [24] in 2007. They investigated the effect of aerobic exercise training on glucose control in diabetes mellitus. A total of 60 overweight individuals with type 2 DM, but without vascular complications, were randomly assigned to either a 6-month aerobic exercise training program (four times per week, 45–60 min/session), designated as exercise group, or to the control group. All participants were on an oral antidiabetic regimen. Blood pressure (BP) and glycemic profile were measured at baseline and at the end of the study. They reported that in comparison with baseline and control group, exercise-treated patients improved glucose control and exercise capacity (VO_2 peak) and exhibited decreased insulin resistance and systolic BP considerably (p<0.05). They concluded that aerobic exercise training without significant weight loss improves metabolic profile and exerts anti-inflammatory effects in patients with type 2 DM.

The findings of this study were also supported by the work of Yavari et al. [25] on the effects of aerobic exercise, resistance training, or combined training on glycemic control and cardiovascular risk factors in patients with type 2 diabetes. In their study, 80 type 2 DM participants (37 men, 43 women) were equally randomized into aerobic, resistance, combined training, and control. Exercise training was performed three times per week for 52 weeks. The results showed that all subjects of training groups experienced improvement in post-prandial glucose, blood pressure, VO_2 max, and muscular percentage.

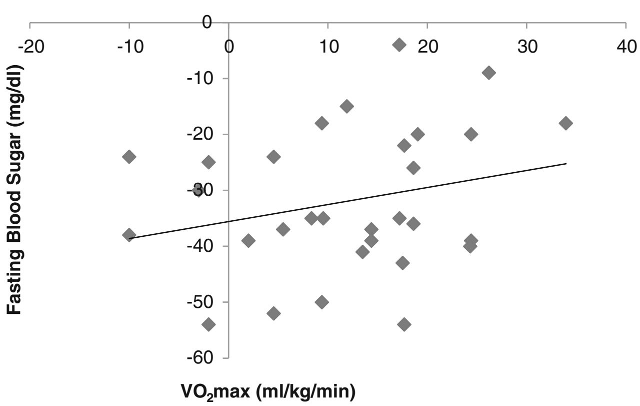

Fig. 2 Correlation between training changes in VO_2 max and FBS (N=30)

The result of this present study on VO_2 max was also supported by the work of Kwon et al. [26] on the effects of aerobic exercise versus resistance training on endothelial function in women with type 2 DM. In their study, 40 overweight women with type 2 DM were assigned into three groups: an aerobic exercise group (AEG, n=13), resistance exercise group (REG, n=12), and control group (CG, n=15), and followed either brisk walking for the AEG or resistance band training for the REG, 60 min per day, 5 days per week for 12 weeks with monitoring daily activity using accelerometers. Aerobic capacity was assessed by oxygen uptake at anaerobic threshold (AT_VO_2) at baseline and following training program. A significant increase in AT_VO_2 was found only in AEG. Although the above studies were in agreement with the findings of the present study, the method used in the assessment of VO_2 max was different from that used in this current study. There will be a need to conduct further studies using a larger sample size and direct assessment procedure among black population.

Another related study was carried out by Gordon et al. [27]. They conducted a prospective randomized study to investigate the efficacy of Hatha yoga and aerobic exercise over control. In their study, 77 subjects with type 2 diabetes in the Hatha yoga exercise group were matched with a similar number of type 2 diabetic patients in the conventional aerobic exercise and control groups. Fasting blood glucose (FBG) was determined at baseline and at two consecutive 3-month intervals. They reported significant reduction in the concentrations of FBG in the Hatha yoga and conventional aerobic exercise groups after 6 months and decreased by 29.48 and 27.43 %, respectively (p<0.0001). They concluded and demonstrated the efficacy of Hatha yoga exercise and conventional aerobic exercises on fasting blood glucose in patients with type 2 diabetes and suggested that Hatha yoga exercise and conventional aerobic exercise may have therapeutic preventative and protective effects on diabetes mellitus.

Boulé et al. [28] in a meta-analysis review investigated the effects of aerobic exercise on glycemic control in T2DM. They selected studies that evaluated the effects of exercise interventions (duration, 8 weeks) in adults with T2DM. Fourteen (11 randomized and 3 non-randomized) controlled trials were included. They concluded that exercise training reduces glycosylated hemoglobin (HbA1c) by an amount that should decrease the risk of diabetic complications compared with control groups. A similar and more recent meta-analysis study was conducted by Umpierre et al. [29]. They reported that supervised exercise training significantly improved glycemic control compared with control groups for aerobic exercise. They concluded that the reductions in glycated hemoglobin were associated with exercise frequency in supervised aerobic training

The mechanism of blood glucose reduction by aerobic training could be linked to three major pathways: the acute stimulation of muscle glucose transport pathway, acute enhancement of insulin action, and long-term upregulation of the insulin signaling pathway resulting from regular exercise training [30–32]. The probable reason for the significant reduction in FBS in the exercise group over the control group might not be unconnected to the fact that aerobic bouts of exercise training may help train the motor units, enhancing the anaerobic and aerobic energy systems. This may lead to more effective utilization of fats and carbohydrates [33].

Conclusion

The present study supports the recommendations of moderate-intensity (continuous) training program as an adjunct non-invasive management of T2DM and dual therapeutic downregulation effects on blood pressure.

Practical application

The present study demonstrated a rationale bases for the adjunct role of long-term moderate-intensity continuous exercise training in the downregulation of blood glucose level. Therefore, exercise specialists and other clinical specialists should feel confident in the use of continuous exercise training in the non-pharmacological adjunct management of T2DM.

Practice (clinical) and research implications

Practice The present study recommended to clinical specialists the use of continuous exercise training in the non-pharmacological adjunct management of T2DM. However, these finding and recommendation are limited to South-East Nigeria and could not be generalized to the entire T2DM population outside this region.

Research While the present study demonstrated a rational basis for the adjunct role of continuous aerobic exercise training in the downregulation of blood glucose, there are limitations, including the following: few participants, single exercise regimen (frequency, intensity, mode, and short duration of 8-week training), and lack of follow-up. All these limitations warrant attention in future study.

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