Changes in clinical and metabolic parameters after exercise therapy in patients with type 2 diabetes

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Abstract

Introduction: The study was carried out to investigate the effect of Hatha yoga and conventional physical training (PT) exercise intervention on clinical and biochemical parameters in patients with type 2 diabetes.
Material and methods: The patient population consisted of 77 type 2 diabetic patients in the Hatha yoga exercise group, matched with the same number of patients in the conventional PT exercise and control groups. The clinical parameters were weekly diastolic and systolic blood pressures, along with body mass index (BMI). Biochemical parameters included weekly blood glucose, serum creatinine, microalbumjinuria and glycosylated haemoglobin (HbA_{1c}) measured at baseline and two consecutive three monthly intervals.
Results: There were significant differences in the blood glucose concentrations "before exercise" and "after exercise" for the Hatha yoga and conventional PT exercise groups at different weekly intervals ($P<0.05$). The frequency of signs and symptoms of hypoglycaemia and hyperglycaemia over the weeks during exercise was greater in the conventional PT exercise than in the Hatha yoga exercise group ($P=0.004$). The HbA_{1c} concentration decreased after six months in the Hatha yoga and conventional PT exercise groups and was significantly different from that of the control group ($P<0.05$). There were significant reductions in systolic and diastolic blood pressures observed before and after exercise for the Hatha yoga and conventional PT exercise groups ($P=0.0001$).
Conclusions: These findings suggest that better glycaemic and blood pressure control can be obtained in type 2 diabetic patients after Hatha yoga and conventional PT exercises.

Key words: yoga, diabetes, exercise, glucose, blood pressure, glycosylated haemoglobin.

Introduction

Diabetes mellitus is a chronic debilitating condition that causes significant morbidity and mortality. Type 2 diabetes mellitus is by far the most common and is increasing rapidly in many populations around

the world primarily because of the increase in obesity and a sedentary lifestyle [1]. Type 2 diabetes mellitus is a heterogeneous disorder, characterized by a genetic predisposition and interaction between insulin resistance and decreased pancreatic β-cell function [2]. Basic therapeutic modalities to achieve euglycaemia in type 2 diabetic patients include diet, exercise, oral agents, and insulin [3]. Physical exercise is perhaps the best therapy for the prevention of diabetes mellitus and the metabolic syndrome. There are a number of studies that have investigated the role of physical activity and exercise in type 2 diabetes. Results by the Diabetes Prevention Program Research Group demonstrated that at least one hundred and fifty minutes per week of moderate physical exercise as part of a lifestyle intervention significantly decreased the progression of type 2 diabetes in patients with pre-existing impaired glucose tolerance [4]. Similar findings were observed in the Finnish Diabetes Program where type 2 diabetes was found to be preventable by changes in the lifestyles of high-risk subjects [1]. A recent meta-analysis suggested that exercise training (i.e. aerobic exercise, resistance training) reduced glycosylated haemoglobin (HbA_{1c}) level in type 2 diabetes mellitus by approximately 0.66%, an amount that would be expected to significantly reduce the risk of diabetic complications [5]. In a two-year randomized controlled trial of 179 individuals with type 2 diabetes, moderate intense physical activity resulted in reduced body weight and fasting HbA_{1c} concentrations [6]. A Chinese trial in individuals with impaired glucose tolerance found that those randomized at the clinic level to a combination of moderate and vigorous activities had a 47% reduction in incidence of type 2 diabetes as compared with the control group [7]. A *post hoc* analysis of the Finnish Diabetes Prevention Study examined the association between walking during follow-up and incidence of type 2 diabetes. After adjustments for other activities, dietary factors, and body mass index (BMI), at least 2.5 hours/week of walking for exercise was associated with a 63% lower risk of type 2 diabetes as compared with less than 1.0 h/week [8].

For individuals with diabetes, aerobic physical activity of moderate intensity has been recommended by the American Diabetes Association [9], American Obesity Association [10], and other organizations. Exercise training that includes aerobic physical activity has resulted in numerous beneficial adaptations in skeletal muscles, including an increase in glucose transporter 4 (GLUT-4) expression. The increase in muscle GLUT-4 in trained individuals contributes to an increase in the responsiveness of muscle glucose uptake to insulin, although not all studies show that exercise training in patients with diabetes mellitus improves overall glucose control [11]. There is evidence that physical exercise stimulates muscle glycogen synthesis, increases insulin sensitivity, reduces blood glucose levels and has other benefits in relationship with the stimulation of the production of β-endorphin [12]. However, research suggested that adherence to physical exercise training is low among patients with type 2 diabetes [13, 14]. The low adherence may be due to factors such as time, venue, transportation, weather, equipment, cost, physical capability, priority, and interest.

Yoga is an alternative form of physical activity which may assist in achieving recommended levels of physical exercise for some individuals. It is a commonly practised, mind-body approach that has components centring on meditation, breathing, and actions or postures. In recent United States surveys of adults, 7.5% reported having used yoga at least once in their lifetime and 3.8-5.1% reported having used it in the previous twelve months [15, 16]. Yoga may be attractive as an alternative to traditional aerobic and strength training programmes because it requires little space, virtually no equipment, and has limited harmful side effects [17]. The efficacy of lifestyle interventions incorporating elements of yoga has been widely seen in cardiovascular disease [18] and diabetes mellitus [19]. Studies have shown that incorporation of yoga therapy in the management of dia-betes mellitus has resulted in dosage reduction of hypoglycaemic agents and insulin [20], weight control, increased glucose tolerance, and reduction in hyperglycaemia [21]. In the study by Jain et al., 70% of the participants exhibited a fairly good response to yoga therapy and after forty days there was significant reduction in hyperglycaemia measured by fasting blood glucose and oral glucose tolerance [22]. Few studies have investigated the outcomes of lifestyle interventions based on yoga and conventional PT exercises for more than three months. This study evaluated the effects of Hatha yoga and conventional PT exercise regimens on weekly blood glucose, and systolic and diastolic blood pressures in patients with type 2 diabetes mellitus. Changes in serum creatinine, micro-albuminuria, HbA_{1c}, BMI at baseline and two consecutive 3-month intervals as a result of interventions of both exercise regimens were evaluated.

Material and methods

Study design

This prospective randomized control study was conducted at the National Institute of Endocrinology and the "Hermanos Ameijeiras" Hospital, Havana, Cuba from September 1998 to February 1999. The patients were selected according to

the CONSORT declaration [23] and included only those with type 2 diabetes who had been trained in diabetes education and instruction, exercise, diet and medication according to the recommendations of the International Diabetes Federation (IDF), for a minimum of 3 months, and who met the following criteria for the study: type 2 diabetes mellitus without malnutrition or severe complications of the disease (cardiovascular, renal, visual and cerebral), 40-70 years old, duration of the disease between 1 and 10 years, good psychological condition (according to the psychologist's consideration), non-smoker and non-alcoholic. The study was approved by the "Hermanos Ameijeiras" Hospital ethics committee and informed consent was obtained from all patients who participated in the study.

The managed groups (Hatha yoga and conventional PT exercise) were trained for 24 weeks in basic exercise techniques, diabetes education and instructions. The yoga class was designated by a certified Hatha yoga instructor and a physician. The programmes were carefully illustrated through workshops and subjects were required to attend one yoga class weekly for twenty-four weeks along with home exercise. None of the subjects in the Hatha yoga group were exposed to yogic practices. Each yoga session consisted of 20 min of pranayamas (breath-control exercises), 25 min of dynamic warm-up exercises, 60 min of asanas (yogic postures), and 15 min of supine relaxation in savasana (corpse pose). Subjects were given a booklet illustrating the specific pose to help with their independent practice [24]. Subjects in the conventional exercise PT exercise group also attended classes and were engaged mainly in aerobic exercise for 2 h. A certified exercise instructor directed the conventional PT exercise intervention arm of the study. The conventional PT exercises consisted of one class per week for 24 weeks along with home exercise. The conventional PT sessions consisted of 15 min of warm-up exercises, 30 min of aerobic walking on an outdoor 400-meter track, 20 min of body flexibility exercises, 20 min of aerobic dance, 25 min of games and 10 min of warm-down exercises. Daily home exercise 3-4 times per week for 1 h in the same Rate of Perceived Exertion was encouraged for subjects in both the Hatha yoga and conventional PT exercise classes. Intensity of exercise was determined by measurement of the pulse rate, and heart rate before, during and after exercises in subjects in the Hatha yoga and conventional PT exercise groups. The heart rate was recorded using a heart rate monitor (PE-3000, Polar Instruments, Finland). Target heart rate was initially estimated as 70% of maximum based on morning resting heart rate and age. Perceived Exertion during and immediately following exercise was done in the Hatha yoga and conventional PT groups by using the modified Borg Rate of Perceived Exertion Scale [25].

A questionnaire with statements as given in Borg's rating scale was used to assess the magnitude of exertion during and immediately after exercise. The Perceived Exertion Scale consisted of statements between 6 and 20 ('no exertion at all' to 'maximum exertion'). Subjects were instructed to exercise at a level of 8-10 on the Perceived Exertion Scale. Each managed group fulfilled a specific weekly programme that included the following: medical and psychological evaluation of patients and instructions on: education, diet, specific treatments, personal care and exercises (conventional PT or Hatha yoga). Subjects were also given a booklet in which they noted dietary compositions, medications taken daily, signs and symptoms, daily blood pressure, weekly glycaemia and information on adherence to home-based exercise programmes. Compliance with the interventions was assessed by having study participants complete daily 1-week log sheets that recorded whether or not they exercised or practiced yoga and for how long. The booklets were reviewed weekly by personnel blinded to the study. Class attendance was also recorded. The control group followed a treatment plan as recommended by their clinics or general physicians and was never seen by the personnel of this study for diabetes management. They were not engaged in any kind of active exercise intervention during the entire study period. All subjects were encouraged to see their attending physician regularly.

A total of 231 subjects were recruited for this prospective randomized study: 77 type 2 diabetic patients in the Hatha yoga exercise group (62 females and 15 males) who were matched with 77 type 2 diabetic patients in the conventional PT exercise group (62 females and 15 males) and another 77 type 2 diabetic patients serving as the control group (62 females and 15 males). All 231 patients completed the study.

Measurement of the weekly variations of clinical and metabolic parameters was used to check the effectiveness of both interventions (Hatha yoga or conventional PT exercise). Baseline assessment of outcome measures and parameters was performed before the subjects were randomized and occurred 1 to 14 days before classes started. On the baseline visit, medical history was reviewed, demographic data were recorded, and blood samples taken for biochemical investigations. Blood was drawn from an antecubital vein at baseline, 3 months and 6 months for biochemical investigations, in post-absorptive state. The blood was drawn between 7:30 am and 9:00 am, without stasis, and the serum was separated within an hour

of collection. On the day of the blood collection, subjects were asked to abstain from Hatha yoga or conventional PT exercises.

Clinical and biochemical analysis

All the laboratory determinations were carried out at the "Hermanos Ameijeiras" Hospital. The personnel of the laboratories were blinded to the study. During the study both groups (Hatha yoga and conventional PT exercises) were required to attend a weekly clinic for six months to monitor blood glucose levels and blood pressure 15 min before and 30 min after exercise. The main reactions of importance were the appearance of signs and symptoms of hypoglycaemia and hyperglycaemia during the test periods. At home, the subjects were asked to note any symptoms of hypoglycaemia or hyperglycaemia in notebooks provided, so that the endocrinologists could help to adjust individual treatment on a weekly basis. Measurements of the weekly variation of clinical and biochemical parameters were used to evaluate the effectiveness of both regimens (conventional PT exercise vs. Hatha yoga exercise) and included: blood glucose before and after exercise, frequency of manifestations of hypoglycaemia or hyperglycaemia during exercises and blood pressure before and after exercise. The changes in parameters measured at baseline, 3 and 6 months were: BMI, fasting blood glucose (FBG), HbA_{1c}, microalbuminuria and creatinine.

The weekly blood glucose concentrations before and after exercise for each group was determined by using Reflolux S type 1172115 glucometers [26] (Boehringer Mannheim, Germany). The method used was based on the glucose-oxidase method [27]. Venous blood was also taken from each patient weekly, at baseline, and at third and sixth months. Glycosylated haemoglobin was determined by the fast ion-exchange resin separation method [28]. Microalbuminuria was determined using the Micral test II [29]. Serum creatinine was quantified by the kinetic method [30]. The body mass index was calculated using the formula: BMI = weight/height^2 (kg/m^2). Standard blood pressure (systolic and diastolic) measurements were done using the auscultatory technique which involves the use of a mercury sphygmomanometer by a trained health professional [31].

Statistical analysis

The data were collected and recorded on questionnaires, and a database was developed in Microsoft Excel 2000. The calculations were carried out with the softwares EPI-INFO Version 6.0 and SPSS Version 10.0 with a level of statistical significance of 95%. The individual variables were evaluated to determine the changes in the three groups (Hatha yoga, conventional PT and control) during the different periods (baseline, third or sixth month). To investigate the effects of a variable within a group the within-subjects factor analysis, and the effects between the groups between-subjects analysis were used according to two-way ANOVA with a 95% confidence interval. Two-way ANOVA was applied to detect differences among groups (Hatha yoga, conventional PT exercise and control) and within groups over the duration of treatment. According to the behaviour of the variables, each table was represented by the mean and the standard error of the mean (SEM). As the three groups were of equal sizes, Tukey's Honestly Significant Difference (Tukey HSD, available in SPSS) was used for *post hoc* comparisons. Differences were considered significant if $P<0.05$.

Results

There were 231 type 2 diabetic patients, 186 (80.5%) females and 45 (19.5%) males. Subjects were matched according to age and sex and the mean ages were very similar in the three groups according to gender (Table I). All 231 patients completed the study by participating in the 6-month assessment. Compliance with home-based exercise in the Hatha yoga and conventional PT groups was in the range of 80-85% and average attendance at classes was 90-95%. In Hatha yoga and conventional PT exercise groups there were significantly decreased blood glucose concentrations "before exercise" and "after exercise" in the Hatha yoga and conventional PT exercise groups over 24 weeks. Significant differences in blood glucose con-centrations "before exercise" and "after exercise" were seen in both managed exercise groups particularly in weeks 1, 2, 4, 5, 7, 8, 9, 10, 17, 19, 20 and 23 ($P=0.0001$, Figures 1 and 2). In week 1 the blood glucose concentrations for "before exercise" and "after exercise" differed by 37.9% in the conventional PT group, and 30.4% in the Hatha yoga group ($P=0.0001$). In week 10 the blood glucose concentrations for "before exercise" and "after exercise" differed by 28.4% in the conventional PT group, and 24.9% in the Hatha yoga group ($P=0.0001$). In week 17 the blood glucose con-centrations for "before exercise" and "after exercise" differed by 22.4% in the Hatha yoga group, and 13.5% in the conventional PT group ($P=0.0001$).

Over the 24 weeks there were always greater accumulative frequencies of signs and symptoms of hypoglycaemia and hyperglycaemia in the conventional PT exercise group compared to the Hatha yoga exercise group (Figure 3). There was a statistically significant difference ($P=0.004$) in the total frequency of crises of hypoglycaemia or hyperglycaemia between both groups with

Table I. Frequency of type 2 diabetic patients according to group, sex and age

Group	Female			Male			Total		
	no.	%	mean age	no.	%	mean age	no.	%	mean age
Conventional	62	80.5	63.5	15	19.5	65.6	77	100.0	63.9
Yoga	62	80.5	63.8	15	19.5	64.7	77	100.0	64.0
Control	62	80.5	63.8	15	19.5	62.5	77	100.0	63.6

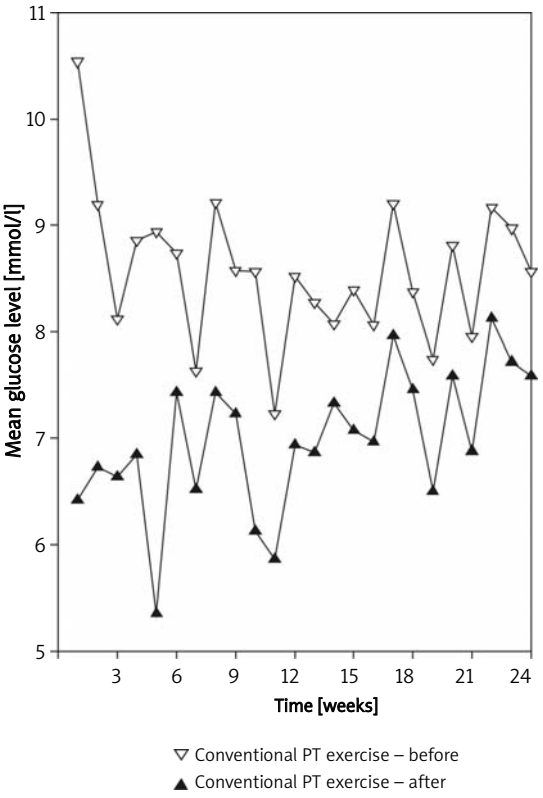

Figure 1. Mean weekly blood glucose concentration in type 2 diabetic patients before and after conventional PT exercise

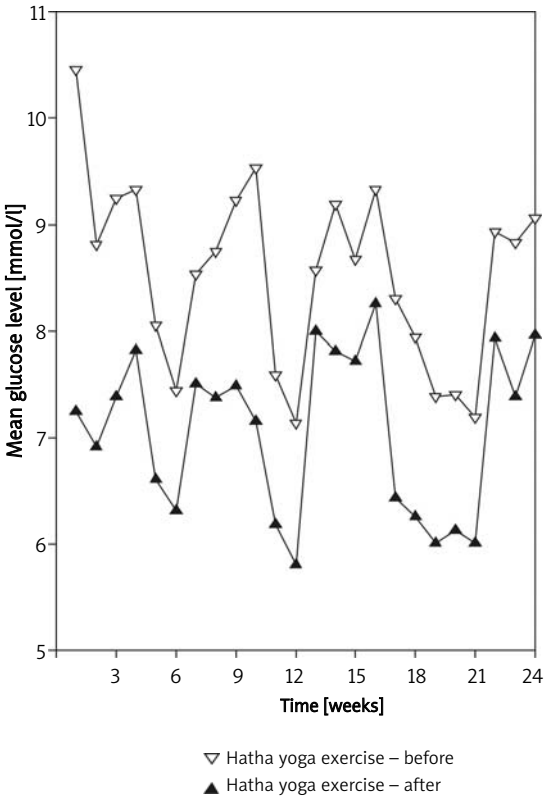

Figure 2. Mean weekly blood glucose concentration in type 2 diabetic patients before and after Hatha yoga exercise

prevalence of 31/77 (40.3%) representing 31 crises in the conventional PT exercise group compared with 16 crises and prevalence of 16/77 (20.8%) in the Hatha yoga exercise group. In the conventional PT exercise group these 31 crises occurred in 22 patients (15 with one crisis, 5 with two crises and 2 with three crises). In the Hatha yoga exercise group 16 crises occurred in 14 patients (10 with one crisis and 2 with two crises).

In the Hatha yoga exercise group the HbA_{1c} concentration decreased by 2.2% after 6 months (P=0.0001) whilst in the conventional PT exercise group the reduction was 0.6% (Table II). In the control group HbA_{1c} concentration increased by 13.1% and there were significant differences between the managed exercise groups and control group (P=0.001). Microalbuminuria in the Hatha yoga and conventional PT exercise groups decreased by 26.3 and 18.2% respectively after 6 months (P=0.0001). There were significant differences in microalbuminuria between the managed exercise groups and control (P=0.012, Table II). The BMI in the Hatha yoga and conventional PT exercise groups decreased by 1.0 and 2.3% respectively whilst in the control group it increased by 3.3% after 6 months. There were significant differences in BMI between the managed exercise groups and control group after 6 months (P=0.0001, Table III). No significant difference was found in the serum creatinine concentration in the managed exercise group after six months (P=0.075) or when compared with the control group (P=0.383, Table III).

The SBP was lower in "after exercise" than in "before exercise" in all weeks in the conventional PT exercise group except in week 19. In the Hatha yoga

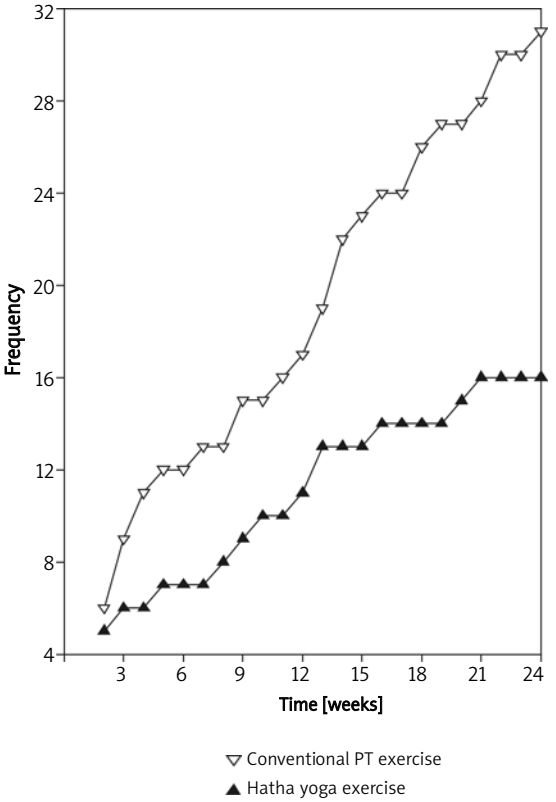

Figure 3. Frequency of signs and symptoms of hypo- and hyperglycaemia during exercise according to week and group

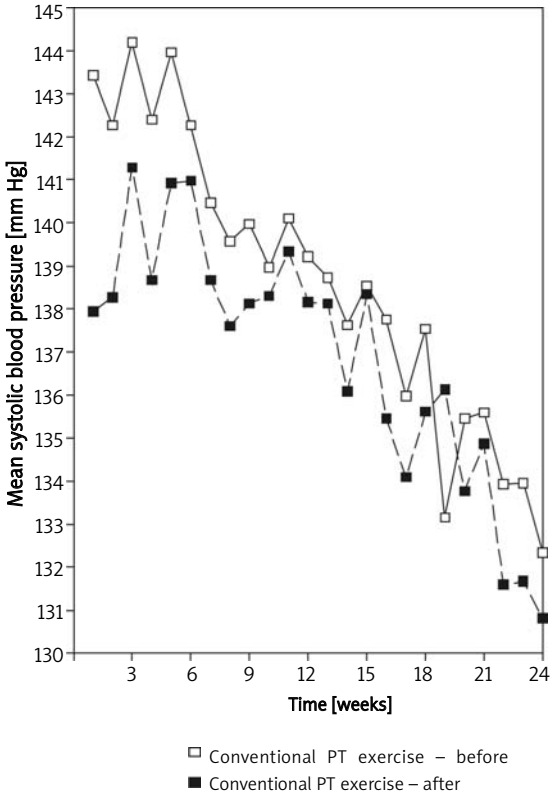

Figure 4. Mean systolic blood pressure in type 2 diabetic patients before and after conventional PT exercise

exercise group SBP was greater "after exercise" than "before exercise" in 6 weeks (12, 13, 14, 19, 20, 21). Significant differences in reduction of SBP "after exercise" compared to "before exercise" in the conventional PT exercise group were observed in 12 weeks (1, 2, 3, 4, 5, 7, 15, 16, 17, 18, 22, 23) and similarly in 12 weeks (1, 2, 3, 4, 5, 6, 9, 16, 17, 18, 23, 24) in the Hatha yoga exercise group (P=0.0001, Figures 4 and 5). In the Hatha yoga and conventional PT exercise groups DBP was greater "after exercise" than "before exercise" in 4 weeks (18, 19, 20, 21) and 3 weeks (8, 9, 11) respectively. Significant differences in reduction of SBP "after exercise" compared to "before exercise" in the Hatha yoga exercise group were observed in 11 weeks (1, 2, 3, 4, 9, 10, 11, 12, 13, 16, 23) and 7 weeks (1, 2, 4, 5, 10, 22, 23) in the Hatha yoga exercise group (P=0.0001, Figures 6 and 7). There were no significant differences in SBP or DBP between both exercise groups (P<0.05).

Table II. Comparison of HbA_{1c} and microalbuminuria in type 2 diabetic patients in conventional PT exercise, Hatha yoga exercise and control groups during a 6-month period

Variable/Group	Baseline	3 Months	6 Months
Glycosylated haemoglobin [%]			
Conventional	6.40±0.15	6.38±0.17*	6.36±0.15*
Yoga	6.36±0.21	6.34±0.19*	6.22±0.22*
Control	6.59±0.17	7.65±0.15	7.45±0.2
Microalbuminuria [g/l]			
Conventional	26.62±2.51	25.35±2.29	21.78±2.38*
Yoga	27.87±2.90	25.84±2.90	20.54±2.56*
Control	26.31±2.63	28.78±2.65	27.09±2.11

*Statistically significant differences are indicated by *P<0.05 vs. control at the third month or at the sixth month*

Table III. Comparison of creatinine and BMI in type 2 diabetic patients in conventional PT exercise, Hatha yoga exercise and control groups during a 6-month period

Variable/Group	Baseline	3 Months	6 Months
Creatinine [mmol/l]			
Conventional	87.09±1.45	87.32±1.54	86.01±1.63
Yoga	89.77±1.70	86.38±1.74	86.06±1.65
Control	89.05±1.83	87.71±1.86	88.32±1.89
BMI [kg/m^2]			
Conventional	27.28±0.39	27.03±0.39	26.65±0.32
Yoga	27.35±0.51	27.12±0.49	27.07±0.40
Control	27.62±0.47	28.36±0.46	28.53±0.39

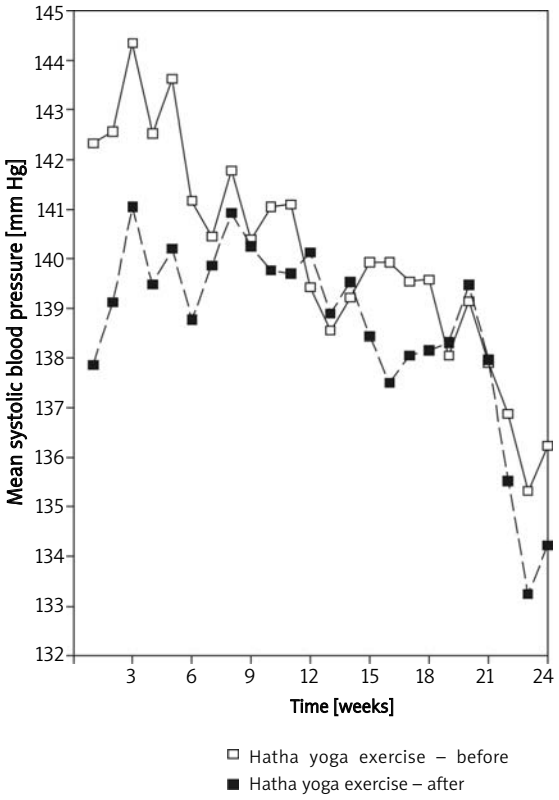

Figure 5. Mean systolic blood pressure in type 2 diabetic patients before and after Hatha yoga exercise

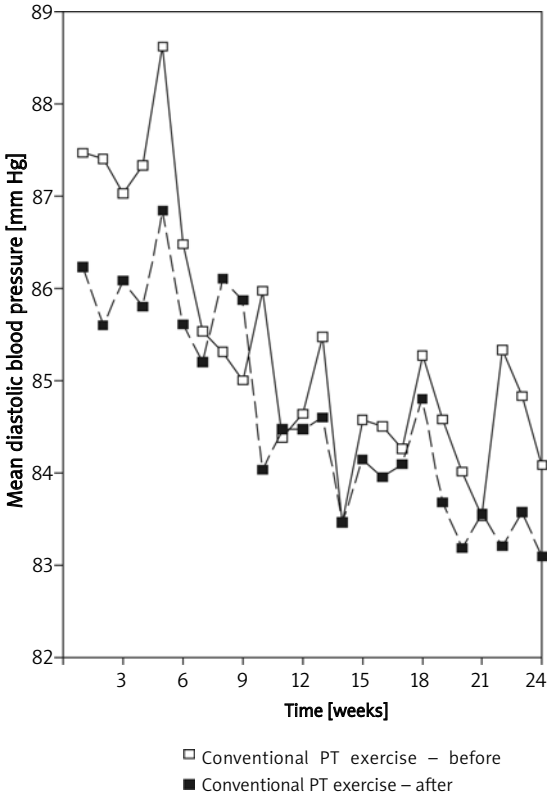

Figure 6. Mean diastolic blood pressure in type 2 diabetic patients before and after conventional PT exercise

Discussion

The present study found that intervention with Hatha yoga and conventional PT exercises improved clinical and biochemical indices in patients with type 2 diabetes mellitus, and confirmed the useful role of both exercise regimens in the control of this disease. Hatha yoga and conventional PT exercises significantly reduced weekly blood glucose, systolic and diastolic blood pressures, HbA_{1c}, and microalbuminuria. However, there was no significant effect on BMI and serum creatinine. The study also found more signs and symptoms of hypoglycaemia and hyperglycaemia in the conventional PT exercise compared with the Hatha yoga exercise group.

Yoga has been shown to be a simple and economical therapeutic modality that may be considered as a beneficial adjuvant for type 2 diabetic patients. The beneficial effects of yoga on glycaemic control are well documented. In this study, Hatha yoga exercise significantly reduced blood glucose concentrations in nearly all weeks of treatment. The favourable changes in glycaemia

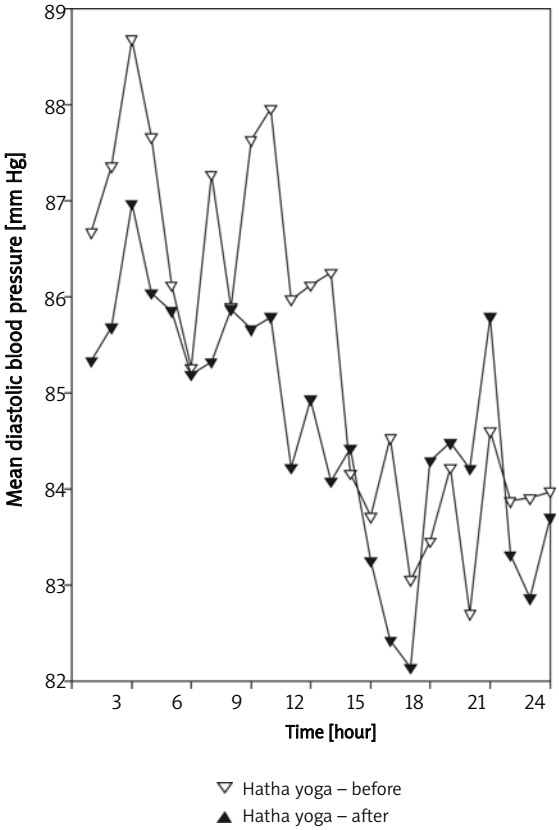

Figure 7. Mean diastolic blood pressure in type 2 diabetic patients before and after Hatha yoga exercise

by Hatha yoga exercise observed in this study are similar to findings by an earlier study where yoga asanas caused a reduction in fasting and postprandial blood glucose in patients with diabetes mellitus [32]. Sahay et al. [33] reported significant reduction in fasting and postprandial blood glucose concentrations within three months of yoga exercise in type 2 diabetic patients. In a similar group of patients, Mercuri et al. [34] found significantly decreased glycaemia after three months of yoga exercise. Adults with normal blood glucose also had significantly lower blood glucose concentrations after 3-4 h of yoga practice for eight days [35]. The results of this study and others indicate the positive effect of yoga exercise on glycaemia control and suggest that such would be beneficial for the treatment of diabetes mellitus.

The reductions in blood glucose concentrations denote the capacity of Hatha yoga exercise or conventional PT exercise to attenuate the metabolic changes in type 2 diabetes mellitus. The mechanism of the anti-glycaemic activity of yoga exercise has yet to be clearly elucidated. In a recent study by Sahay, yoga asanas caused a significant decrease in fasting and postprandial blood glucose. There was a shift of the peak level of insulin to the left and there was a normalization of the insulin/glucose ratio with a reduction in the free fatty acid levels, suggesting a better peripheral utilization of insulin [36]. The beneficial effect of yoga asanas on the insulin kinetics and the lipid metabolism prevents the exhaustion of the β-cell and the development of a β-cell secretory defect, thereby preventing the development of type 2 diabetes mellitus [37]. Manjunatha et al. performed a similar study in healthy volunteers and reported that serum insulin levels after yoga asanas were lower than before. In addition, serum insulin levels were higher after post-asana oral 75 g glucose challenge [38]. The observations suggested that the performance of yoga asanas led to an increase in insulin sensitivity of β-cells of the pancreas to the glucose signal, which could explain the mechanism by which yoga asanas have a beneficial effect of lowering blood glucose in diabetes mellitus [37].

The reduction in weekly blood glucose during the practice of Hatha yoga exercise demonstrates that it may have a positive impact on the progress of type 2 diabetes mellitus. It was observed that blood glucose levels were maintained within the normal ranges during Hatha yoga exercise, thereby reducing the occurrence of hyperglycaemia as well as hypoglycaemia, the most important complications seen during physical training exercises in patients with type 2 diabetes. There was lower frequency of signs and symptoms of hypoglycaemia and hyperglycaemia, which implies that Hatha yoga exercise has many important benefits for patients with type 2 diabetes. This study confirmed the results of other authors [39, 40] who have shown that yoga postures and breathing exercises have physiological and metabolic influences that can help diabetic subjects to prevent hypoglycaemia and hyperglycaemic crises. In another study that involved a group of diabetics who practiced yoga regularly, there was a significant reduction in the frequency of hyperglycaemia and area index total under the oral glucose tolerance test curve. This experimental study showed that there was also a decrease in the need for oral hypoglycaemics to maintain adequate blood glucose control in the population that practised yoga [20].

The most common potential complication due to conventional PT exercise observed in this study was hypoglycaemia. A study by Guiagnano et al. demonstrated that unexpected physical exertions may represent a cause of mild hypoglycaemia in type 2 diabetic patients receiving oral anti-diabetic therapy [41]. Conventional PT exercises caused more crises of hypoglycaemia or hyperglycaemia than Hatha yoga exercises, and this can have negative consequences for type 2 diabetic patients. There are differences between Hatha yoga and conventional PT exercises, as Hatha yoga exercises mainly affect the parasympathetic nervous system

and the subcortical regions of the brain, while in conventional PT exercises the sympathetic nervous system dominates with its effects on the cortical regions of the brain [42, 43]. There are studies that have found that strenuous physical exercise leads to an increase in metabolic rate, increased production of reactive oxygen species, and compromised antioxidant defence systems [44]. A study of 31 male subjects who participated in a 6-month, 5 days/week training schedule involving two extreme marches of 50 and 80 km at sea level, separated by 2 weeks of regular training, showed that protein carbonyl content, a marker of protein oxidative damage, decreases significantly during each march [45]. Serum malondialdehyde, a marker of lipid peroxidation, was found to be elevated in runners following an 80 km race [46], and Nies et al. demonstrated the occurrence of damage to DNA in the circulating leukocytes after exhaustive exercise on a treadmill [47].

Glycosylated haemoglobin has become the internationally established method of assessing long-term glycaemic control in diabetics [48]. The rate of synthesis of HbA_{1c} is a function of the exposure of the red blood cell to glucose [49]. The ability of Hatha yoga and conventional PT exercises to favourably modify the level of blood glucose was confirmed by the significant reduction over 6 months of treatment with both exercise regimens in HbA_{1c}. The levels of HbA_{1c} were reduced at the third and sixth months during conventional PT and Hatha yoga exercises, demonstrating an improvement in glycaemic control in the patients studied. In a controlled trial on 21 subjects with type 2 diabetes, fasting blood glucose and HbA_{1c} were reduced significantly in the group of 11 with type 2 diabetes mellitus who practised an integral programme of yoga compared to a matched group of 10 who did not practice yoga [50]. In a recent study of 30 type 2 diabetic patients who underwent a yoga programme comprising various asanas and pranayamas along with the anti-diabetic therapy, there was a significant reduction in HbA_{1c} [51].

The BMI was slightly non-significantly decreased in type 2 diabetic patients in the conventional PT group. The results of this study are similar to those of Boule et al., who found that exercise training reduces HbA_{1c} by an amount that should decrease the risk of diabetic complications, but no significantly greater change in body mass was found when exercise groups were compared with control groups [52]. The effect of physical activity and exercise on BMI is well documented and studies have shown that physical activity is known to decrease the risk of type 2 diabetes [53, 54]. Although physical activity has multiple beneficial effects that can improve insulin and glucose delivery to muscle [55], it may not fully abolish the adverse effects of obesity [56]. Obesity is known to increase peripheral insulin resistance and reduce β-cell sensitivity to glucose [57]. Production of adipokines from adipocytes is known to influence insulin sensitivity and type 2 diabetes [58]. Decreased weight and thus BMI may therefore be a key mechanism to reduce the secretion of these factors by decreasing adipose tissue volume and subsequently reducing the risk of diabetes [59, 60].

Microalbuminuria is an important intermediary end-point that correlates strongly with future advanced renal disease and cardiovascular mortality [61]. It is considered as a putative marker of endothelial dysfunction [62]. It is not only a clinical predictor of increased diabetic nephropathy in patients with diabetes [63], but has been significantly associated with increased risk of coro-nary heart disease in type 2 diabetes [64] and as a risk factor in cardiovascular mortality [65]. The levels of microalbuminuria were reduced over a period of 6 months of Hatha yoga and conventional PT exercises. This suggests that these exercise regimens may provide a protective function in the endothelium in type 2 diabetic patients, reducing the risks of diabetic nephropathy and coronary artery disease. Creatinine constitutes an indicator of renal function and intensity of physical exercise, and could be used to evaluate the evolution of the disease [66]. The reduction in the concentration of serum creatinine though not significant indicates the positive effect of Hatha yoga on renal function.

Although regular aerobic exercise can have a beneficial effect on high blood pressure, this effect is significantly inferior to that produced by pharmacotherapy. It has been very convincingly demonstrated in a randomized controlled study that even a short period (11 weeks) of regular yogic practice at 1 h/day is as effective as medical therapy in controlling blood pressure in hyper-tensive subjects [67]. Other studies have shown that yoga practice also significantly improved blood pressure among people with hypertension [68], cardiovascular disease [69] or type 2 diabetes [70]. These studies have found ample evidence that Hatha yoga and conventional PT exercises demonstrated the capacity to improve systemic arterial blood pressure in type 2 diabetes as there were significant reductions in systolic and diastolic blood pressures during the 6 months of inter-vention. In an open study comprising 23 hyper-tensive patients, Sachdeva et al. observed significant reduction in systolic and diastolic blood pressures after two months of yogic lifestyle change [71]. The mechanism of yoga-induced blood pressure reduction may be attributed to its beneficial effects on autonomic neurological function. Impaired baroreflex sensitivity has been increasingly postulated to be one of the major causative factors

of essential hypertension [72]. Practice of yogic postures has been shown to restore baroreflex sensitivity. Yogic practice, through the restoration of baroreceptor sensitivity, caused a significant reduction in the blood pressure of pa-tients who participated in yoga exercise [73].

In conclusion, it is evident that Hatha yoga and conventional PT exercises have a positive influence on weekly blood glucose concentrations, weekly systolic and diastolic blood pressures, HbA_{1c} and microalbuminuria. The diminished levels of weekly blood glucose observed after intervention based on both exercise regimens suggest that they can be used as part of a therapeutic strategy to control clinico-metabolic state in individuals with type 2 diabetes.

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