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Influence of combined exercise training on indices of obesity, diabetes and cardiovascular risk in type 2 diabetes patients

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Objective: To investigate the influence of combined exercise training on indices of obesity, diabetes and cardiovascular risk in type 2 diabetes patients.
Design: A double-blind randomized controlled trial with patients receiving either combination (COM), endurance (END) or no training (C).
Setting: Sint-Jozef hospital (Belgium), general practice (Holland).
Subjects: Forty-six type 2 diabetes patients (17 female, 29 male).
Interventions: COM versus END and C. Patients exercised for three months, three times a week for 1 hour.
Main measures: Six-minute walk test (6MWT), peak Vo_2, strength in upper and lower limbs, sit-to-stand, height, weight, body mass index, fat mass, glycosylated haemoglobin (HbA1c), glycaemia, triglycerides, high-density lipoprotein (HDL), total cholesterol and quality of life (General Health Survey Short Form (SF-36)).
Results: COM had significant better results on sit-to-stand ($P<0.05$), 6MWT ($P<0.01$), strength in upper ($P<0.001$) and lower limbs ($P<0.001$) compared with C. A different evolution among COM and C was found for HbA1c ($P<0.05$) and cholesterol ($P<0.01$), both decreased in COM and increased in C. HDL increased in COM and decreased in C ($P<0.01$). END had significant higher results on the 6MWT ($P<0.01$) compared with C. Compared with END, COM had significantly higher results on strength in upper ($P<0.01$) and lower limbs ($P<0.01$). The evolution of SF-36 items was not significantly different between the three groups.
Conclusion: In diabetes type 2 patients, COM had significant better effects on indices of physical condition, diabetes and cardiovascular risk compared with C. Compared with END, COM gave a tendency towards better results, however more research with a larger number of participants is needed.

Introduction

Chronic hyperglycaemia is strongly associated with long-term complications, such as cardiomyopathy, micro- and macroangiopathies and neuropathy.[1] It thus has an important influence on general morbidity and mortality. Abdominal

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obesity is one of the most important predisposing factors in the development of insulin resistance, hyperinsulinaemia, hyperglycaemia, dyslipidaemia and arterial hypertension.[2,3] Together with specific medication, a well-balanced diet and physical exercise are keystones in diabetes therapy.[4]

Several studies have investigated the effect of exercise in type 2 diabetes patients. The majority of these studies have used aerobic (endurance) exercises in the training protocol. These studies showed significant reductions in indices of obesity (reduction in body mass index (BMI), total fat mass, sum of skin fold measurements, waist and/or waist-to-hip ratio),[5–8] improved cardiovascular risk profile (increase of high-density lipoprotein/low-density lipoprotein (HDL/LDL) ratio, normalization of lipid profile and a main reduction of systolic and diastolic arterial blood pressure),[9] increase of the (sub)maximal aerobic exercise capacity,[7,9] a significant decrease of glycaemia[7] and status quo[9,10] or significant increase of insulin sensitivity, insulin secretion and/or glycosylated haemoglobin (HbA1c) concentration.[5,11–15]

Besides endurance training, segmental strength training of the major muscle groups is used in the management of type 2 diabetes. This kind of training results in an improvement of the indices of obesity, cardiovascular risk profile and insulin sensitivity and self-reported glycaemia and/or HbA1c concentration.[14–19] Moreover, strength training induces a conservation or even an increase in the fat-free mass in combination with an increased muscle strength in the trained muscle groups.[16,20–22] As a result, the ACSM (American College of Sports Medicine) has recommended strength training as part of the exercise programme in an elderly population or in patients with a poor physical condition with a tendency towards sarcopenia, low functionality, increased adiposity and insulin resistance.[13] Moreover, strength training is in some cases more feasible in type 2 diabetes patients.[13]

Recently some studies have described the effects of a combined endurance and strength training. These studies show a positive effect of combination training on body composition (BMI, fat mass, waist or waist to hip),[23–26] a decrease of cardiovascular risk,[23,24,27] an improvement of strength, muscle endurance and exercise capacity and an increase or status quo of insulin sensitivity, glucose tolerance, glycaemia and HbA1c concentration.[23–27]

To our knowledge, only one study[28] compared combined exercise with endurance training. Combined training seemed to be most effective in improving insulin sensitivity and these improvements were associated with changes in muscle characteristics caused by strength training. In this study muscle characteristics were expressed as the cross-sectional area of muscle and were separated into the cross-sectional areas of low-density muscle or normal-density muscle. In contrast to our study, only postmenopausal women with diabetes type 2 were included. Moreover, HDL was not measured in these women. The effects of different modes of exercise training on measures of glucose control and other risk factors for complication of diabetes were also meta-analysed by Snowling and Hopkins.[29] The results showed that all forms of exercise training that were examined produce small benefits in HbA1c, and that combined training was generally superior to aerobic and resistance training.

The aim of the current study was to assess the effects of combination and endurance training in well-controlled diabetes type 2 patients, because we found only one study about combination training in this subpopulation.[24]

In the literature, few data are available on the influence of exercise training on quality of life scores in this population. Allbright *et al*.[27] showed an amelioration of the quality of life scores after combined exercise training in type 2 diabetes patients. Tessier *et al*.[10] observed no significant change in regard to the quality of life assessment after a 16-week training programme.

Therefore, in this study we investigate the influence of combined endurance and strength training on different indices of obesity, diabetes and cardiovascular risk and quality of life in type 2 diabetes patients compared to endurance and no training.

Materials and methods

Participants

Sixty-five type 2 diabetes patients aged between 35 and 65, with HbA1c of 6.5% or above were assessed for eligibility. They were medical outpatients.

Of these, 11 were unwilling to participate. During the experimental period 8 patients dropped out (2 in the combination group, 1 in the endurance group and 5 in the control group) due to non-compliance, illness and lost to follow-up. So, 29 males and 17 females with stable type 2 diabetes, all free of exercise-limiting co-morbidities, such as cerebrovascular disease, musculoskeletal impairment or vascular disease of the lower extremities from two centres (Sas-Van-Gent, General Practice, Holland; AZ Sint-Jozef, Bornem, Belgium) were enrolled in a 40-session rehabilitation programme (three sessions each week) (Figure 1).

Twenty-two patients were treated with oral medication, 12 with insulin injections and two with combination therapy (insulin injection and oral medication). The characteristics of the groups are shown in Table 1.

Randomization and blinding procedures

The randomization was performed using envelopes. Before commencing the first training, each patient had to choose a randomization envelope. The message inside stated that they were in group 1 (combined exercise training), 2 (endurance training) or 3 (control group).

The measurements were done by masked assessors. They examined the participants without being aware of the programme followed by each individual.

Exercise programme

Combined exercise training

Each training session included the following: Cardiovascular warming up with inclusion of

Table 1 Basic characteristics of the combination, endurance and control group

	Combination group	Endurance group	Control group
Number (*n*)	17	18	11
Gender male/female	7/10	16/2	6/5
Age (years)	55.8 (9.66)	52.2 (8.26)	57.5 (8.69)
Medication (diet only/oral/insulin/combination/missing) (*n*)	0/7/3/3/4	0/10/2/4/2	1/6/1/2/1

Data are *n* or means ± SD.

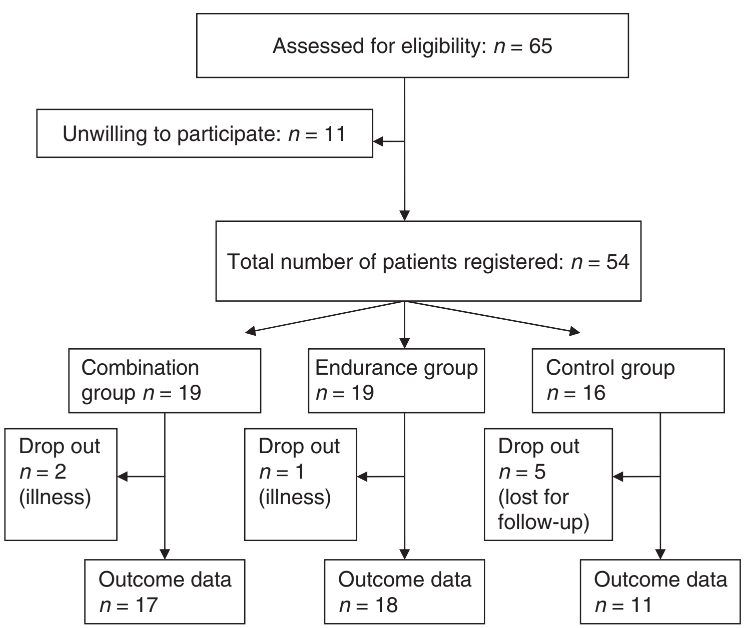

Figure 1 Participants' flow diagram.

stretching of the main muscle groups (10 minutes), circuit training (50 minutes): walking or jogging (10 minutes), elbow flexion and extension (10 minutes), cycling (10 minutes), knee flexion and extension (10 minutes), stepping (10 minutes), cooling down (general relaxation and stretching of the trained muscle groups).

Endurance training involved indivually prescribed exercise starting at 60% of heart rate reserve calculated from peak HR, which increased up to 85%, using treadmills, stationary bicycles and steppers. During the training sessions, heart rates were monitored by Polar Heart Watches (Polar, Lake Success, NY, USA). Strength exercises were performed using stack weight equipment. Intensity of strength training was calculated from one repetitive maximum (1RM) values. The starting level was 60% of 1RM, which increased up to 85% (Table 2). Each muscle group was trained in three sets of 10–15 repetitions. Between two sets a resting period of 60 seconds was allowed.

Endurance training

The endurance training protocol was comparable with the combined exercise training in terms of volume, frequency and intensity. However, the strength components were substituted by additional endurance components, namely treadmill walking (or jogging) and cycling.

Control group

The control group continued with their normal daily activities during the three months of research without additional guided physical activities.

The training sessions were organized in the physiotherapy ward of the hospital and general practice and supervised by experienced physiotherapists.

Measurements

Before and after the training period the following measurements were performed:

Peak oxygen consumption (peak Vo_2)

Patients were tested on a computer-driven cyclo-ergometer (Marquette Case, Marquette Electronics, Milwaukee, WI, USA) using a gradual protocol starting at 30 W with gradual increase of 15 W every minute. Twelve-lead ECG and heart rate were recorded continuously during the test, whereas blood pressure was measured with a manual sphygmomanometer every 2 minutes. Subjects were encouraged to exercise to the self-determined limits of their functional capacities or until the physician stopped the test because of severe adverse events, such as increasing chest pain, dizziness, potentially life-threatening arrhythmias, significant ST-segment deviations, marked systolic hypotension or hypertension. Respiratory gas measurements were obtained by using an Oxycon Pro spirometer (Jaeger–Viasys Healthcare, Hoechberg, Germany). The oxygen consumption (Vo_2), carbon dioxide production (Vco_2), minute ventilation (V_E), tidal volume, respiratory rate and mixed expiratory carbon dioxide concentration were measured continuously with breath-by-breath analysis. Peak Vo_2 was expressed as the highest attained Vo_2 during the final 30 seconds of exercise.

Table 2 Intensity of the progressive endurance training (calculated from the theoretical maximal heart rate or peak heart rate) and of the resistance training (calculated from 1RM values)

	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Weeks 9–12
Session 1	60	60	60	65	70	75	75	80	85
Session 2	60	65	65	70	75	80	80	80	85
Session 3	60	70	70	75	80	80	80	85	85

Concerning the strength exercises, in one training session three sets of 10–15 repetitions were performed for each muscle group. The values shown in the table are percentages of 1RM.

Six-minute walk test (6MWT)

All patients performed a standardized, self-paced 6MWT in a 20-m long corridor at the two test moments. Before the 6MWT, patients were instructed to cover as much distance as possible within 6 minutes without running. Patients were allowed to stop at every moment of the test, but were encouraged to restart as soon as possible. During the test, patients were instructed and encouraged with standardized comments and encouragements. Covered distance after 6 minutes was measured to the nearest 1 m.

Muscular strength

1RM was determined with the indirect Holten method[30] using commercial available strength training equipment.

A physiotherapist defined for each patient a test weight so that patients would not be able to exceed 25 repetitions. From the achieved number of repetitions the 1RM was calculated using the Holten diagram. The Holten diagram relates the number of repetitions to the percentage of maximum strength.

Functional sit-to-stand test (STS)

Each patient stood in front of an armless chair and was asked to take a seated position followed by a standing position as many times as possible within 30 seconds. The number of completed stands (up–down) is the participant's score. This assessment is highly correlated with 1RM measurements and has a high test–retest reliability.[31,32]

Anthropometric variables

Body Mass Index or BMI (weight/height^2) and waist were determined using an digital balance, a stadiometer and a measuring tape.

Body composition

Body composition was assessed by bio-impedance (Bodystat 1500 MDD; Bodystat Ltd, Douglas, Isle of Man, UK). Patients were in supine position for at least 5 minutes. Surface electrodes were attached to the lower part (1/3) of the right tibia respectively the upper part (1/3) of the right forearm. Fat percentage was calculated using the formula of Wabitsch.[33]

Blood tests

After taking blood samples (after night fasting) the following parameters were evaluated: HbA1c was determined by high-pressure liquid chromatography (HPLC) (Pierce Chemical Co., Rockford, IL, USA), glucose (Gluco-quant glucose/HK hexokinase; Roche Diagnostics, Basel, Switzerland), HDL-C (PEG + cholesterol oxidase; Roche Diagnostics), tryglicerides (glycerol phosphate-PAP; Roche Diagnostics), total cholesterol (cholesterol oxidase-PAP; Roche Diagnostics).

Quality of life (SF-36)

The General Health Survey Short Form (SF-36) measures perceived health in the areas of physical functioning, role-physical, bodily pain, general health, vitality, social functioning, role-emotional and mental health, with higher scores (range 0–100) reflecting better perceived health. The Dutch version of the SF-36 was used in this study.[34]

Statistics

Continuous data are expressed as mean (standard deviation). Data were analysed with a commercially available statistical software programme (SPSS 12.0, SPSS Inc, Chicago, IL, USA). To compare baseline values between the experimental groups univariate ANOVA, post hoc Bonferroni was used. A repeated measure ANOVA post hoc Bonferroni was also used to evaluate the interaction effects (time × group). Significance was defined as $P < 0.05$, while statistical tendency was defined as $0.1 > P > 0.05$.

Results

Baseline characteristics

Table 3 shows baseline characteristics of the three experimental groups. In general all groups were well matched except for weight ($P < 0.05$) and waist circumference ($P < 0.05$).

Table 3 Indices of obesity, physical capacity, diabetes, cardiovascular risk and quality of life at baseline and after three months in the different experimental groups

	Combination group ($n = 17$)		Endurance group ($n = 18$)		Control group ($n = 11$)	
	Baseline	After intervention	Baseline	After intervention	Baseline	After 3 months
Height (cm)	170.7 (9.5)	170.7 (9.5)	176.11 (9.3)	176.11 (9.3)	169.27 (7.6)	169.27 (7.6)
Weight (kg)	84.1 (10.80)	83.1 (10.37)	96.3 (16.65)	95.7 (17.47)	87.0 (11.33)	86.7 (11.69)
Waist (cm)	101.3 (8.09)	99.9 (7.56)	111.2 (9.95)	109.9 (11.97)	108.1 (10.36)	107.3 (10.55)
BMI (kg/m^2)	28.9 (2.84)	28.5 (2.85)	30.9 (4.03)	30.6 (4.39)	30.4 (4.32)	30.3 (4.34)
FM (kg)	20.7 (7.97)	20.7 (8.09)	29.0 (12.17)	28.7 (10.87)	23.3 (9.41)	22.8 (9.42)
Peak $\dot{V}o_2$ (L/min)	1.7 (0.38)	1.8 (0.39)	2.3 (0.25)	2.5 (0.53)	2.5 (9.41)	2.6 (0.76)
6MWT (m)	539.8 (61.26)	594.2 (60.25)**	538.1 (76.32)	583.4 (61.48)§§	528.9 (88.36)	521.3 (86.27)
Sit-to-stand (number/30 seconds)	14.2 (2.59)	16.8 (2.30)*	13.4 (2.73)	15.3 (4.41)	13.1 (2.17)	12.8 (1.72)
Strength upper limb (kg)	45.06 (20.03)	56.3 (24.63)***,##	60.3 (13.70)	60.0 (16.46)	55.7 (22.02)	51.4 (19.16)
Strength lower limb (kg)	56.7 (30.31)	72.6 (29.63)***,###	64.5 (14.80)	65.3 (17.97)	62.5 (14.18)	58.0 (12.6)
Glycaemia (mmol/L)	8.1 (1.96)	6.6 (1.11)	9.7 (2.67)	8.5 (3.26)	8.3 (2.72)	8.3 (1.72)
HbA1c (%)	7.4 (1.45)	6.9 (1.20) *	7.4 (1.70)	7.0 (1.61)	6.7 (0.97)	7.0 (0.88)
HDL (mmol/L)	1.26 (0.29)	1.33 (0.29)	1.09 (0.34)	1.11 (0.30)	1.34 (0.25)	1.25 (0.26)
Cholesterol (mmol/L)	5.0 (0.67)	4.6 (0.67)**	4.8 (0.91)	4.8 (1.08)	4.7 (1.01)	5.0 (1.18)
Triglycerides (mmol/L)	1.46 (0.48)	1.2 (0.46)	2.0 (0.98)	1.8 (1.32)	2.0 (1.08)	1.9 (0.90)
Physical functioning	71.5 (22.13)	66.8 (30.62)	57.8 (29.83)	66.8 (27.50)	75.0 (27.92)	60.0 (36.13)
Role-physical	79.7 (34.42)	67.6 (43.99)	64.1 (39.76)	73.3 (34.68)	61.4 (46.59)	65.9 (39.17)
Bodily pain	76.5 (24.01)	76.0 (22.94)	67.7 (29.21)	68.4 (35.26)	68.1 (20.13)	85.3 (13.25)
General health	51.3 (17.46)	57.1 (22.50)	51.1 (20.11)	52.9 (15.78)	66.5 (16.68)	63.5 (15.64)
Vitality	55.0 (22.78)	25.3 (12.56)	53.7 (24.01)	24.3 (11.24)	67.5 (15.14)	21.4 (14.85)
Social functioning	76.5 (24.56)	67.6 (23.82)	72.7 (24.67)	84.17 (21.89)	79.5 (18.77)	80.7 (17.11)
Role-emotional	64.7 (46.35)	68.6 (39.91)	68.8 (39.38)	93.3 (18.69)	63.6 (50.45)	81.8 (31.14)
Mental health	67.1 (18.30)	61.6 (17.44)	68.5 (22.87)	73.3 (18.50)	75.3 (16.76)	68.7 (17.11)

Data are means ± SE.
*$P<0.05$, **$P<0.01$, ***$P<0.001$ control versus combination; ##$P<0.01$, ###$P<0.001$ combination versus endurance; §§$P<0.01$ control versus endurance.
BMI, body mass index; 6MWT, six-minute walk test; HDL, high-density lipoprotein; upper (lower) limb strength value is the total sum of the upper (lower) limb, calculated from the individual muscle 1RM scores.

Programme compliance and adverse effects

All participants performed minimal 34, maximal 40 training sessions within the three months. Adverse events depending on the exercise programme were very rare and mild. In the general practice (Holland) we had to interrupt the training only twice because of training-induced hypoglycaemia. In Sint-Jozef hospital (Bornem) no adverse effects were experienced. No one was injured by the training programme.

Differences in evolution between the three experimental groups (Table 3)

Body composition

No significant difference in evolution in weight, waist, BMI and fat mass was noticed between the three experimental groups.

Indices of diabetes

HbA1c concentration decreased in the combination group while it increased in the control group ($P<0.05$). As in the combination programme, HbA1c decreased with endurance training, but the difference between endurance training and no training was not significant. We did not find any significant difference in the evolution of the glycaemia between the groups.

Physical performance

The increase in overall strength of the upper and lower limbs was significantly higher in the combination group compared with the control group (upper limb $P<0.001$; lower limb $P<0.001$) and with the endurance group (upper limb $P<0.01$;

lower limb $P < 0.001$). In both training groups covered 6MWT distance was increased, while a slight decrease was noticed in the control group ($P < 0.01$). After training, patients in the combination group completed more sit-to-stands than the controls did ($P < 0.05$). Peak $\dot{V}o_2$ did not change significantly in the three experimental groups.

Cardiovascular risk

Total cholesterol decreased significantly in the combination group compared with the control group ($P < 0.01$). The evolution in the endurance group was not significantly different from the control group. HDL increased in the combination group compared with the control group ($P < 0.01$). The increase in the endurance group was not significantly different from the decrease in the control group. Training had no significant effect on triglycerides in both training groups.

Perceived health

In global the evolution of quality of life was not different amongst the three groups.

Discussion

In our study we compared the effects of combination training and endurance training on indices of obesity, diabetes and cardiovascular risk.

Indices of obesity

No significant difference in evolution in weight, waist, BMI and fat mass was noticed between the three experimental groups. Other studies found only minor[23–26] or no[7] effects on these parameters. Also, due to the fact that a relative low number of participants were included, statistical significance could not be achieved.

Indices of diabetes

As in the literature,[23–26] we found a significant decrease of HbA1c and a positive tendency concerning glycaemia, when combination training is compared with no training. A possible explanation for these results can be found in the fact that training can decrease the intramyocytic lipid concentration and increases the fatty acid oxidation capacity.[35] In the combination group more muscles (upper and lower limbs) were trained than in the endurance group (only lower limb). Because in the combination programme larger muscle mass was involved, it is possible that the total intramyocytic fat content decreases and/or that the fatty acid oxidation capacity increases more by combination than endurance training, resulting in an increased glucose uptake after combination training.

Physical performance

In type 2 diabetes patients the effect of combined exercise training is not as extensively investigated as endurance training. However, our aerobic capacity and strength data are comparable with the few data from the literature.[25,26,28]

Muscle strength in both upper and lower limbs (1RM) increased only significantly in the combination group.

After the training programme, the sit-to-stand improved in the two intervention groups, but only the combination group could be differentiated in a significant manner from the control group. This finding is in line with the larger increase in lower limb strength that was found in the combination group compared with the endurance group. The literature also confirms that quadriceps strength is the most important variable in explaining the variance in sit-to-stand results.[36]

The distance covered by the patients in the 6MWT was significantly higher after both combination and endurance training. In contrast, the total distance walked by the patients in the control group even decreased. The 6MWT is a useful measure of functional capacity, targeted at people with at least moderate impairment. It is also used for measuring the response to therapeutic interventions.[37] BMI, peak $\dot{V}o_2$ and quadriceps muscle strength are important predictors of walking distance which can explain that both combination and endurance training showed improved 6MWT scores.[38]

Cardiovascular risk

The literature describes a decrease of cardiovascular risk by combination training.[24,25,27] This was confirmed by our results which showed an increase of HDL and a decrease of total cholesterol in the combination group versus less evolution in the endurance group and a decrease of HDL and increase of cholesterol in the control group. As stated above, a possible explanation can be found in the fact that in combination training a larger muscle mass was involved, possibly resulting in a greater decrease of intramyocytic fat content and/or a greater increase of fatty acid oxidation capacity compared with the endurance and control groups. These favourable effects may have been responsible for an increased clearance of lipids from the blood.

Perceived health

Comparing combination, endurance and no training, perceived health scores obtained by the SF-36 questionnaire did not change throughout the programme. This finding is in line with the results of Tessier *et al.* and Holton *et al.*[10,39]

Limitations

This is one of only a few studies that have compared combined and endurance training, besides a control group. We investigated the influence of combination training on indices of obesity, diabetes and cardiovascular risk. However, some limitations to our study should be considered.

A first weakness of this study is the relative small number of participants. For a power of 80% (alpha = 0.05), at least 50 patients are needed to draw firm conclusions. Unfortunately, many patients could not be motivated to join a training programme. In addition, the inclusion criteria were narrow. Because of the low power of the study, statistical significance was not reached for the difference in evolution in HbA1c and HDL in the combination group versus the endurance group. Nevertheless, we want to emphasize this clinically relevant surplus value of combination training.

Second, it is remarkable that the results in endurance training hardly exceed those obtained in the control group. Perhaps the underlying condition is a selection bias because patients in the control group in fact wanted to participate in the intervention programme, and because they were not selected for participation, they presumably were motivated to increase their daily physical activities at that time.

Third, in this study the food intake of the participants was not recorded. On the other hand, every patient was seen regularly by a dietician. However, the results about evolution in weight and BMI should be treated with caution.

Finally, consequent on the random selection, there was a difference in the male/female ratios in the groups. In the literature, it is not yet clear whether gender may affect the outcomes of a training programme.[29]

Conclusion

In diabetes type 2 patients, combined exercise had significant better effects on indices of physical condition, diabetes and cardiovascular risk compared with the control. Compared with endurance training, combined exercise gave a tendency towards better results, however more research with a larger number of participants is needed.

Clinical messages

- Three months of combination training (strength + endurance) has a favourable effect on cholesterol, HDL, HbA1c and physical fitness (6-minute walk test, sit-to-stand test, strength upper and lower limbs) in type 2 diabetes patients compared with no training.
- Three months of combination training has a positive effect on physical fitness in type 2 diabetes patients compared with endurance training by increasing the strength of the upper and lower limbs.
- Three months of combination training has a tendency towards a positive effect on HDL and HbA1c in diabetes type 2 patients compared with endurance training, but a larger number of participants are needed to prove significance.

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References

1 Yki-Yarvinen H. Diabetes mellitus and heart disease. *Idrugs* 1998; **2**: 576–78.
2 Després JP. Visceral obesity, insulin resistance, and dyslipidemia; contribution of endurance exercise training to the treatment of the plurimetabolic syndrome. *Exerc Sport Sci Rev* 1997; **25**: 271–300.
3 Bouchard C, Shephard RJ, Stephens TE. *Physical Activity Fitness, and Health: Second International Consensus Symposium*. Human Kinetics, 1994; **111**: 1049–79.
4 Joslin EP, Root EF, White P. *The treatment of diabetes mellitus*. Lea and Febiger, 2003: 126–38.
5 Hulver MW, Zheng D, Tanner CJ *et al*. Adiponectin is not altered with exercise training despite enhanced insulin action. *Am J Physiol Endocrinol Metab* 2002; **283**: E861–65.
6 Christ-Roberts CY, Pratipanawatr T, Pratipanawatr W *et al*. Exercise training increases glycogen synthase activity and glut4 expression but not insulin signalling in overweight nondiabetic and type 2 diabetic subjects. *Metabolism* 2004; **53**: 1233–42.
7 Lee S, Kuk JL, Davidson LE, Hudson R *et al*. Exercise without weight loss is an effective strategy for obesity reduction in obese individuals with and without type 2 diabetes. *J Appl Physiol* 2005; **99**: 1220–25.
8 Ross R, Janssen I, Dawson J *et al*. Exercise-induced reduction in obesity and insulin resistance in women: a randomized controlled trial. *Obes Res* 2004; **12**: 789–98.
9 Banz WJ, Maher MA, Thompson WG *et al*. Effects of resistance versus aerobic training on coronary artery disease risk factors. *Exp Biol Med* 2003; **228**: 434–40.
10 Tessier D, Ménard J, Fülöp T *et al*. Effects of aerobic physical exercise in the elderly with type 2 diabetes mellitus. *Arch Geront Geriatr* 2000; **31**: 121–32.
11 Mourier A, Gautier JF, De Kerviler E *et al*. Mobilization of visceral adipose tissue related to the improvement in insulin sensitivity in response to physical training in NIDDM. Effects of branched-chain amino acid supplements. *Diabetes Care* 1997; **20**: 385–91.
12 Boulé NG, Kenny GP, Haddad E, Wells GA, Sigal RJ. Meta-analysis of the effect of structured exercise training on cardiorespiratory fitness in Type 2 diabetes mellitus. *Diabetologia* 2003; **46**: 1071–81.
13 Willey KA, Singh MA. Battling insulin resistance in elderly obese people with type 2 diabetes: bring on the heavy weights. *Diabetes Care* 2003; **26**: 1580–88.
14 Boulé NG, Haddad E, Kenny GP, Wells GA, Sigal RJ. Effects of exercise on glycemic control and body mass in type 2 diabetes mellitus. A meta-analysis of controlled clinical trials. *JAMA* 2001; **286**: 1218–27.
15 Thomas DE, Elliott EJ, Naughton GA. Exercise for type 2 diabetes mellitus. *Cochrane Database Syst Rev* 2006; **3**: CD002968.
16 Castaneda C, Layne JE, Munoz-Orians L *et al*. A randomised controlled trial of resistance exercise training to improve glycemic control in older adults with type 2 diabetes. *Diabetes Care* 2002; **25**: 2335–41.
17 Dunstan DW, Daly RM, Owen N *et al*. High resistance training improves glycemic control in older patients with type 2 diabetes. *Diabetes Care* 2003; **25**: 1729–36.
18 Andersen JL, Schjerling P, Andersen LL, Dela F. Resistance training and insulin action in humans: effects of de-training. *J Physiol* 2003; **551**: 1049–58.
19 Fenicchia LM, Kanaley JA, Azevedo JL *et al*. Influence of resistance exercise training on glucose control in women with type 2 diabetes. *Metabolism* 2004; **53**: 284–89.
20 Joseph LJ, Trappe TA, Farrell PA *et al*. Short-term moderate weight loss and resistance training do not affect insulin-stimulated glucose disposal in postmenopausal women. *Diabetes Care* 2001; **24**: 1863–69.
21 Hejnova J, Majercik M, Polak J *et al*. Effect of dynamic strength training on insulin sensitivity in men with insulin resistance. *Cas Lek Cesk* 2004; **143**: 762–65.
22 Holten MK, Zacho M, Gaster M, Juel C, Wojtaszewski JFP, Dela F. Strength training increases insulin-mediated glucose uptake, glut4 content, and insulin signalling in skeletal muscle in patients with type 2 diabetes. *Diabetes* 2004; **53**: 294–305.
23 Balduci S, Leonetti F, Di Mario U, Falluca F. Is a long term aerobic plus resistance training program feasible for and effective on metabolic

profiles in type 2 diabetic patients? *Diabetes Care* 2004; **27**: 841–42.
24 Wagner H, Degerblad M, Thorell A *et al*. Combined treatment with exercise training and acarbose improves metabolic control and cardiovascular risk factor profile in subjects with mild type 2 diabetes. *Diabetes Care* 2006; **29**: 1471–77.
25 Maiorana A, O'Driscoll G, Cheetham C *et al*. The effect of combined aerobic and resistance exercise training on vascular function in type 2 diabetes. *J Am Coll Cardiol* 2001; **38**: 860–66.
26 Maiorana A, O'Driscoll G, Goodman C, Taylor R, Green D. Combined aerobic and resistance exercise improves glycemic control and fitness in type 2 diabetes. *Diabetes Res Clin Pract* 2002; **56**: 115–23.
27 Allbright A, Franz M, Hornsby G, Kriska A, Marrero D, Ulrich I. American College of Sports Medicine position stand. Exercise and type 2 diabetes. *Med Sci Monit* 2002; **8**: 59–65.
28 Cuff DF, Meneilly GS, Marin A, Ignaszewski A, Tildesley HD, Frohlich JJ. Effective exercise modality to reduce insulin resistance in women with type 2 diabetes. *Diabetes Care* 2003; **26**: 2977–82.
29 Snowling NJ, Hopkins WG. Effects of different modes of exercise training on glucose control and risk factors for complications in type 2 diabetic patients. A meta-analysis. *Diabetes Care* 2006; **29**: 2518–27.
30 Wathen D. Load assignment. In Baechle TR ed. *Essentials of strength training and conditioning*. Human Kinetics 1994; 435–46.
31 Rikli RE, Jones CJ. Development and validation of a functional fitness test for community-residing older adults. *J Aging Phys Act* 1999; **7**: 129–61.
32 Jones CJ, Rikli RE, Beam WC. A 30-s chair-stand test as a measure of lower body strength in community-residing older adults. *Res Quart Exerc Sports* 1999; **70**: 113–19.
33 Wabitsch M, Braun U, Heinze E *et al*. Body composition in 5–18-year-old obese children and adolescents before and after weight reduction as assessed by deuterium dilution and bioelectrical impedance analysis. *Am J Clin Nutr* 1996; **6**: 41–61.
34 Van der Zee KI, Sanderman R. *Het meten van de gezondheidstoestand met de RAND-36: een handleiding*. Noordelijk Centrum voor Gezondheidsvraagstukken, 1993.
35 Kim HJ, Lee JS, Kim CK. Effect of exercise training on muscle glucose transporter 4 protein and intramuscular lipid content in elderly men with impaired glucose tolerance. *Eur J Appl Physiol* 2004; **93**: 353–58.
36 Lord SR, Murray SM, Chapman K, Munro B, Tiedemann A. Sit-to-stand performance depends on sensation, speed, balance, and psychological status in addition to strength in older people. *J Gerontol* 2002; **57**: M539–43.
37 Enright P. The six minute walk test. *Respir Care* 2003; **48**: 783.
38 Hulens M, Vansant G, Claessens AL, Lysens R, Muls E. Predictors of 6-minute walk test results in lean, obese and morbidly obese women. *Scand J Med Sci Sports* 2003; **13**: 98–105.
39 Holton DR, Colberg SR, Nunnold T, Parson HK, Vinik AI. The effect of an aerobic exercise training program on quality of life in type 2 diabetes. *Diabetes Educ* 2003; **29**: 837–46.