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Physical activity in the prevention of type 2 diabetes

Summary

Type 2 diabetes is a common chronic disease with multiple complications, most notably cardiovascular diseases. In the past decade, the associations of physical activity, physical fitness, and changes in the lifestyle with the risk of type 2 diabetes have been assessed by a number of prospective studies and clinical trials. A few studies also evaluated joint associations of physical activity, Body Mass Index and glucose levels with the risk of type 2 diabetes. The results based on 21 prospective studies and four clinical trials have shown that moderate or high levels of physical activity or physical fitness, and changes in the lifestyle (dietary modification and increase in physical activity) can prevent type 2 diabetes. Not only leisure-time physical activity, but also occupational and commuting physical activities are important components of healthy lifestyle and can protect against type 2 diabetes.

Key words: physical activity; prevention; type 2 diabetes

Introduction

Diabetes is one of the fastest growing public health problems in both developed and developing countries. It has been estimated that the number of patients with diabetes in the world will double from the current 171 million in 2000 to 366 million in 2030 [1]. Both genetic and environmental factors are important in the etiology of type 2 diabetes [2]. Of lifestyle risk factors for type 2 diabetes most important are physical inactivity and obesity [3]. Results from prospective studies [4–24] and clinical trials [25–28] have shown that moderate or high levels of physical activity or physical fitness, and changes in the lifestyle (dietary modification and increase in physical activity) can prevent type 2 diabetes. In this review, we summarise current evidence about the role of physical activity in the primary prevention of type 2 diabetes.

Physical activity and type 2 diabetes in prospective epidemiological studies

Nineteen prospective epidemiological studies of physical activity on the risk of type 2 diabetes are summarised in table 1. The first study investigated the association between leisure time physical activity and the risk of type 2 diabetes in 5990 male alumni of the University of Pennsylvania [4]. It found that higher levels of leisure time physical activity were effective in the prevention of type 2 diabetes. A 2-year follow-up study in Malta showed that low overall physical activity during work, leisure time and commuting was associated with a 3.7-fold risk of diabetes and impaired glucose tolerance compared with high physical activity among subjects with normal or impaired glucose tolerance at baseline [6]. The Nurses' Health Study involved 87 253 US women aged 34–59 years free of diabetes at baseline [5]. During the 8-year of follow-up (1980 to 1988), 1303 cases of self-reported type 2 diabetes were ascertained. Women who were engaged in vigorous exercise at least once per week had a 33% reduced aged-adjusted relative risk of type 2 diabetes ($p < 0.001$) compared with women who did not exercise. Multivariate adjustment for age, family history of diabetes, Body Mass Index, and other variables did not alter the observed risk reduction. Another prospective 5-year study of 21 271 US male physicians aged 40–84 years (1982–1988) indicated that men who exercised at least once a week had a multivariate-adjusted relative risk of diabetes of 0.71 ($p = 0.015$) [7]. After a new follow-up period, the Nurses' Health Study (1986 to 1994) and

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Table 1
Prospective studies of physical activity and the risk for type 2 diabetes.

Study (year of publication)	sample size	age rang (years)	incidence cases; duration	type of physical activity and comparison groups	relative risk (95% CI)	adjusted for confounding factors
Alumni Health Study (1991) [4]	5990 men	39–68	202 cases; 14 years	each 500 kcal /week increase in leisure time physical activity	0.94 (0.90–0.98)	age, parental history of diabetes, BMI, and history of hypertension
Nurses' Health Study (1991) [5]	87 253 women	34–59	1303 cases; 8 years	vigorous exercise in leisure time at least once weekly versus less than once weekly	0.67 (0.60–0.75) 0.84 (0.75–0.94)	age age, family history of diabetes, BMI, hypertension, high serum cholesterol, smoking, and alcohol consumption
Population Sample of Maltase (1991) [6]	196 men and women	>20	37 cases; 2 years	low overall physical activity (including work, leisure time and commuting) versus high activity among subjects with normal glucose or IGT at baseline	3.7 times higher risk of IGT and diabetes	age
Physicians' Health Study (1992) [7]	21271 men	40–84	285 cases; 5 years	vigorous exercise in leisure time at least once weekly versus less than once weekly	0.64 (0.51–0.82) 0.71 (0.54–0.94)	age age, BMI, hypertension, high serum cholesterol, smoking, and alcohol consumption
Honolulu Heart Program (1995) [8]	6815 men	45–68	391 cases; 6 years	highest quintile of physical activity index versus lower four quintiles	0.55 (0.41–0.75) 0.49 (0.34–0.72)	age age, parental history diabetes, BMI, systolic blood pressure, triglycerides, glucose, and haematocrit
British Regional Heart Study (1995) [9]	7735 men	40–59	194 cases; 12.8 years	moderate activity (including leisure time and commuting) versus inactivity	0.4 (0.2–0.8)	age, BMI, systolic blood pressure, HDL choles-terol, smoking, alcohol consumption, and prevalent CHD
Malmö Preventive Trials (1996) [10]	4637 men	48–54	116 cases; 6 years	men developed with diabetes versus men did not develop diabetes	16% low of mean value of physical activity score	
Kuopio Ischemic Heart Disease Risk Factor Study (1996) [11]	897 men	42–60	46 cases; 4 years	leisure time physical activity with intensity of ≥5.5 METs for at least 40 min/week versus less activity	0.44 (0.22–0.88)	age, parental history of diabetes, BMI, triglycer-ides, baseline glucose, and alcohol consumption
Population Sample from Northeastern Finland (1997) [12]	891 men and 973 women	35–63	118 cases; 10 years	total weekly leisure time and commuting physical activity: low (0–1100 kcal/week) versus high (>1900 kcal/week) in men; low (0–900 kcal/week) versus high (>1500 kcal/week) in women	men: 1.54 (0.83–2.84) women: 2.64 (1.28–5.44)	age
Pitt County Study (1998) [13]	598 men and 318 women	30–55	78 cases; 5 years	moderate work and leisure time physical activity (strenuous exercise/work or both regular walk >15 min at a time and home maintenance or gardening) versus inactivity	0.35 (0.12–0.98)	age, sex, BMI, waist-to-hip ratio, and education

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Table 1 cont.

Study (year of publication)	sample size	age rang (years)	incidence cases; duration	type of physical activity and comparison groups	relative risk (95% CI)	adjusted for confounding factors
Nurses' Health Study (1999) [14]	70 102 women	40–65	1419 cases; 8 years	at least 21.8 MET-hours/week of leisure time physical activity (highest quintile) versus ≤2.0 (lowest quintile); at least 10.8 MET-hours/week of walking (highest quintile) versus ≤0.5 (lowest quintile)	0.74 (0.62–0.89) 0.74 (0.59–0.93)	age, parental history of diabetes, BMI, history of hypertension, history of high cholesterol, smoking, menopausal status, and alcohol consumption
Iowa Women' Health Study (2000) [16]	34 257 women	55–69	1997 cases; 12 years	any leisure time physical activity versus no physical activity physical activity index	0.86 (0.78–0.95) low: 1.00 moderate: 0.91 (0.82–1.02) high: 0.79 (0.70–0.90)	age, parental history of diabetes, BMI, waist-to-hip ratio, smoking, education, alcohol consumption, energy intake, whole intake, and key's score
Osaka Health Survey (2000) [17]	6013 men	35–60	444 cases; 10 years	leisure time physical activity at least once/week versus less often; vigorous activity only once at weekend versus sedentary	0.75 (0.61–0.93) 0.55 (0.35–0.88)	age, parental history of diabetes, BMI, blood pressure, smoking, and alcohol consumption
British Regional Heart Study (2000) [18]	5159 men	40–59	196 cases; 16.8 years	moderate or vigorous activity during leisure time and commuting versus no physical activity	moderate: 0.53 (0.31–0.92) moderately vigorous to vigorous: 0.51 (0.30–0.89)	age, BMI, smoking, alcohol consumption, social class, preexisting CHD, and insulin
Physicians' Health Study (2001) [19]	37 918 men	40–75	1058 cases; 10 years	at least 40.9 MET-hours/week of leisure time physical activity (highest quintile) versus <6.0 (lowest quintile); each increase 10 MET hours/week of walking	0.62 (0.50–0.76) 0.89 (0.82–0.96)	age, parental history of diabetes, BMI, smoking, alcohol consumption
FIN-MONICA Study (2003) [20]	6898 men and 7392 women	35–64	373 cases; 12 years	including work, leisure time and commuting physical activity	see table 2	see table 2
Pima Indians Community Study (2003) [21]	676 men and 1052 women	15–59	346 cases; 6 years	high leisure time physical activity (≥16 MET-hours/week) versus low (<16)	men: 0.66 (0.45–0.99) women: 0.70 (0.53–0.92)	age
Göteborg BEDA Study (2004) [23]	1351 women	39–65	73 cases; 18 years	sedentary versus any leisure time physical activity	2.08 (1.29–3.34)	age
FIN-MONICA Study (2004) [24]	2017 men and 2352 women	45–64	120 cases; 12 years	high versus low index of combined work, leisure time and commuting physical activity	0.43 (0.25–0.74)	age, sex, BMI, systolic blood pressure, smoking, and education

the Health Professionals' Follow-up Study (1986–1996) found a progressive reduction in the multivariate-adjusted relative risk of type 2 diabetes with increasing leisure time physical activity [14, 19]. These studies also reported that walking prevented type 2 diabetes as well as vigorous physical activity [14, 19].

In the Honolulu Heart Program the risk of type 2 diabetes was inversely related to total physical activity during a 2 to 6-year follow-up of 6815 Japanese-American men aged 45–68 years [8]. The result from the British Regional Heart Study indicated that men engaged in moderate levels of physical activity had a substantially reduced risk of type 2 diabetes compared with the physically inactive men after adjustment for age, Body Mass Index, systolic blood pressure, high density lipoprotein cholesterol, smoking, alcohol intake, and prevalent coronary heart disease [9]. The Malmö Preventive Trial found that men who developed with diabetes during 6-year follow-up had a 16% lower baseline mean value of physical activity score compared with men who did not develop diabetes [10]. In the Kuopio Ischemic Heart Disease Risk Factor Study of 897 middle-aged Finnish men, physical activity of moderate intensity (≥5.5 metabolic units) that was undertaken for at least a 40 minutes duration per week protected against the development of type 2 diabetes after adjusting for age, baseline glucose levels and known risk factors [11]. Another Finnish prospective study also examined 891 men and 973 women aged 35–63 years during a 10-years follow-up [12]. Only women with a higher overall activity or weekly vigorous activity had a reduced risk of type 2 diabetes. An aged-adjusted relative risk of 2.6 for diabetes was found for the lowest third of physical activity compared with the highest third [12]. The Pitt County Study demonstrated that the risk of type 2 diabetes among African-Americans who engaged in moderate physical activity was 65% lower than that of their physically inactive counterparts [13]. The Iowa Women' Health Study investigated 34 257 postmenopausal women aged 55–69 years without clinical diabetes at baseline [16]. Women who reported any leisure time physical activity had a relative risk of 0.86 compared with sedentary women after adjustment for age, and other confounding factors. The Osaka Health Survey included 6013 Japanese men aged 35–60 years who were free of clinical diabetes, impaired fasting glycaemia, or hypertension at baseline [17]. Men who participated in physical exercise at least once a week or vigorous activity only once a week at weekends had a decreased risk of type 2 diabetes. The result from Pima Indians Community Study also indicated that leisure time physical activity plays a significant role in preventing type 2 diabetes [21]. The Gothenburg BEDA Study found a significant inverse association between leisure time physical activity and the risk of type 2 diabetes among 2017 Swedish women [23].

Recently, we investigated 6898 Finnish men and 7392 women of 35 to 64 years of age without a history of stroke, coronary heart disease, or diabetes at baseline [20]. During a mean follow-up of 12 years, there were 373 incident cases of type 2 diabetes. Moderate or vigorous activity at work and moderate or high levels of leisure time physical activity were associated with a significantly reduced risk of type 2 diabetes (table 2). Walking or cycling to and from work for more than 30 minutes a day

Table 2
Relative risk of type 2 diabetes according to different levels of occupational, commuting, and leisure time physical activity, with various forms of adjustment among Finns*. Published with permission from: Hu G, Qiao Q, Silventoinen K, Eriksson JG, Jousilahti P, Lindstrom J, et al. Occupational, commuting, and leisure-time physical activity in relation to risk for type 2 diabetes in middle-aged Finnish men and women. Diabetologia 2003;46:322–9.

Physical activity	no. of new cases	person-year	adjusted hazards ratios (95% confidence intervals)		
			model 1	model 2	model 3
Occupation					
Light	199	67 250	1.00	1.00	1.00
Moderate	63	48 184	0.57 (0.43–0.76)	0.66 (0.49–0.90)	0.70 (0.52–0.96)
Active	111	55 695	0.76 (0.60–0.97)	0.73 (0.56–0.94)	0.74 (0.57–0.95)
P value for trend			<0.001	0.008	0.020
Walking or cycling to/from work					
0 min/day	242	81 556	1.00	1.00	1.00
1–29 min/day	93	54 576	0.75 (0.59–0.96)	0.88 (0.68–1.15)	0.96 (0.74–1.25)
≥30 min/day	38	34 998	0.42 (0.30–0.59)	0.54 (0.38–0.77)	0.64 (0.45–0.92)
P value for trend			<0.001	0.003	0.048
Leisure time					
Low	173	56 387	1.00	1.00	1.00
Moderate	166	88 350	0.63(0.50–0.78)	0.67 (0.53–0.84)	0.81 (0.64–1.02)
Active	34	26 392	0.52 (0.36–0.75)	0.61 (0.41–0.90)	0.84 (0.57–1.25)
P value for trend			<0.001	0.001	0.186

* Model 1: adjusted for age, sex, and study year; Model 2: adjusted for age, sex, study year, systolic blood pressure, smoking status, education, and other two physical activity; Model 3: adjusted for age, sex, study year, systolic blood pressure, smoking status, education, other two physical activity, and Body Mass Index

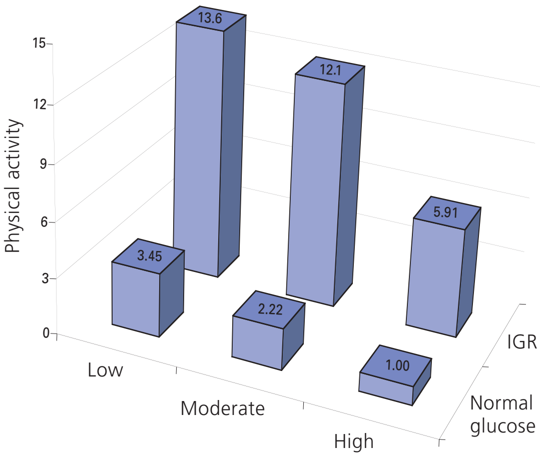
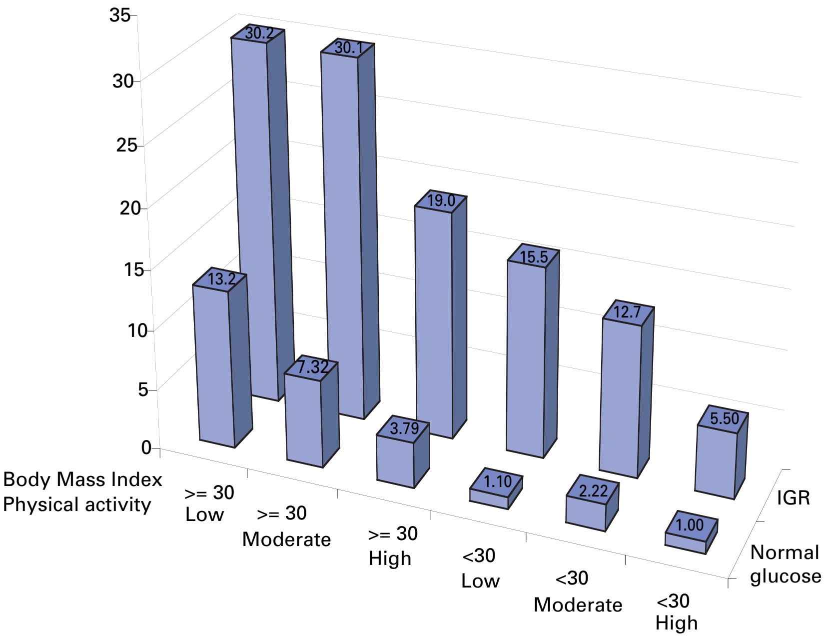


Figure 1
Relative risk of type 2 diabetes according to different levels of physical activity and Body Mass Index (<30 kg/m² and ≥30 kg/m²); A. physical activity and glucose (normal glucose, impaired glucose regulation). Published with permission from: Hu G, Lindstrom J, Valle TT, Eriksson JG, Jousilahti P, Silventoinen K, et al. Physical activity, body mass index, and risk of type 2 diabetes in patients with normal or impaired glucose regulation. Arch Intern Med 2004;164:892–6. Copyrighted © 2004, American Medical Association. All rights reserved.
B. adjusted for age, sex, study year, systolic blood pressure, smoking status, education and Body Mass Index.
IGR = impaired glucose regulation

was also significantly and inversely associated with the risk of type 2 diabetes. These associations were independent of age, systolic blood pressure, smoking, education, the other two types of physical activity, and Body Mass Index. Simultaneous engagement in two or three types of moderate or high levels of occupational, commuting, and leisure time physical activity was independently and significantly associated with a lower risk of type 2 diabetes than doing only one type of moderate or high physical activity.

In a sub-sample of 2017 Finnish men and 2352 women who participated in the standard oral glucose tolerance test at baseline, we evaluated the single and joint association of physical activity, Body Mass Index, and glucose levels with the risk of type 2 diabetes [24]. Physical activities were merged and regrouped into three categories: (1.) low was defined as subjects who reported light levels of occupational, commuting (<30 minutes) and leisure time physical activity; (2.) moderate was defined as subjects who reported only one of the all three types of moderate to high physical activity; (3.) high was defined as subjects who reported two or three types of moderate to high physical activity. Higher levels of physical activity were associated with a significantly reduced risk for type 2 diabetes, and this inverse association was persistent in subgroup analyses based on Body Mass Index (<30 and ≥30 kg/m²) and glucose levels (normal glucose, and impaired glucose regulation) (fig. 1A and 1B). In the joint analyses of different levels of physical activity, Body Mass Index, and plasma glucose with the risk of type 2 diabetes (fig. 2), the direct association of Body Mass Index and the inverse association of physical activity were found among both normoglycaemic subjects and subjects with impaired glucose regulation. In comparison with non-obese persons who reported higher levels of physical activity and had normal glucose tolerance/homeostasis, obese subjects who reported low level of physical activity and had impaired glucose regulation showed a 30 times higher risk for the development of type 2 diabetes. Individuals who were inactive, obese and had normal glucose levels had a higher risk of type 2 diabetes compared with those who were physically active, non-obese and had impaired glucose regulation.

Figure 2
Relative risk of type 2 diabetes according to joint levels of physical activity, Body Mass Index, and glucose tolerance status. Adjusted for age, sex, study year, systolic blood pressure, smoking status, and education. Published with permission from: Hu G, Lindstrom J, Valle TT, Eriksson JG, Jousilahti P, Silventoinen K, et al. Physical activity, body mass index, and risk of type 2 diabetes in patients with normal or impaired glucose regulation. Arch Intern Med 2004;164:892–6. Copyrighted © 2004, American Medical Association. All rights reserved.
IGR = impaired glucose regulation.



Physical fitness and type 2 diabetes in prospective epidemiological studies

Only four prospective epidemiological studies have assessed the association of physical fitness with the risk of type 2 diabetes (table 3) [10, 11, 15, 22]. The Malmö Preventive Trial found that poor physical fitness, measured by vital capacity and maximal oxygen uptake, was inversely associated with the risk of type 2 diabetes [10]. In the Kuopio Ischemic Heart Disease Risk Factor Study, higher levels of cardiorespiratory fitness (≥31.0 ml of oxygen per kilogram per minute) protected against the development of type 2 diabetes after adjusting for age, baseline glucose levels and other risk factors [11]. The Aerobic Center Longitudinal

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Study involved 8633 men aged 30–79 years without diabetes at baseline [15]. Men in the low cardiorespiratory fitness group (the least fit 20% of the cohort) had a 3.7-fold risk for development of diabetes compared with those in the high fitness group (the most fit 40% of the cohort) [15]. The Tokyo Gas Company Study including 4747 non-diabetic Japanese men aged 20–40 years found a significant inverse association between cardiorespiratory fitness and the risk of type 2 diabetes [22].

Changes in the lifestyle and type 2 diabetes in clinical trials

Two early reports from Sweden and China demonstrated that changes in lifestyle can prevent type 2 diabetes, but a major limitation of these two studies was that the subjects were not randomly assigned to the intervention and control groups [25, 26]. Recently results from two well-designed randomised controlled trials in Finland and the United States have been reported [27, 28].

The Malmö study from Sweden used increased physical exercise and weight loss as major intervention strategies to prevent and delay type 2 diabetes [25]. Subjects with impaired glucose tolerance had less than half the risk of developing type 2 diabetes compared with those who chose not to take part in the exercise program during the 5-year follow-up. In the Chinese study from Da Qing, 577 individuals with impaired glucose tolerance were randomised by clinic into one of the four groups: exercise only, diet only, diet plus exercise, and a control group [26]. The cumulative incidence of type 2 diabetes during 6 years was significantly lower in the three intervention groups compared with the control group (41% in the exercise group, 44% in the diet group, 46% in the diet plus exercise group, and 68% in the control group) and remained significant even after adjusting for differences in baseline Body Mass Index and fasting glucose.

In the Finnish Diabetes Prevention Study (DPS), 522 middle-aged (mean age 55 years), overweight (mean Body Mass Index 31 kg/m^2) men (33%) and women (67%) with impaired glucose tolerance were randomised either to the intensive lifestyle intervention group or the control group [27, 29]. The five main goals of the lifestyle intervention were based upon available evidence on diabetes risk factors. They were weight reduction 5%, moderate intensity physical activity 30 minutes/day, dietary fat <30 proportion of total energy (energy%), saturated fat <10 energy%, and fiber 15 g/1000 kcal. During the first year of the study the intervention was intensive, including seven individual dietary counselling sessions with the study nutritionist. After the intensive intervention period, there was a main-

Table 3

Prospective studies of physical fitness and the risk for type 2 diabetes.

	sample size	age rang (years)	incidence cases; duration	comparison group	relative risk (95% CI)	adjusted for confounding factors
Malmö Preventive Trials (1996) [10]	2673 men	48–54	60 cases; 6 years	each unit increase in physical fitness (vital capacity, litres)	0.51 (0.37–0.69)	fasting blood glucose, BMI, 40-min insulin increment, and 2-h insulin
Kuopio Ischemic Heart Disease Risk Factor Study (1996) [11]	751 men	42–60	39 cases; 4 years	cardiorespiratory fitness ≥31.0 versus <25.8 ml of oxygen per kg per min	0.26 (0.08–0.82)	age, parental history of diabetes, BMI, triglycerides, baseline glucose, and alcohol consumption
The Aerobit Center Longitudinal Study (1999) [15]	8633 men	30–79	149 cases; 6 years	men with lowest 20% of cardiorespiratory fitness versus men with highest 40%	2.6 (1.6–4.2)	age, parental history of diabetes, BMI, high blood pressure, high levels of HDL cholesterol, total cholesterol, and triglycerides, smoking, and alcohol consumption
Tokyo Gas Company Study (2003) [22]	4747 men	20–40	280 cases; 14 years	quartile 3 versus quartile 1 of cardiorespiratory fitness; quartile 4 versus quartile 1 of cardiorespiratory fitness	0.63 (0.45–0.89) 0.56 (0.37–0.84)	age, parental history of diabetes, BMI, systolic blood pressure, smoking, and alcohol consumption

tenance phase which included a counselling session every three months. At each of these counselling sessions exercise habits were also discussed and all kinds of physical activity was strongly recommended, and increased physical activity was considered as an essential part of successful weight loss program. Endurance exercise (walking, jogging, swimming, aerobic ball games, skiing) was recommended to increase aerobic capacity and cardiorespiratory fitness. The study subjects were also offered an opportunity to attend supervised, progressive, individually tailored circuit-type resistance training sessions. The moderate intensity and medium to high volume programmes were designed to improve the functional capacity and strength of the large muscle groups of the upper and lower body. The cumulative incidence of diabetes after four years was 11% in the intervention group and 23% in the control group. During the entire trial, the risk of diabetes was reduced by 58% ($p < 0.001$) in the intervention group. The reduction in the incidence of diabetes was directly associated with changes in lifestyle, since more of the people who reached four or five of the five lifestyle targets developed diabetes.

In the DPS the role of leisure time physical activity in preventing type 2 diabetes was assessed by examining the association of the changes in leisure time physical activity during the study with the incidence of diabetes in the combined intervention and control groups [30]. In the combined groups, the change in total leisure time physical activity was more strongly associated with incident diabetes than changes in subcategories of leisure time physical activity (table 4). Adjusting for age, sex, group, smoking and major risk factors for diabetes at baseline, including Body Mass Index, fasting and two-hour plasma glucose and insulin levels and family history of diabetes, and baseline total leisure time physical activity, participants in the upper third of the change in total leisure time physical activity were 80% less likely to develop diabetes during the trial than those in the lower third (relative risk 0.20; 95% CI 0.10–0.41). Participants who were in the upper third for a change in moderate-to-vigorous leisure time physical activity were 49 to 65% less likely to develop diabetes than those who were in the lower third after adjustment for confounding factors including low-intensity leisure time physical activity and its changes (table 4). Changes in low-intensity leisure time physical activity also predicted a 59 to 64% reduction in the risk of incident diabetes, even with simultaneous adjustment for moderate-to-vigorous leisure time physical activity and its changes.

In the U.S. Diabetes Prevention Program (DPP), the 3234 non-diabetic persons with

Table 4
Relative risk (95% confidence intervals) of developing type 2 diabetes during the study according to tertiles of the change in leisure-time physical activity in DPS study* [30].

Change in total leisure-time physical activity			
Tertiles (h/wk)	**model 1**	**model 2**	**model 3**
–3.2 (–35 – –0.5)	1	1	1
0.5 (–0.5–1.7)	0.47 (0.28–0.79)	0.48 (0.28–0.82)	0.52 (0.31–0.89)
3.8 (1.8–19)	0.26 (0.15–0.47)	0.29 (0.16–0.53)	0.34 (0.19–0.62)
P for the trend	<0.001	<0.001	<0.001
Change in moderate-to-vigorous leisure-time physical activity (≥3.5 METs)			
Tertiles (h/wk)	**model 1**	**model 2**	**model 3**
–1.5 (–13.5 – –0.1)	1	1	1
0.5 (–0.1–1.3)	0.78 (0.46–1.33)	0.86 (0.49–1.48)	0.95 (0.54–1.65)
2.6 (1.3–14.4)	0.35 (0.18–0.65)	0.40 (0.21–0.76)	0.51 (0.26–0.97)
P for the trend	0.001	0.004	0.037
Change in low-intensity leisure-time physical activity (<3.5 METs)			
Tertiles (h/wk)	**model 1**	**model 2**	**model 3**
–3.2 (–34 – –1.0)	1	1	1
0.8 (–0.9–1.1)	0.83 (0.47–1.45)	0.85 (0.47–1.53)	0.63 (0.34–1.17)
3.1 (1.1–15.0)	0.38 (0.20–0.70)	0.41 (0.22–0.77)	0.36 (0.1–0.67)
P for the trend	0.001	0.003	0.001

* The median and the range of the thirds for the change in leisure-time physical activity (LTPA) are shown under tertiles.
Model 1: adjusted for age, sex, group, the respective form of LTPA at baseline and, for moderate-to vigorous and low-intensity LTPA, the other intensity of LTPA and its changes (eg, for moderate-to-vigorous LTPA, also adjustment for baseline values and changes in low-intensity LTPA);
Model 2: adjusted variables in model 1 and baseline values and changes in dietary intake of energy, total fat, saturated fat and fiber;
Model 3: adjusted for variables in model 2 and baseline values and changes in BMI

elevated fasting and post-load plasma glucose concentrations were randomised into placebo, metformin, or a lifestyle-modification program with the goals of at least a 7% weight loss and at least 150 minutes of physical activity per week [28, 31]. The mean age of the participants was 51 years, the mean Body Mass Index was 34 kg/m^2, 68% of the participants were women, and 45% of them were members of non-Caucasian ethnic groups. The exercise intervention emphasized brisk walking, but also other activities with equivalent intensity (aerobic dance, bicycle riding, skating, swimming) were recommended. The participants were advised to distribute the physical exercise throughout the week, with at least 10 minutes per session. Voluntary, supervised physical activity sessions were offered at least twice per week throughout the study, including group walks, aerobic classes, and one-to-one personal training. After an average follow-up of 2.8 years, the incidence of diabetes was 11.0, 7.8 and 4.8 cases per 100 person-years in the placebo, metformin and lifestyle groups, respectively. The lifestyle intervention reduced the incidence by 58% and metformin by 31%, as compared with placebo; the lifestyle intervention was significantly more effective than metformin in the prevention of type 2 diabetes.

Prevention of cardiovascular disease by physical activity in diabetic patients

In previous years, several studies assessed the association between physical activity and the risk of cardiovascular mortality among diabetic patients [32–36]. The results from the Aerobic Center Longitudinal Study [32], the Nurses' Health Study [33], the Whitehall Study [34], the National Health Interview Survey [35], and the Health Professionals' Follow-up Study [36] have indicated that regular leisure-time physical activity is associated with reduced CVD and total mortality among patients with diabetes. Walking had similar inverse association with the risk of CVD and total mortality to vigorous leisure-time physical activity [33–36]. In the Aerobic Center Longitudinal Study, low fitness group had a high relative risk for total mortality compared with the fit group [32]. The analyses from our group also evaluated whether other types of physical activities, such as occupational and daily commuting physical activity on foot or by bicycle, are related to reduced CVD mortality among diabetic patients [37]. We reviewed data on 3316 people age 25 to 74 with type 2 diabetes who participated in surveys of randomly selected samples from the Finnish population conducted between 1972 and 1997. The data included questionnaires on the level of physical activity on the job; on the way to and from work; and during their leisure time. During an average follow-up of 18.4 years, 1410 of the subjects died, including 903 (64%) from cardiovascular disease. After adjusting for age, gender, Body Mass Index, systolic blood pressure, total cholesterol, smoking and the other two categories of physical activity, we found that moderately active work was associated with a 9% reduction in cardiovascular mortality and active work was associated with a 40% reduction in cardiovascular death. High level of leisure-time physical activity was associated with a 33% drop in cardiovascular mortality and moderate activity was linked to a 17% drop in cardiovascular mortality compared to the most sedentary group. Daily walking or cycling to and from work decreased cardiovascular mortality, but this relation was no longer significant after additional adjustment for occupational and leisure-time physical activity. Simultaneously doing one, two or three types of moderate or high occupational, commuting, and leisure-time physical activity reduced total and CVD mortality [37].

Although the mechanisms of the protective effect of regular exercise are not addressed in these studies, the large body of literature demonstrates that regular physical activity can improve insulin sensitivity and other components of the metabolic syndrome, eg decrease blood pressure, increase plasma levels of high-density lipoprotein cholesterol, decrease plasma levels of triglycerides, reduce body weight and maintain healthy weight [18, 38], and also reduce the risk of developing the metabolic syndrome [39]. The Kuopio Ischemic Heart Disease Risk Factor Study suggested that poor cardiorespiratory fitness is not only associated with all components of the metabolic syndrome but could also be considered a feature of the syndrome [40]. A recent analysis from the Insulin Resistance Atherosclerosis Study showed that both vigorous and non-vigorous activities were associated with higher insulin sensitivity among 1467 men and women of 40 to 69 years of age [38]. The British Regional Heart Study examined the role of serum insulin concentration and components of the metabolic syndrome in the relation between physical activity and the incidence of type 2 diabetes among 5159 men of 40 to 59 years of age [18]. It showed that physical activity was significantly and inversely associated with serum insulin concentrations and many components of the metabolic syndrome, and serum insulin concentrations and the components of the metabolic syndrome was a mediating factor in the relation between physical activity and the incidence of type 2 diabetes.

Another critical factor in preventing type 2 diabetes is the prevention or treatment of obesity through dietary energy restriction and increasing physical activity. Epidemiological evidence has shown that physical activity and body weight loss are of medical benefit, not just for preventing diabetes, but also for cardiovascular health and quality of life [41–47]. Regular physical activity is a crucial component of a healthy lifestyle. Health care professionals and policy makers should more aggressively promote physical activity and weight control.

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