Physical Activity in the Prevention of Type 2 Diabetes

The Finnish Diabetes Prevention Study

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Clinical trials have demonstrated that lifestyle changes can prevent type 2 diabetes, but the importance of leisure-time physical activity (LTPA) is still unclear. We carried out post hoc analyses on the role of LTPA in preventing type 2 diabetes in 487 men and women with impaired glucose tolerance who had completed 12-month LTPA questionnaires. The subjects were participants in the Finnish Diabetes Prevention Study, a randomized controlled trial of lifestyle changes including diet, weight loss, and LTPA. There were 107 new cases of diabetes during the 4.1-year follow-up period. Individuals who increased moderate-to-vigorous LTPA or strenuous, structured LTPA the most were 63–65% less likely to develop diabetes. Adjustment for changes in diet and body weight during the study attenuated the association somewhat (upper versus lower third: moderate-to-vigorous LTPA, relative risk 0.51, 95% CI 0.26–0.97; strenuous, structured LTPA, 0.63, 0.35–1.13). Low-intensity and lifestyle LTPA and walking also conferred benefits, consistent with the finding that the change in total LTPA (upper versus lower third: 0.34, 0.19–0.62) was the most strongly associated with incident diabetes. Thus increasing physical activity may substantially reduce the incidence of type 2 diabetes in high-risk individuals. *Diabetes* 54:158–165, 2005

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ACSM, American College of Sports Medicine; CDC, Centers for Disease Control and Prevention; DPS, Diabetes Prevention Study; IGT, impaired glucose tolerance; KIHD study, Kuopio Ischemic Heart Disease Risk Factor study; LTPA, leisure-time physical activity; OGTT, oral glucose tolerance test.

Epidemiological studies have suggested that moderate-to-vigorous leisure-time physical activity (LTPA) protects against the development of type 2 diabetes (1–6) as well as the metabolic syndrome (7), which commonly precedes diabetes and cardiovascular disease (8,9). In intervention trials, physical exercise has variably reduced body weight, visceral fat accumulation (10–13), and insulin resistance (10,11,14–17); improved glucose tolerance (12,15,17) and lipid profile (12,18); and decreased blood pressure (12,15,19). It is not yet clear to what extent concomitant weight loss and alterations in body composition influence these metabolic changes (20). Moderate-to-vigorous LTPA may be more beneficial than low-intensity LTPA with respect to metabolic and chronic disease end points (2,7,12,21).

Structured aerobic exercise has traditionally been emphasized as being effective in reducing diabetes risk, but the benefits of walking (3,5), resistance training (16,22,23), and lifestyle physical activity (24) have become increasingly evident. Based on trial and epidemiological evidence, the Centers for Disease Control and Prevention (CDC) and the American College of Sports Medicine (ACSM) have jointly published recommendations that adults should engage in at least 30 min of moderate physical activity (e.g., brisk walking) on most, and preferably all, days of the week (25).

Recently, both the Finnish Diabetes Prevention Study (DPS) (26) and the Diabetes Prevention Program (27) found that multiple relatively modest lifestyle changes, including weight loss, dietary changes more in line with current recommendations, and increased LTPA reduce the risk of type 2 diabetes by 58% in individuals with impaired glucose tolerance (IGT). Post hoc analyses of the independent role of increased physical activity in these two randomized controlled trials have not been published, however. In the Chinese Da Qing Impaired Glucose Tolerance and Diabetes Study (28), which was randomized by clinic rather than by participant, diabetes risk was reduced

46% in the exercise group, 42% in the diet and exercise group, and 31% in the diet-treated group. Physical activity levels were already greater at baseline in the exercise only group, however, which may partly explain why the greatest risk reduction seemed to be in this group. Furthermore, low-intensity and moderate-to-vigorous LTPA or structured and lifestyle LTPA were not separately reported. Therefore, more evidence on the role of LTPA in the prevention of type 2 diabetes is urgently needed.

We report the results of post hoc analyses on the role of LTPA in the prevention of type 2 diabetes in the Finnish DPS. We extended the follow-up period of the original trial (26) from 3.2 to 4.1 years. We first studied the effect of the intervention on different forms of LTPA by comparing the changes in LTPA between the control and intervention groups. We then assessed the role of LTPA in preventing diabetes by examining the association of changes in LTPA during the study with the incidence of diabetes in the combined intervention and control groups. Our final goal was to examine the role of compliance with current LTPA recommendations, and more specifically the role of walking for exercise, in the prevention of diabetes.

RESEARCH DESIGN AND METHODS

The Finnish DPS is a multicenter, randomized, controlled trial designed to test the hypothesis that lifestyle changes can prevent type 2 diabetes in high-risk individuals. The design of the DPS has been described in detail elsewhere (29). Briefly, overweight or obese individuals ages 40–65 years with IGT were eligible for the study. IGT was defined as a plasma glucose concentration of 7.8–11.0 mmol/l 2 h after a 75-g oral glucose challenge in subjects whose fasting glucose concentration was <7.8 mmol/l (30). The study protocol was approved by the ethics committee of the National Public Health Institute in Helsinki, Finland, and all participants gave written informed consent.

In all, 522 individuals from five study centers were randomly assigned to the intervention (n = 265) or control (n = 257) group (26). Of these 522 subjects, 487 completed a questionnaire at baseline and at least once during follow-up quantifying the previous 12 months of LTPA and were included in the present analyses. The original trial ended after an average follow-up of 3.2 years, during which time 86 cases of incident diabetes were diagnosed (26). In this study, we extended the follow-up period to 4.1 years (range 1–6 years), during which time the original random allocation and intensive intervention was continued. In all, 107 of the 487 participants developed diabetes during the 4.1-year follow-up.

The intervention group was given detailed advice on how to achieve the goals of the intervention, which were moderate-to-vigorous exercise for at least 30 min per day; a reduction in body weight to ≥5%, total intake of fat to <30% of energy consumed, and intake of saturated fat to <10% of energy consumed; and an increase in fiber intake to at least 15 g/1,000 kcal. Endurance exercise (e.g., swimming, bicycling, jogging, aerobic ball games, skiing) was encouraged. No-cost, supervised circuit-type resistance training was offered to the intervention group 4–6 months after the randomization. Walking and lifestyle physical activity were also recommended. The control group was given general verbal and written information about exercise and diet at baseline and at subsequent annual visits, but no specific individualized programs were offered.

Assessment of leisure-time physical activity. LTPA questionnaires were filled out at baseline and during yearly follow-up visits. The percentage of those remaining in the study who completed the forms ranged from 89 to 98% throughout the study. The validated Kuopio Ischemic Heart Disease Risk Factor Study (KIHD) 12-month LTPA questionnaire was used, as previously described (31,32). The questionnaire provides detailed quantitative information on the duration, frequency, and mean intensity of the most common lifestyle and structured LTPA as recalled over the previous 12 months (33). In a sample of these overweight men and women with IGT, maximal oxygen uptake during a bicycle exercise test was ~30% lower than in the younger and leaner men who participated in the population-based KIHD cohort study for whom the questionnaire was designed (data not shown). We therefore decreased the METs (1 MET is defined as metabolic expenditure at rest, corresponding to an oxygen uptake of 3.5 ml O_2/kg) assigned to different subjective intensities for given forms of physical activity by 30%. Moderate-to-vigorous LTPA was defined as ≥3.5 METs. LTPA was quantified in hours per week. Men and women were assigned the same MET value for a given subjective intensity of a given physical activity.

Common moderate-to-vigorous LTPA included walking at a moderate or very strenuous intensity, bicycling, swimming, resistance training, skiing, jogging, ball games, and lifestyle activities such as chopping wood or clearing brush. Common low-intensity activities included casual or mildly exertive walking, bicycling at a leisurely intensity, gardening and yard work, and picking berries and mushrooms.

Structured LTPAs other than walking (e.g., bicycling, skiing, jogging, swimming, resistance training, ball sports, rowing) were classified as strenuous if practiced at a moderate or high subjective intensity (e.g., causing moderate or heavy sweating or breathlessness) and nonstrenuous if practiced at lower intensities. Walking for exercise was categorized separately. Lifestyle LTPA included gardening, yard work, shoveling snow, picking berries and mushrooms, hobbies and crafts, hunting, fishing, chopping wood, or clearing brush. Walking or cycling to and from work was categorized separately as commuting LTPA.

Clinical, anthropometric, and dietary assessments. At baseline and each annual visit, all study subjects underwent an oral glucose tolerance test (OGTT) and completed a 3-day food diary, as previously described (26,29,34). Changes in dietary factors and body weight have been reported elsewhere (26,34).

Biochemical assessments. Plasma glucose was measured using a glucose dehydrogenase method after precipitation of proteins by trichloroacetic acid. The result of the second OGTT was considered the baseline value. The serum insulin concentration was measured by a radioimmunoassay (Pharmacia, Uppsala, Sweden). Serum total and HDL cholesterol and triglycerides were measured by an enzymatic assay at the National Public Health Institute, Analytical Biochemistry Laboratory.

Determination of diabetes. Diabetes was defined according to the 1985 criteria of the World Health Organization (30) as either a fasting plasma glucose concentration ≥7.8 mmol/l or a plasma glucose concentration ≥11.1 mmol/l 2 h after a 75-g oral glucose challenge. Participants were asked to fast and refrain from strenuous exercise for 12 h before the OGTT. If the diagnosis of diabetes was not confirmed by a second OGTT, the subject continued in the study (26).

Statistical analysis. Two-sided t tests and χ^2 tests were used to analyze the differences between the groups at baseline and during follow-up. Intake of dietary total and saturated fat and fiber (in grams per day) was adjusted by daily energy intake with linear regression analysis before further statistical analysis (35). The change in LTPA during the trial was calculated by subtracting the baseline total LTPA and its components (in hours per week) from corresponding measures of averaged LTPA questionnaires completed during follow-up. Changes in dietary and biochemical measurements and body weight during the trial were similarly calculated. The change in LTPA for the combined intervention and control groups was categorized into thirds to assess the association of the change in LTPA with the risk of type 2 diabetes using Cox proportional hazards models. Moderate-to-vigorous LTPA was also categorized into inactive (<1 h/week) and active (≥2.5 h/week) groups to assess adherence to LTPA goals. Because walking for exercise is the most common form of LTPA and is emphasized in current ACSM/CDC recommendations, we also examined the association of time spent walking for exercise during follow-up with incident diabetes. The covariates for the Cox proportional hazards models were forced into the model. In analyses with fasting and 2-h insulin as covariates, the group mean was substituted for the 44 and 47 individuals with missing values in the intervention and control groups, respectively. Statistical significance was defined as $P < 0.05$. Statistical analyses were performed with SPSS 11.0 for Windows (SPSS, Chicago, IL).

RESULTS

Baseline characteristics between the intervention and control groups were similar (Table 1). Reported participation in <1 h/week of moderate-to-vigorous LTPA was 37% (91 of 249) in the intervention group and 39% (94 of 238) in the control group. Engagement in ≥2.5 h/week of moderate-to-vigorous LTPA was 41% in the intervention group and 40% in the control group.

Changes in LTPA during follow-up for the intervention versus control group. During the 4.1-year follow-up, moderate-to-vigorous intensity LTPA increased 0.8 h/week in the intervention group, whereas little change was reported in the control group (Table 2). Engagement in <1 h/week of moderate-to-vigorous LTPA during follow-up

TABLE 1
Baseline characteristics of participants in the intervention and control groups

	Intervention	Control
n	249	238
Age (years)	55.8 ± 7.2	55.0 ± 6.9
Sex (male/female)	87/162	75/163
Smokers (%)	8	11
Family history of diabetes (%)	67	61
Systolic blood pressure (mmHg)	140 ± 18	136 ± 18
Diastolic blood pressure (mmHg)	86 ± 9	86 ± 10
Antihypertensive drug treatment (%)	28	31
BMI (kg/m^2)	31.3 ± 4.5	31.2 ± 4.6
Serum total cholesterol (mmol/l)	5.6 ± 1.0	5.6 ± 0.9
Serum HDL cholesterol (mmol/l)	1.2 ± 0.3	1.2 ± 0.3
Serum triglycerides (mmol/l)	1.53 (1.15–2.00)	1.60 (1.20–2.10)
Cholesterol-lowering medication (%)	5	7
OGTT		
Fasting plasma glucose (mmol/l)	6.1 ± 0.8	6.2 ± 0.7
2-h plasma glucose (mmol/l)	8.7 (7.9–9.8)	8.8 (7.9–10.0)
Fasting serum insulin (pmol/l)	90 (69–125)	97 (69–125)
2-h serum insulin (pmol/l)	556 (340–837)	542 (403–813)
Dietary intake		
Energy (kcal)	1,695 (1,431–2,023)	1,683 (1,363–2,054)
Total fat, energy adjusted (g)	72 (63–79)	73 (66–81)
Saturated fat, energy adjusted (g)	32.0 (27.0–36.9)	33.6 (28.9–37.9)
Fiber, energy adjusted (g)	19.4 (15.7–23.8)	19.0 (15.2–23.4)
LTPA (h/week)†		
Total	5.8 (3.3–9.2)	5.5 (2.8–9.8)
Moderate and vigorous	2.6 (1.1–4.9)	2.8 (1.1–5.8)
Low intensity	2.2 (0.7–4.5)	1.9 (0.5–4.7)
Strenuous, structured	0.1 (0.0–0.8)	0.2 (0.0–0.8)
Nonstrenuous, structured	0.3 (0.0–1.1)	0.2 (0.0–0.7)
Walking for exercise	1.1 (0.3–2.7)	0.9 (0.2–2.5)
Casual or mildly exertive (%)	71	76
Moderately or very strenuous (%)	29	24
Lifestyle	1.9 (0.4–4.0)	1.8 (0.4–4.9)
Commuting on foot or by bicycle	0.0 (0.0–0.5)	0.0 (0.0–0.5)

Data are means ± SD, medians (interquartile ranges), or percent and are given for participants who provided sufficient information on LTPA. Total LTPA is the sum of moderate and vigorous plus low-intensity LTPA or the sum of strenuous, structured LTPA other than walking; nonstrenuous, structured LTPA other than walking; walking for exercise; lifestyle LTPA; and commuting LTPA. Moderate and vigorous LTPA includes walking at a moderate or very strenuous intensity, bicycling, swimming, resistance training, skiing, jogging, ball games, and lifestyle activities such as chopping wood or clearing brush. Low-intensity LTPA includes casual or mildly exertive walking, bicycling at a leisurely intensity, gardening and yard work, and picking berries and mushrooms. Strenuous, structured LTPA other than walking includes bicycling, swimming, skiing, jogging, resistance training, ball games, and rowing practiced at a moderate or high subjective intensity; nonstrenuous, structured LTPAs are those same activities practiced at lower intensities. Walking for exercise was categorized separately. Lifestyle LTPA includes gardening, yard work, shoveling snow, picking berries, hobbies and crafts, hunting, fishing, and chopping wood. Commuting LTPA was defined as walking or cycling to and from work.

was 15 vs. 25% ($P = 0.004$) in the intervention and control groups, respectively. Reported participation in ≥2.5 h/week of moderate-to-vigorous LTPA during follow-up in the intervention compared with the control group was 62 vs. 46% ($P < 0.001$). The clearest difference in the change in LTPA between groups. other than walking, was for strenuous, structured LTPA (Table 2).

Changes in LTPA and risk of diabetes in the combined intervention and control groups. During the follow-up period, 107 individuals developed diabetes (41 of 249 in the intervention group and 66 of 238 in the control group). In the combined groups, the change in total LTPA was more strongly associated with incident diabetes than changes in subcategories of LTPA (Table 3). Adjusting for age, sex, group, smoking status, major risk factors for diabetes at baseline (BMI, fasting and 2-h plasma glucose and insulin levels, and family history of diabetes), and baseline total LTPA, participants in the upper third of the change in total LTPA were 80% less likely to develop diabetes than those in the lower third (relative risk [RR] 0.20, 95% confidence interval [CI] 0.10–0.41; $P < 0.001$ for linear trend).

When comparing the change in total LTPA from baseline to the first year of follow-up or from baseline to the last year of follow-up, the association of change in LTPA with diabetes was similar, but somewhat weaker, than when using averaged values of LTPA during the follow-up. Those who increased LTPA from the first to the last year of follow-up seemed to have a lower risk of diabetes than those who decreased LTPA after adjusting for baseline levels of LTPA and the change in LTPA from baseline to the first year of follow-up, but the association was not significant.

Participants reporting a change in moderate-to-vigorous LTPA in the upper third were 49–65% less likely to develop diabetes than those in the lower third in multivariate

TABLE 2
Changes in LTPA during the trial period

	Intervention	Control	*P*
n	249	238	
Total	0.4 ± 5.2 (−0.3 to 1.1)	−0.1 ± 5.3 (−0.7 to 0.6)	0.36
Moderate and vigorous	0.8 ± 2.7 (0.4–1.1)	0.2 ± 2.9 (−0.2 to 0.6)	0.028
Low intensity	−0.4 ± 4.6 (−1.0 to 0.2)	−0.3 ± 4.5 (−0.9 to 0.4)	0.79
Strenuous structured (other than walking)	0.6 ± 1.4 (0.5–0.8)	−0.1 ± 1.3 (−0.2 to 0.1)	<0.001
Nonstrenuous structured	−0.1 ± 1.1 (−0.3 to 0.0)	0.0 ± 0.9 (−0.1 to 0.2)	0.063
Walking for exercise	0.2 ± 2.1 (−0.1 to 0.5)	0.3 ± 2.1 (0.0–0.5)	0.91
Increase in walking intensity	121 (49)	109 (46)	0.54
Lifestyle	−0.3 ± 4.4 (−0.8 to 0.2)	−0.3 ± 4.7 (−0.9 to 0.3)	0.75
Commuting on foot or by bicycle	0.0 ± 1.0 (−0.1 to 0.1)	0.0 ± 0.9 (−0.2 to 0.1)	0.80

Data are means ± SD (95% CI) or *n* (%). LTPA data represent hours per week. *P* values were determined using Student's unpaired *t* test, except for change in walking intensity, which was determined with the χ^2 test.

models including low-intensity LTPA and its changes (Table 3). Changes in low-intensity LTPA similarly predicted a reduction in the risk of incident diabetes of 59–64%.

Increased strenuous, structured LTPA other than walking was also associated with a decreased risk of diabetes (Fig. 1*A*). After multivariate adjustment, including baseline BMI and its changes, the association was no longer significant. In separate analyses of the individual forms of LTPA, home exercise, resistance training, and dancing (a single category in the questionnaire) made up the greatest portion of change in strenuous LTPA. The change in this category differed between groups (median change 0.3 vs. 0.0 h/week in the intervention and control groups; $P < 0.001$). In the combined groups, the change was also inversely associated with incident diabetes (median 0.7 vs. 0.0 h/week for the upper and lower thirds; RR 0.54, 95% CI 0.32–0.91) after adjusting for age, sex, group, and respective baseline levels. Bicycling, skiing, and swimming made up smaller portions of the change in strenuous LTPA, but were also individually associated with decreased risk for diabetes (RR 0.53–0.62 for those who increased these activities versus all others). Changes in nonstrenuous, structured LTPA other than walking were not associated with diabetes risk.

An increase in walking for exercise during follow-up also decreased the risk of diabetes (Fig. 1*B*). Furthermore, those who increased the intensity of walking for exercise during follow-up (n = 230, 47%) had a 48% lower risk of diabetes than all others when adjusting for age, sex, group, baseline walking intensity, and the duration of walking for exercise and its changes (RR 0.52, 95% CI 0.33–0.83). Further adjustment for baseline dietary factors and their changes (0.62, 0.38–1.00) and BMI and its changes (0.66, 0.40–1.09) attenuated the association.

Increased lifestyle LTPA also seemed to decrease the risk of incident diabetes (Fig. 1*C*). Changes in commuting LTPA were not associated with incident diabetes, but only 33% of men and women engaged in commuting LTPA, and changes in commuting LTPA were small (Table 2). As an alternative approach, we categorized average engagement in commuting LTPA during follow-up into none (n = 253), <30 min/week (n = 100), and ≥30 min/week (median 1.3 h/week; n = 134). In models adjusting for age, sex, change in commuting LTPA from baseline, and average duration of other forms of LTPA during follow-up and their changes from baseline, at least 30 min of commuting LTPA during follow-up decreased the risk of diabetes (model 1: RR 0.54, 95% CI 0.33–0.89; model 2: 0.58, 0.34–0.97), but additional adjustment for average BMI during follow-up and its

TABLE 3
Relative risk of developing type 2 diabetes during the trial period according to tertiles of change in LTPA

	Model 1	Model 2	Model 3
Change in total LTPA			
−3.2 (−35 to −0.5)	1	1	1
0.5 (−0.5 to 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 trend	<0.001	<0.001	<0.001
Change in moderate-to-vigorous LTPA (≥3.5 METs)			
−1.5 (−13.5 to −0.1)	1	1	1
0.5 (−0.1 to 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 trend	0.001	0.004	0.037
Change in low-intensity LTPA (<3.5 METs)			
−3.2 (−34 to −1.0)	1	1	1
0.1 (−0.9 to 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 (0.19–0.67)
P for trend	0.001	0.003	0.001

Data are relative risk (95% CI). LTPA data represent hours per week. 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.

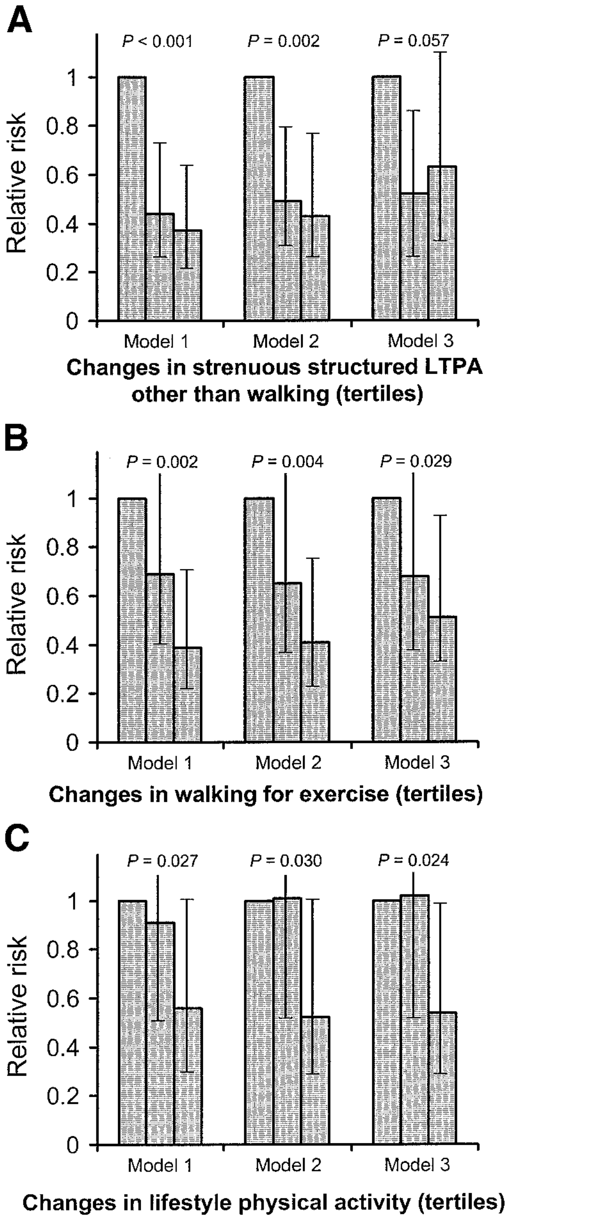

FIG. 1. Association of risk of diabetes with changes in strenuous, structured LTPA other than walking (*A*), walking for exercise (*B*), and lifestyle LTPA (*C*) according to tertiles in the combined intervention and control groups. Medians and ranges for tertiles of changes in strenuous, structured LTPA other than walking: −0.2 h/week, −14.6 to 0.0 (reference); 0.2 h/week, 0.0–0.5; 1.1 h/week, 0.5–8.3. Medians and ranges for tertiles of changes in walking for exercise: −1.1 h/week, −12.4 to −0.1 (reference); 0.2 h/week, −0.1 to 0.6; 1.5 h/week, 0.6–11.5. Medians and ranges for tertiles of changes in lifestyle physical activity: −1.8 h/week, −37 to −0.3 (reference); 0.0 h/week, −0.3 to 0.5; 1.9 h/week, 0.6–17. *P* values are for linear trends. Model 1: Adjusted for age, sex, group, the respective form of LTPA at baseline, and the other forms of LTPA and their changes (e.g., for strenuous structured LTPA other than walking, also adjustment for nonstrenuous structured LTPA other than walking, lifestyle LTPA, LTPA while commuting, and walking for exercise). Model 2: Adjusted variables in model 1 and baseline values and changes in dietary intake of energy, total and saturated fat, and fiber. Model 3: Adjusted for variables in model 2 and baseline values and changes in BMI.

change from baseline weakened the association (model 3: 0.72, 0.43–1.22).

Adherence to leisure-time physical activity recommendations and type 2 diabetes. Men and women whose average levels of moderate-to-vigorous LTPA during follow-up were in compliance with current ACSM/CDC recommendations (≥2.5 h/week; n = 265/487) were 44% less likely to develop diabetes than those remaining sedentary (<1 h/week; n = 97/487) in models adjusting for age, sex, group, change in moderate-to-vigorous LTPA from baseline, and average low-intensity LTPA during follow-up and its change from baseline (Fig. 2*A*). Further adjustment for dietary variables and BMI during follow-up and changes from baseline attenuated the associations, however. Analysis of adherence to the stated goals of the trial (≥3.5 h/week) yielded similar results. Similarly analyzed, individuals engaging in ≥2.5 h/week of walking for exercise during follow-up (n = 157/487) were 63–69% less likely to develop diabetes than those who walked <1 h/week (n = 192/487) (Fig. 2*B*).

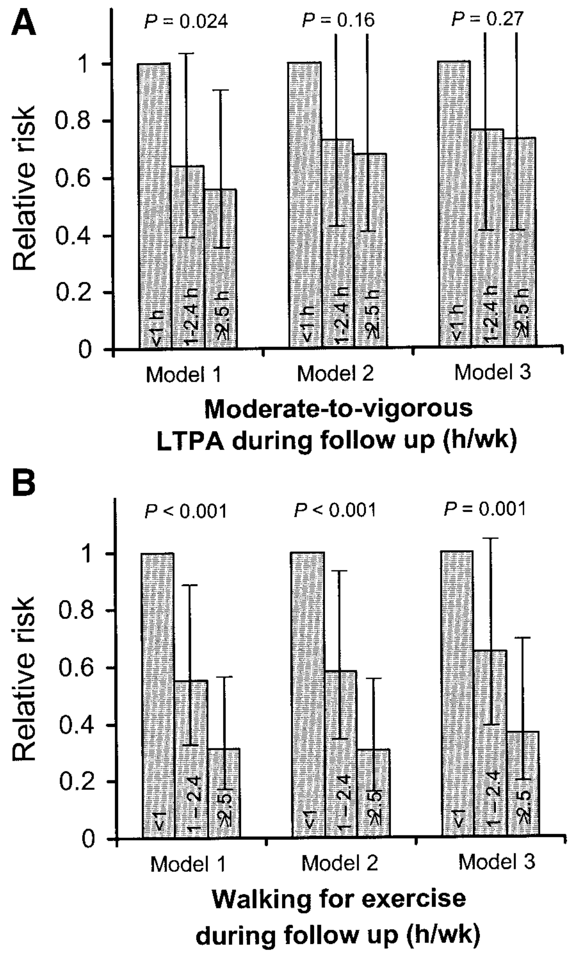

FIG. 2. Likelihood of developing diabetes during follow-up according to average duration of moderate and vigorous physical activity during follow-up (<1, 1–2.4, and ≥2.5 h/week) (*A*), and average duration of walking for exercise (<1, 1–2.4, and ≥2.5 h/week) (*B*). Model 1: Adjusted for age, sex, and *1*) change in moderate-to-vigorous LTPA from baseline and average low-intensity LTPA during follow-up and its change from baseline, or *2*) change in duration of walking for exercise from baseline and other forms of LTPA as in Fig. 1 and their changes from baseline. Model 2: Adjusted variables in model 1 and average values of dietary intake of energy, total and saturated fat, and fiber during follow-up and their changes from baseline. Model 3: Adjusted for variables in model 2 and average BMI during follow-up and its change from baseline.

Influence of sex and group. At baseline, men engaged in more total LTPA (median 7.3 vs. 5.3 h/week) and moderate-to-vigorous (median 2.3 vs. 1.4 h/week) LTPA than women, but amounts of low-intensity LTPA did not differ significantly between men and women (median 3.2 vs. 2.9 h/week). For both sexes, walking was the most common form of any LTPA, bicycling the most common form of structured LTPA other than walking, and gardening, yard work, and snow shoveling the most common lifestyle activity. The changes in the LTPA categories shown in Table 2 did not differ between sexes.

Although the trial is not powered sufficiently to study complex interactions among LTPA, group, and sex, the association of LTPA with incident diabetes was present in women in the intervention group but not in the control group, whereas the association was overall present for men in both the intervention and control groups (data not shown).

DISCUSSION

Moderate-to-vigorous and strenuous structured LTPA increased in the intervention group by ~36–48 min/week during the 4-year follow-up period. Consistently, adherence to the CDC/ACSM physical activity recommendations (≥2.5 h/week) during follow-up was 62% in the intervention group but only 46% in the control group. In the combined groups, an increase in moderate-to-vigorous and strenuous structured LTPA was associated with a large reduction in the risk of diabetes. Moreover, an increase in the duration and intensity of walking for exercise and even lifestyle LTPA predicted a decrease in incident diabetes.

We used the validated KIHD 12-month LTPA questionnaire (31) in this study. The questionnaire provides detailed information on the frequency, duration, and intensity of common structured and lifestyle physical activities as recalled for the preceding 12 months. The questionnaire is quite repeatable (intraclass correlation coefficient 0.58) (31). Measurement error was nonetheless large. To reduce measurement variability and better reflect the actual levels of LTPA throughout the study, we administered the questionnaire yearly and used the average of LTPA levels during follow-up. As in Finland in general (36), reported LTPA levels were quite high. Participants may nonetheless have overestimated the amount of habitual LTPA. The questionnaire was originally designed for a cohort study in men, but contains the same forms of LTPA as the validated questionnaire used in the Nurses Health Study, except for climbing stairs (37). Despite these limitations, the questionnaire seems suitable for use in lifestyle intervention trials.

The increase in strenuous, structured LTPA other than walking best represented the effect of the exercise intervention. In the combined groups, an increase in structured, strenuous LTPA seemed to decrease the risk of diabetes by 57% for the upper versus lower third after adjusting for dietary changes, but further adjustment for changes in BMI attenuated the decrease to 47%. Strenuous, structured LTPA thus likely mediated the decrease in diabetes risk in part through weight loss and weight maintenance. Weight loss is a powerful determinant of improved insulin sensitivity, as has been shown in a subgroup of the DPS (38), and plays a critical role in diabetes prevention. Our findings nonetheless indicate that LTPA may influence glucose and insulin metabolism through mechanisms other than weight loss or changes in body composition (20,39).

Both endurance LTPA and resistance training practiced at an at least moderately strenuous intensity appeared to protect against progression from IGT to diabetes. In the questionnaire, home exercise, resistance training, and dancing were part of the same category. Because this category increased during the study only in the intervention group, however, resistance training is likely to make up most of the increase. In type 2 diabetic women, adding resistance training to aerobic training enhances insulin sensitivity, decreases abdominal subcutaneous and visceral adipose tissue, and increases muscle density more than a similar quantity of aerobic training alone (23). Resistance training also improves insulin sensitivity in IGT (16). Changes in casual, structured LTPA were not associated with incident diabetes, even though low-intensity and lifestyle LTPA seemed to be protective. This may be because more time is spent in most low-intensity and lifestyle activities than in structured LTPA.

The stated goal of the LTPA intervention, moderate-to-vigorous LTPA, also increased more in the intervention group. In the combined groups, an increase in moderate-to-vigorous LTPA in the upper third was associated with a 49% lower risk of incident diabetes even after further adjustment for diet, BMI, and their changes. The risk of diabetes was consistently halved in those who complied with the CDC/ACSM recommendations during follow-up compared with risk in sedentary persons, but not after adjustment for dietary changes and weight loss.

Participants whose increase in walking for exercise was in the upper third were 59% less likely to develop diabetes than those whose change was in the lower third, independent of other factors. Moreover, a subjective increase in the pace of walking also decreased the likelihood of diabetes independently of time spent walking. A key message from a public health standpoint would be that at least 2.5 h/week of walking for exercise during follow-up seemed to decrease the risk of diabetes by 63–69%, largely independent of dietary factors and BMI. Walking for exercise is unlikely to have contributed to the overall effect of the intervention, because the median duration of walking did not change in either group. In the Nurses Health Study (3) and the Health Professionals Study (5), both the amount of walking for exercise and the pace were strongly associated with a decreased risk of diabetes, with some attenuation when adjusted for BMI. Changes in walking or bicycling to work were not associated with incident diabetes, but engagement in >30 min/week of commuting LTPA during follow-up also appeared to protect against diabetes, consistent with the findings of another Finnish study (6).

In the Da Qing Impaired Glucose Tolerance and Diabetes Study (28), incident diabetes decreased by 46% in the exercise group, 42% in the diet and exercise group, and 31% in the diet-treated group. LTPA was assessed by recall of the previous week's activities and quantified according to arbitrary units assigned to three intensities of LTPA, which also took into account duration of activity. According to this crude assessment, LTPA was already greater at baseline in the exercise group. The amount of LTPA increased during the study in within-group assessments, but not compared with the control group. Moderate-to-vigorous and low-intensity LTPA was not separately reported. In the nonrandomized Malmö Feasibility Study in 260 middle-aged men with IGT, the incidence of diabetes was 50% lower in the intervention group after 5 years (40). Weight loss and increased maximal oxygen uptake independently predicted improved glucose tolerance, suggesting that increased LTPA contributed to the decreased risk of diabetes.

One interesting finding was that changes in lifestyle and low-intensity LTPA also seemed to decrease risk of diabetes independently of moderate-to-vigorous or structured LTPA, dietary factors, and weight loss. Because the amount of lifestyle or low-intensity LTPA did not change in either group, changes in low-intensity or lifestyle LTPA did not explain the decrease in incident diabetes brought about by the intervention. We (2,7,21,32) and others (rev. in 12) have generally found that more vigorous LTPA has greater benefits on metabolic and chronic disease end points. Low-intensity LTPA may nonetheless confer benefits that are independent of or complementary to those of moderate-to-vigorous LTPA. The total time or energy spent on LTPA may therefore have been more important than the intensity in these middle-aged, obese, generally unfit individuals at high risk for diabetes. Indeed, the increase in total LTPA was associated with a greater reduction in diabetes risk than increases in any of its subcategories.

The strengths of this study include its randomized controlled design (26), detailed assessment of LTPA using a validated questionnaire, and repeated measurement of LTPA. The trial was designed to assess the effect of multiple interventions on the prevention of diabetes and did not include a separate exercise-only group. Therefore, we cannot rule out residual confounding with the other interventions. Detailed assessment of adherence to the dietary and weight loss interventions nonetheless allowed statistical adjustment for the other lifestyle interventions. Another limitation of our study was the lack of serial measurements of maximal oxygen uptake or other objective measures of LTPA. The MET values assigned to different forms of LTPA and their subjective intensities are somewhat arbitrary, but the assignment of higher MET values or cutoff points $>$ or $<$3.5 METs has little effect on the results.

A program promoting lifestyle changes that also included structured aerobic and resistance LTPA increased participation in moderate-to-vigorous LTPA and especially in strenuous, structured LTPA. Increased moderate-to-vigorous and strenuous, structured LTPA strongly decreased the risk of type 2 diabetes, as did walking for exercise, low-intensity LTPA, and lifestyle LTPA. Our findings extend those from prospective cohort studies indicating that LTPA decreases the risk of diabetes through mechanisms beyond weight loss alone. Compliance with current physical activity recommendations may substantially reduce the incidence of type 2 diabetes and should be widely encouraged, especially in high-risk individuals. Low-intensity physical activity may also be beneficial.

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