Exercise, genetics and prevention of type 2 diabetes

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Abstract

Type 2 diabetes is one of the fastest growing public health problems in both developed and developing countries. Cardiovascular disease is the most prevalent complication of type 2 diabetes. 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 have also evaluated the joint associations of physical activity, body mass index and glucose levels with the risk of type 2 diabetes. The results based on prospective studies and 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.

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Introduction

It has been estimated that the number of individuals with diabetes among adults 20 or more years of age will double from the current 171 million in 2000 to 366 million in 2030 [1]. Both genetic and environmental factors are involved in the etiology of type 2 diabetes [2]. Results from prospective cohort studies and clinical trials have shown that moderate or high levels of physical activity or physical fitness, and changes in lifestyle (dietary modification, increase in physical activity and weight loss) can prevent type 2 diabetes. Despite sedentary lifestyle and obesity being the two important lifestyle risk factors for type 2 diabetes [3], few studies have been conducted on the interactions between exercise and genetic markers on type 2 diabetes and related metabolic traits in humans. It would be important to understand which genotypes are well and which are poorly responsive to diverse physical activity levels or exercise training programmes; that is, they may or may not result in favourable modifications in disease progression or outcome. In this chapter, we summarize the current evidence regarding the role of physical activity, physical fitness and the interactions between physical activity and the genotype in the primary prevention of type 2 diabetes.

Physical activity and type 2 diabetes: data from prospective cohort studies

The association between physical activity and the risk of type 2 diabetes was studied in 5990 male alumni from the University of Pennsylvania [4]. Leisure-time physical activity was inversely associated with the risk of type 2 diabetes. For each 500 kcal/week increment in leisure-time physical activity, the age-adjusted risk of developing diabetes decreased by 6%, even after adjustment for obesity, hypertension and parental history of diabetes. Two large studies confirmed these findings. The Nurses’ Health Study and the Health Professionals’ Follow-up Study found a progressive reduction in the multivariable-adjusted relative risk of type 2 diabetes across increasing quintiles of leisure-time physical activity, with risks being 26%–38% lower in the highest versus the lowest quintile [5,6].

Subsequently, the inverse relation between physical activity and type 2 diabetes has also been observed in prospective studies from several different countries. The results from the British Regional Heart Study indicated that men who engaged in moderate levels of physical activity had a 60% reduced risk of type 2 diabetes compared with physically inactive men, after adjustment for BMI (body mass index) and other confounding factors [7]. In Japanese male office workers, aged 35–59 years, who were free of diabetes, impaired fasting glucose, hypertension and cardiovascular disease at baseline, found that physical activity in daily life, expressed in terms of daily energy expenditure, was inversely associated with the risk of developing impaired fasting glucose or type 2 diabetes after adjustment for BMI and other potential confounding factors [8]. The MONICA/KORA Augsburg Cohort Study examined...
sex-specific associations between leisure-time physical activity and incidence of type 2 diabetes among 4069 German men and 4034 women 25–74 years of age, who were followed for 7.4 years [9]. A significant inverse association between leisure-time physical activity and incidence of type 2 diabetes was found in both men and women, but more consistently in women, after adjustment for BMI and other confounding factors.

We recently investigated 6898 Finnish men and 7392 women 35–64 years of age without a history of stroke, coronary heart disease or diabetes at baseline [10]. During a mean follow-up of 12 years, there were 373 incident cases of drug-treated or clinically diagnosed type 2 diabetes. A moderate level of physical activity at work was associated with a 30% reduction in the risk of type 2 diabetes compared with a low level, whilst a high level of physical activity at work was associated with a 26% reduction in the risk (Table 1). For moderate and high levels of leisure-time physical activity, the risk reductions were 19% and 16% respectively, compared with low levels. Daily walking or cycling to and from work for more than 30 min was also inversely associated with the risk. These associations were independent of BMI and other factors. We also evaluated the independent and joint associations of physical activity, BMI and plasma glucose levels on the risk of type 2 diabetes [11]. We classified participants into three levels of physical activity: (i) low occupational, leisure-time and commuting physical activity, (ii) moderate to high physical activity for only one kind of activity, and (iii) moderate to high physical activity for at least two kinds of activity. Level 2 physical activity was associated with a 15% reduction and level 3 with a 57% decrease in the risk of type 2 diabetes compared with level 1. The inverse association was observed both among individuals with BMI <30 kg/m² and ≥30 kg/m², and among those with normal and impaired glucose homeostasis (Figures 1A and 1B). We also examined the joint relations among physical activity, BMI, plasma glucose and risk of type 2 diabetes (Figure 2). Obese individuals with low physical activity and impaired glucose homoeostasis had a 30-fold risk compared with non-obese persons with high physical activity and normal glucose.

These prospective studies, conducted among different populations and assessing different domains of activity, indicate that regular physical activity at work or during commuting, leisure time or daily life reduces the risk of type 2 diabetes by 15%–60%, with most studies showing a 30%–50% reduction in the risk. The benefit of physical activity is apparent in both men and women, and independent of age and other factors. Nevertheless, residual confounding due to unmeasured factors may still be present. In addition, questionnaires that are typically used in these studies are imprecise measurements of habitual physical activity. Random misclassification of physical activity, particularly over-report of the amount of physical activity, may have resulted in underestimation of the risk reduction between physical activity and type 2 diabetes. Studies assessing cardiorespiratory fitness, an objective indicator of physical activity level, provide additional information on the health effects of physical activity.
## Table 1. Relative risks of type 2 diabetes according to different levels of occupational, commuting, and leisure-time physical activity among Finns

Model 1, adjusted for age, sex, and study year; Model 2, adjusted for the factors in Model 1, plus systolic blood pressure, smoking status, education, and the two other kinds of physical activity; Model 3, adjusted for the factors in Model 2, plus BMI. Data taken from [10].

<table>
<thead>
<tr>
<th>Physical activity</th>
<th>No. of cases</th>
<th>Person-years</th>
<th>Model 1</th>
<th>Model 2</th>
<th>Model 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Occupational physical activity</td>
<td></td>
<td></td>
<td>Model 1</td>
<td>Model 2</td>
<td>Model 3</td>
</tr>
<tr>
<td>Light</td>
<td>199</td>
<td>67250</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>Moderate</td>
<td>63</td>
<td>48184</td>
<td>0.57 (0.43–0.76)</td>
<td>0.66 (0.49–0.90)</td>
<td>0.70 (0.52–0.96)</td>
</tr>
<tr>
<td>Active</td>
<td>111</td>
<td>55695</td>
<td>0.76 (0.60–0.97)</td>
<td>0.73 (0.56–0.94)</td>
<td>0.74 (0.57–0.95)</td>
</tr>
<tr>
<td><strong>P value for trend</strong></td>
<td></td>
<td></td>
<td>&lt;0.001</td>
<td>0.008</td>
<td>0.020</td>
</tr>
<tr>
<td>Walking or cycling to/from work</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0 min/day</td>
<td>242</td>
<td>81556</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>1–29 min/day</td>
<td>93</td>
<td>54576</td>
<td>0.75 (0.59–0.96)</td>
<td>0.88 (0.68–1.15)</td>
<td>0.96 (0.74–1.25)</td>
</tr>
<tr>
<td>≥ 30 min/day</td>
<td>38</td>
<td>34998</td>
<td>0.42 (0.30–0.59)</td>
<td>0.54 (0.38–0.77)</td>
<td>0.64 (0.45–0.92)</td>
</tr>
<tr>
<td><strong>P value for trend</strong></td>
<td></td>
<td></td>
<td>&lt;0.001</td>
<td>0.003</td>
<td>0.048</td>
</tr>
<tr>
<td>Leisure-time physical activity</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low</td>
<td>173</td>
<td>56387</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>Moderate</td>
<td>166</td>
<td>88350</td>
<td>0.63 (0.50–0.78)</td>
<td>0.67 (0.53–0.84)</td>
<td>0.81 (0.64–1.02)</td>
</tr>
<tr>
<td>Active</td>
<td>34</td>
<td>26392</td>
<td>0.52 (0.36–0.75)</td>
<td>0.61 (0.41–0.90)</td>
<td>0.84 (0.57–1.25)</td>
</tr>
<tr>
<td><strong>P value for trend</strong></td>
<td></td>
<td></td>
<td>&lt;0.001</td>
<td>0.001</td>
<td>0.186</td>
</tr>
</tbody>
</table>
How much physical activity is required for a reduction in risk of type 2 diabetes? Whilst the data are sparse, it appears that even 30 min of moderate intensity physical activity per day is sufficient to reduce the risk. Additional benefits will

Figure 1. Relative risks of type 2 diabetes according to different levels of (a) physical activity and BMI (< 30 kg/m$^2$ and $\geq$ 30 kg/m$^2$) and (b) physical activity and glucose (normal glucose, IGR)


How much physical activity is required for a reduction in risk of type 2 diabetes? Whilst the data are sparse, it appears that even 30 min of moderate intensity physical activity per day is sufficient to reduce the risk. Additional benefits will
likely be derived if activity levels exceed this level. Several studies found that the magnitude of the inverse association between walking and the risk of type 2 diabetes was similar to that between vigorous leisure activity and risk \[5,6,8\]. Perhaps some 30 min/day of brisk walking is sufficient. Additionally, sedentary behaviours, especially television watching, were associated with significantly elevated risk of type 2 diabetes \[6\]. Each 2 h increment in television watching per day was shown to be associated with a 14%–20% increase in the risk of type 2 diabetes \[6\].

**Physical fitness and type 2 diabetes: data from prospective cohort studies**

There is a much smaller body of evidence on the role of physical fitness in preventing type 2 diabetes. In the Aerobics Center Longitudinal Study comprising 8633 U.S. men aged 30–79 years men with low cardiorespiratory fitness (the least fit 20%) had a 3.7-fold risk of developing type 2 diabetes compared with men with high fitness (the most fit 40%) \[12\]. The CARDIA (Coronary Artery Risk Development in Young Adults) Study among 4487 U.S. men and women 18–30 years of age assessed whether low fitness, estimated by a short duration on a maximal treadmill test, predicted the development of type 2 diabetes or the metabolic syndrome, and whether improving fitness (increase in treadmill test duration between examinations) was associated with risk reduction \[13\]. After adjustment for BMI and other factors, participants with low fitness (bottom 20%) were about twice as likely to develop type 2 diabetes or the metabolic syndrome as those with high fitness (top 40%). Moreover, increasing fitness level during the 7 year study was

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**Figure 2. Relative risks of type 2 diabetes according to joint levels of physical activity, BMI and glucose homoeostasis**

associated with a 60% reduction in risk of type 2 diabetes and 50% reduction in risk of the metabolic syndrome [13].

These studies of physical fitness, primarily in men, show similar findings to the studies of physical activity, but with generally larger magnitudes of association. One explanation for this may be that measures of fitness are less prone to measurement error and misclassification than measures of physical activity. Additionally, factors other than physical activity may influence both physical fitness and health through related biological factors [14].

**Change in lifestyle and type 2 diabetes: data from clinical trials**

In recent years, several clinical trials have assessed whether regular physical activity, with or without dietary intervention, can reduce progression to type 2 diabetes among adults with impaired glucose tolerance [15–19].

The Malmö Study from Sweden targeted increased physical activity and weight loss as major intervention strategies to prevent and delay type 2 diabetes in a non-randomized clinical trial conducted among participants with impaired glucose tolerance [15]. Subjects participating in the exercise programme had less than half the risk of developing type 2 diabetes during a 5 year follow-up, compared with those who did not participate. In the Chinese study from Da Qing, 577 individuals with impaired glucose tolerance were randomized, by clinic, into one of the four groups: exercise only, diet only, diet plus exercise, and a control group [16]. The cumulative incidence of type 2 diabetes during 6 years was significantly lower in the exercise group (41%), diet group (44%), and diet plus exercise group (46%), compared with the control group (68%), 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 men (33%) and women (67%), who were overweight (mean BMI 31 kg/m²) and had impaired glucose tolerance, were randomized either to an intensive lifestyle intervention group or a control group [17]. The participants in the intervention group had frequent consultation visits with a nutritionist. They received individual advice about how to achieve the intervention goals, which were: (i) reduction in body weight of 5% or more, (ii) total fat intake less than 30% of energy consumed, (iii) saturated fat intake less than 10% of energy consumed, (iv) fibre intake of at least 15 g per 1000 kcal, and (v) moderate exercise for at least 30 min per day. After the intensive intervention period, there was a maintenance phase that included a counselling session every three months. At each of these counselling sessions, exercise habits were discussed, and all kinds of physical activity were strongly recommended. Endurance exercise, including walking, jogging, swimming, aerobic ball games and skiing, was recommended to increase aerobic capacity and cardiorespiratory fitness. Participants were also offered an opportunity to attend supervised, progressive, individually
tailored circuit-type resistance training sessions. The mean amount of weight lost between baseline and the end of year two was 3.5 kg in the intervention group and 0.8 kg in the control group. The cumulative incidence of type 2 diabetes after four years was 11% in the intervention group and 23% in the control group ($P<0.001$). During the entire trial, the risk of diabetes was reduced by 58% in the intervention group ($P<0.001$). The reduction in the incidence of diabetes was directly associated with changes in lifestyle; there was a strong inverse correlation between the number of intervention goals achieved (zero to five) and the incidence of diabetes. In fact, none of the participants achieving four or five of the five intervention goals developed diabetes.

A similar randomized clinical trial of lifestyle change and the risk of developing type 2 diabetes among persons at high risk, the DPP (Diabetes Prevention Program), was conducted in the U.S. Non-diabetic persons with elevated fasting and post-load plasma glucose concentrations were randomized to a placebo group, a group assigned metformin, or a group assigned to a lifestyle-modification program with the goals of at least a 7% weight loss and at least 150 min of physical activity per week [18]. The physical activity intervention emphasized brisk walking, but other activities with equivalent intensity were also recommended. Participants were advised to distribute their physical activity throughout the week, with sessions lasting at least 10 min. 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% (95% confidence interval, 48%–66%) and metformin by 31% (95% confidence interval 17%–43%), compared with placebo. Noteworthy was the finding that the lifestyle intervention was significantly more effective than metformin in the prevention of type 2 diabetes.

Recently, in the Indian Diabetes Prevention Programme, 531 individuals with impaired glucose tolerance were randomized into four groups: a group assigned metformin, a group assigned to a lifestyle-modification, a group assigned to both lifestyle-modification and metformin, and a control group [19]. The cumulative incidence of type 2 diabetes during the median follow-up period (30 months) was significantly lower in the lifestyle-modification group (39%), the metformin group (41%), and the lifestyle-modification plus metformin group (40%), compared with the control group (55%).

**Gene: physical activity interactions and diabetes risk**

**Genome-wide linkage scans**

Genome-wide linkage scans provide useful information about regions of the genome that might be linked to a quantitative trait. Two genomic scans have been reported for the changes in quantitative metabolic traits related to type 2
diabetes in response to endurance exercise training of three bouts a week for 20 weeks in sedentary healthy individuals [20,21]. A linkage for the changes in fasting insulin in response to exercise training was found with a marker in the leptin gene on chromosome 7q31 in whites [21]. Linkage for insulin sensitivity in response to exercise training was found on 20q13 and 22q11–12, and for acute insulin response to glucose on chromosomes 15q15 and 18q12 in African Americans [20]. The changes in the disposition index after exercise training were linked to markers on chromosomes 1p35, 3q25, 6p21–22, 7q21, 1p13 and 12q24 in Caucasians, and on 6p22 and 13q14 in African Americans [20]. For the response of glucose effectiveness to exercise training the linkage was found with markers on chromosomes 1p31, 1q44, 2p22–21, 10p12, 10q23, 12q13, 15q26 and 19q13 in African Americans [20]. Genes that are harboured in these genomic regions may modify the effects of a standardized endurance exercise training programme on diabetes related traits.

**Association studies**

In previous studies, several candidate genes have been tested. Of the genes encoding for the two subunits of the ATP-sensitive potassium channels in pancreatic β-cells (SUR1 and Kir6.2 genes) the Finnish DPS showed that a haplotype in the SUR1 gene was associated with the risk for conversion to type 2 diabetes in the control group, but not in the group receiving an intensive exercise and diet intervention, indicating potential benefits for exercise in subjects at a high risk of diabetes [22].

The common polymorphism Ala23Thr, in linkage disequilibrium with the class III VNTR (variable number of tandem repeat) allele, in the insulin gene, as well as the polymorphisms K121Q in the PC-1 gene and the M326I in the PI3K gene did not regulate body mass or conversion to diabetes during the intervention period in the Finnish DPS [23]. The VNTR variation in the insulin gene modified the association between physical activity and the insulin area under the curve during an oral glucose tolerance test in healthy men [24].

Allelic variations in the VDR (vitamin D receptor) gene have been associated with body weight, glucose homoeostasis, diabetes and its vascular complications [25]. Men homozygous for the B allele of the BsmI VDR gene polymorphism had higher fasting glucose levels than the B allele carriers in those with low physical activity (≤3 h per week), but not in those with high physical activity [26].

PPAR-γ2 (peroxisome proliferator-activated receptor γ2) gene is a transcription factor that regulates adipocyte differentiation, fat-specific gene expression and insulin action [27], and is a major candidate gene for type 2 diabetes [28]. The interaction of the Pro12Ala gene variant and physical activity has been examined in a number of studies. In a study in patients with diabetes, the alanine carriers had a larger decrease in fasting plasma glucose after endurance or resistance exercise training [29]. In individuals with impaired glucose tolerance of the Finnish DPS, Ala12 homozygotes lost more weight compared
to the Pro\textsuperscript{12} carriers after a lifestyle intervention and none of the Ala\textsuperscript{12} homozygotes developed diabetes [30]. In offspring of patients with type 2 diabetes, body weight decreased more in the Ala\textsuperscript{12} allele carriers than in the Pro\textsuperscript{12} homozygotes after a ten week training programme [31]. In healthy Japanese men, the alanine allele was associated with improvement in insulin resistance after exercise training [32]. In sedentary subjects, endurance training resulted in a greater improvement in insulin area under the curve during an oral glucose tolerance test in the Pro12Ala heterozygotes than in the Pro\textsuperscript{12} homozygotes among men [33].

Among individuals in the Finnish DPS, the risk for developing type 2 diabetes in the Lys\textsuperscript{109} homozygotes of the Lys109Ala polymorphism and in the Gln\textsuperscript{223} homozygotes of the Gln223Arg polymorphism in the LEPR (leptin receptor) gene was more pronounced in the control group compared with the lifestyle intervention group [34]. In sedentary Caucasians without diabetes, endurance exercise training increased insulin sensitivity and disposition index in the alanine allele carriers, increased glucose disappearance index more in alanine homozygotes, and decreased fasting glucose only in the Arg\textsuperscript{109} allele carriers of the Lys109Ala polymorphism of the LEPR gene [35]. An interaction was found in the leptin gene and the LEPR gene after training; the decrease in insulin was strongest in the Ala109Ala homozygotes of the LEP gene who carried the Ala\textsuperscript{109} allele in the LEPR gene [35].

\(\alpha_2\), \(\beta_2\)-, and \(\beta_3\)-ADR (\(\alpha_2\)-, \(\beta_2\)-, and \(\beta_3\)-adrenergic receptor) genes are activated by catecholamines and play a major role in the regulation of lipolysis. In the Finnish DPS, the carriers of the Glu\textsuperscript{9} allele for the 12 Glu\textsuperscript{9} polymorphism in the \(\alpha_2\beta\)-ADR (ADRA2B) gene in the intensive lifestyle intervention group had impaired first-phase insulin secretion and an increased risk of developing type 2 diabetes [36]. Adrenaline and noradrenaline bind to the \(\beta_2\)-ADR and stimulate lipolysis. The elevation of plasma NEFAs (non-esterified fatty acids) during lipolysis is associated with insulin resistance and the development of type 2 diabetes [37]. In non-diabetic people physical activity modified the effect of the Arg16Arg genotype of the Gly16Arg polymorphism of the \(\beta_2\)-ADR gene on the suppression of NEFA levels after an oral glucose load [38]. Also, men with low physical activity levels who were homozygous for the Gln\textsuperscript{27} allele of the Gln27Glu polymorphism in the \(\beta_2\)-ADR gene were more obese, but this was not the case in men who were regularly physical active [39]. The Arg\textsuperscript{64} allele of the Trp64Arg polymorphism of the \(\beta_3\)-ADR gene has been associated with an earlier onset of type 2 diabetes [40]. In the Finnish DPS, people in the lifestyle intervention group who possessed the Arg\textsuperscript{64} allele in the \(\beta_3\)-ADR gene tended to have a higher incidence of type 2 diabetes [41].

The ACE (angiotensin I-converting enzyme) gene catalyses the conversion of angiotensin I to angiotensin II [42]. In hypertensive individuals with an average age of 63 years old, an aerobic exercise programme resulted in a greater increase in insulin sensitivity and a decrease in acute insulin response to glucose in the I/I homozygotes of the Insertion (I)/Deletion (D) polymorphism in
intron 16 of the ACE gene [43]. In sedentary individuals, carriers of the I allele had a trend for a greater reduction in insulin response to an oral glucose tolerance test after a strength training programme [44]. It has been proposed that the ACE genotype might modify the potential to become physically active and to achieve higher physical fitness. In a population-based Finnish study, however, there were no differences in physical activity patterns by the ACE genotype [45].

Nitric oxide is released from endothelial cells and muscle, and appears to be involved in glucose uptake in muscle [46]. A significant interaction between energy expenditure and a haplotype in the endothelial nitric oxide synthase gene on glucose intolerance was found in Caucasians [47].

A promoter region Gly174Cys polymorphism in the IL-6 (interleukin-6) gene has been associated with the risk of type 2 diabetes [48]. In sedentary men and postmenopausal women, the Gly174Cys polymorphism modified the training induced changes in glucose levels. A significant decrease after six months of aerobic exercise training occurred only in individuals with the GG genotype [49]. In the Finnish DPS, there was no interaction between the intervention group and the IL-6 genotype [50].

A promoter region Gly308Ala polymorphism in the TNF-α (tumour necrosis factor-α) gene has been shown to have an effect on TNF-α transcription and plasma levels by which it may affect insulin signalling and secretion [51]. Among individuals with glucose intolerance in the Finnish DPS, those with the A<sup>308</sup> allele had higher conversion to type 2 diabetes in the exercise and diet intervention group [50].

The HL (hepatic lipase) gene regulates lipoprotein metabolism, and the Gly250Ala polymorphism in the promoter region of the HL gene has been associated with insulin resistance [52]. Exercise-induced improvement in insulin sensitivity was greater in the CC homozygotes in sedentary Caucasians and African Americans [53]. In the Finnish DPS, the proportion of people with the GG genotype of the Gly250Ala polymorphism, who converted to diabetes in the exercise and diet intervention group was higher than the proportion of individuals with the A<sup>250</sup> allele [54].

**Conclusions**

The Centers for Disease Control and Prevention, the American College of Sports Medicine [55], and the National Institutes of Health [56] in the U.S. and the World Health Organization [57] have recommended that every adult should have at least 30 min of moderate-intensity physical activity (such as brisk walking, cycling, swimming, home repair and yard work) on most, preferably all, days of the week. Based on the scientific evidence to date, a level of physical activity consistent with these recommendations, at least 30 min per day of moderate-to-vigorous physical activity, is effective in preventing type 2 diabetes. Regular physical activity should be an important component of a
healthy lifestyle for everyone. Health benefits regarding diabetes prevention from physical activity may vary, depending on the genotype. Even though gene-activity interactions seem to exist according to the results from several observational and a few intervention studies, it is too early at the present to make any specific recommendations regarding genetic testing in this respect. Public health messages, health care professionals, and the health care system should more intensively promote leisure-time, commuting and occupational physical activity in everyday life.

Summary

- Data from prospective studies have shown that at least 30 min per day of moderate-to-vigorous physical activity can prevent type 2 diabetes.
- Moderate or high levels of physical fitness are effective in preventing type 2 diabetes.
- Results from clinical trials have shown that lifestyle changes, including dietary modification and an increase in physical activity, can prevent type 2 diabetes.
- It is likely that certain genotypes can modify the health effects of physical activity, and the potential for the prevention of type 2 diabetes.
- Genome scans and association studies show that genetic variations appear to modify the changes observed in type 2 diabetes-related phenotypes after intervention.


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