

Impact of Positive Family History and Genetic Risk Variants on the Incidence of Diabetes

The Finnish Diabetes Prevention Study

MATTI I. UUSITUPA, MD, PHD^{1,2}
 ALENA STANČÁKOVÁ, MD, PHD³
 MARKKU PELTONEN, PHD⁴
 JOHAN G. ERIKSSON, MD, PHD^{5,6,7,8}
 JAANA LINDSTRÖM, PHD⁴
 SIRKKA AUNOLA, PHD⁹

PIRJO ILANNE-PARIKKA, MD^{10,11}
 SIRKKA KEINÄNEN-KIUKAANNIEMI, MD,
 PHD^{12,13}
 JAAKKO TUOMILEHTO, MD, PHD^{4,5,14}
 MARKKU LAAKSO, MD, PHD³

OBJECTIVE—We aimed to investigate the influence of positive family history (FH+) of diabetes and 19 known genetic risk loci on the effectiveness of lifestyle changes and their predictive value on the incidence of type 2 diabetes in the Finnish Diabetes Prevention Study (DPS).

RESEARCH DESIGN AND METHODS—A total of 522 subjects with impaired glucose tolerance (IGT) were randomized into the control ($n = 257$) and intervention ($n = 265$) groups. The mean follow-up was 6.2 years (median 7 years), and the lifestyle intervention, aimed at weight reduction, healthy diet, and increased physical activity, lasted for 4 years (range 1–6 years). An oral glucose tolerance test (OGTT) and assessment of basic clinical variables were performed annually.

RESULTS—The effect of intervention on the incidence of diabetes was almost similar in subjects with FH+ compared with subjects with a negative family history (FH–) of diabetes during the entire follow-up. In the Cox model, including FH, genetic risk SNPs, and randomization group, and adjusted for the effects of age, sex, BMI, and study center, only lifestyle intervention had a significant effect (hazard ratio 0.55, 95% CI 0.41–0.75, $P < 0.001$) on the incidence of diabetes. Further analyses showed that in addition to the baseline glucose and insulin values, 1-year changes in 2-h glucose and 2-h insulin achieved by lifestyle intervention had a significant effect on the incidence of diabetes.

CONCLUSIONS—These results emphasize the effectiveness of lifestyle intervention in reducing the risk of diabetes in high-risk individuals independently of genetic or familial risk of type 2 diabetes.

Diabetes Care 34:418–423, 2011

.....

From the ¹Institute of Public Health and Clinical Nutrition, Clinical Nutrition, University of Eastern Finland, Kuopio, Finland; the ²Research Unit, Kuopio University Hospital, Kuopio, Finland; the ³Department of Medicine, Institute of Clinical Medicine, University of Eastern Finland and Kuopio University Hospital, Kuopio, Finland; the ⁴Department of Health Promotion and Chronic Disease Prevention, National Institute for Health and Welfare, Helsinki, Finland; the ⁵Department of Public Health, University of Helsinki, Helsinki, Finland; the ⁶Folkhälsan Research Center, Helsinki, Finland; the ⁷Department of General Practice and Primary Health Care, University of Helsinki, Helsinki, Finland; the ⁸Vasa Central Hospital, Vasa, Finland; the ⁹Department of Health, Functional Capacity and Welfare, National Institute for Health and Welfare, Turku, Finland; the ¹⁰Diabetes Centre, Finnish Diabetes Association, Tampere, Finland; the ¹¹Science Centre, Pirkanmaa Hospital District, Tampere University Hospital, Tampere, Finland; the ¹²Institute of Health Sciences, University of Oulu, Oulu, Finland; the ¹³Unit of General Practice, Oulu University Hospital, Oulu, Finland; and the ¹⁴South Ostrobothnia Central Hospital, Seinäjoki, Finland.

Corresponding author: Matti I. Uusitupa, matti.uusitupa@uef.fi.

Received 28 May 2010 and accepted 18 October 2010.

DOI: 10.2337/dc10-1013. Clinical trial reg. no. NCT00518167, clinicaltrials.gov.

This article contains Supplementary Data online at <http://care.diabetesjournals.org/lookup/suppl/doi:10.2337/dc10-1013/-/DC1>.

© 2011 by the American Diabetes Association. Readers may use this article as long as the work is properly cited, the use is educational and not for profit, and the work is not altered. See <http://creativecommons.org/licenses/by-nc-nd/3.0/> for details.

Both genetic and environmental factors play major roles in the development of type 2 diabetes mellitus. In recent years, the research aiming to explore the genetic basis of type 2 diabetes has progressed significantly. Currently, >30 genetic variants have been identified in large multicenter studies with sufficient power to be associated with an increased risk of type 2 diabetes (1–3). Typically, each variant has only a limited effect on the risk, i.e., the risk may increase by 10 to 15% per copy of each risk allele except for *TCF7L2*, which is so far the most convincing type 2 diabetes risk gene, increasing the risk 1.4-fold (2). The known risk variants explain only ~10% of the genetic basis of type 2 diabetes (2). On the basis of findings in a limited number of longitudinal studies, the risk variants have only a small effect on the ability to predict the development of type 2 diabetes (4–6). In two lifestyle-based diabetes prevention trials in persons with impaired glucose tolerance (IGT), the Diabetes Prevention Program (DPP) and the Finnish Diabetes Prevention Study (DPS), it has been possible to examine the interaction between genetic and lifestyle factors regarding the future risk of diabetes. In these studies, lifestyle changes modified the risk of diabetes depending on the genetic variation (2,7,8). Specifically, the increased risk of type 2 diabetes was completely abolished by lifestyles in both DPP and DPS among the persons with the risk allele for *TCF7L2* (9,10). It is commonly believed that type 2 diabetes is highly heritable (11), and a positive family history (FH+) predicts the development of type 2 diabetes even after adjustment for common risk factors for type 2 diabetes (4–6,12–14). In the DPP, the known genetic risk variants were not associated with an increased risk of diabetes, and only one potential genotype-intervention interaction for *CDKN2A/B* was reported previously (15). However, the responses to lifestyle according to FH of diabetes were not documented.

The aim of the current study was to investigate whether an FH+ of diabetes or genetic variants of type 2 diabetes could modulate the effect of lifestyle changes achieved in the Finnish DPS (16,17) on the incidence of type 2 diabetes. Furthermore, we aimed to assess the ability of FH and genetic risk variants, in addition to lifestyle changes and basic clinical variables, to predict the incidence of type 2 diabetes in individuals at high risk of type 2 diabetes.

RESEARCH DESIGN AND METHODS

The DPS is a clinical trial with five participating centers (Helsinki, Kuopio, Turku, Tampere, and Oulu) in Finland (NCT00518167). Details of the DPS study design, methods, and procedures have been published (16–19). Briefly, study participants were recruited mainly by screening of high-risk groups who voluntarily responded to local advertisements. The inclusion criteria were 1) age 40–64 years at screening, 2) BMI >25 kg/m² at screening, and 3) the mean value of two 75-g oral glucose tolerance tests (OGTTs) in the IGT range based on World Health Organization 1985 criteria. Exclusion criteria included recent (within 6 months) cardiovascular disease event. The randomization of participants started in 1993 and continued until 1998.

A total of 522 overweight men and women were randomly allocated to one of the two treatment modalities, the intensive diet-exercise counseling group ($n = 265$, 66% were women) or the control group ($n = 257$, 69% were women). The participants randomized to intensive lifestyle intervention were given individualized counseling by the study nutritionists to achieve the lifestyle goals. They were also advised to increase their level of physical activity, and voluntary physical activity sessions were offered. The lifestyle goals were 1) weight reduction of $\geq 5\%$, 2) <30% of the daily energy intake from fat, 3) <10% of the daily energy intake from saturated fat, 4) fiber intake ≥ 15 g per 1,000 kcal, and 5) moderately intense physical activity ≥ 30 min per day. The control participants were given general health behavior information at randomization. The median length of the active intervention period was 4 years (range 1–6 years).

All participants had an annual OGTT, a medical history, and a physical examination with measurements of height (without shoes), weight (in light indoor clothes), waist circumference

(midway between the lowest rib and iliac crest), and systolic and diastolic blood pressure. Serum total cholesterol, HDL cholesterol, and triglycerides were determined from fasting samples using an enzymatic assay method.

The diagnosis of diabetes was based on the repeated OGTT (16,17). FH of diabetes was based on a questionnaire applied in the DPS. If one of the first-degree relatives (father, mother, sister, brother) had diabetes, FH was regarded as positive (FH+). These data are based on the follow-up of 4 years when active intervention was finished and on the 3 years of follow-up after active intervention with a total follow-up of an average of 6.2 years (median 7 years). Altogether, 75 persons (28%) in the intervention group and 110 persons (43%) in the control group developed diabetes during the entire follow-up. During the entire study period, the incidence of diabetes was substantially lower in the intervention group compared with the control group (HR 0.57, 95% CI 0.43–0.76, $P < 0.001$) (18). No significant difference was found in mortality rates between the groups (19).

Genotyping

Nineteen type 2 diabetes-susceptibility SNPs (*PPARG* rs1801282, *KCNJ11* rs5219, *TCF7L2* rs7903146, *SLC30A8* rs13266634, *HHEX* rs1111875, *CDKN2B* rs10811661, *IGF2BP2* rs4402960, *CDKAL1* rs7754840, *FTO* rs9939609, *HNF1B* rs757210, *WFS1* rs10010131, *JAZF1* rs864745, *CDC123* rs12779790, *TSPAN8* rs7961581, *THADA* rs7578597, *ADAMTS9* rs4607103, *NOTCH2* rs10923931, *KCNQ1* rs2283228, *MTNR1B* rs10830963) were genotyped using the TaqMan Allelic Discrimination Assay (Applied Biosystems, Foster City, CA). The genotyping call rate was 99.2–100%. Genotype distributions of all SNPs were in Hardy–Weinberg equilibrium ($P > 0.05$).

Calculations

Genetic risk score (GRS) for type 2 diabetes was calculated as a sum of type 2 diabetes-risk alleles in 19 confirmed type 2 diabetes-susceptibility SNPs. Furthermore, GRS_{SECR} based on eight SNPs influencing insulin secretion (at loci *KCNJ11*, *TCF7L2*, *SLC30A8*, *HHEX*, *CDKN2B*, *IGF2BP2*, *CDKAL1*, *MTNR1B*) (20) was calculated.

Statistical analysis

Baseline differences in characteristics of the FH+ group and the group with a

negative family history (FH–) of diabetes were tested with the t test for continuous variables and the Fisher exact or χ^2 test for dichotomous variables. Changes during follow-up (Δ values between the value at 1 year of follow-up and the baseline value) in body weight, glucose, and other variables were analyzed with the general linear model, adjusting for age, sex, study center, BMI, and fasting glucose at baseline. Interaction between FH and the randomization group was tested for each model, modeled as fixed factor. Variables with non-normal distribution were log-transformed before analyses. Kaplan–Meier method was used to estimate the incidence of diabetes in the two groups. The difference in incidence between the groups was tested with the log-rank test. The Cox proportional hazards model was used to estimate the hazard ratio for the development of diabetes between the groups. Hazard ratios for continuous traits are expressed as unit change per 1 SD. If not stated otherwise, the models were adjusted for age, sex, BMI at baseline, fasting glucose at baseline, and study center. No multicollinearity problems were found for any model. Interaction between FH (or GRS) and randomization group was modeled as a covariate in Cox regression. All comparisons of the end points were based on the intention-to-treat principle. The results for continuous variables are given as means \pm SD. $P < 0.05$ was considered statistically significant. Analyses were done with the statistics package Stata version 10.1 (StataCorp., College Station, TX) and SPSS 14.0 (SPSS Inc., Chicago, IL).

RESULTS

Baseline characteristics and 1-year changes in clinical variables by family history

No significant difference in the prevalence of FH of diabetes was observed between the intervention and control groups (66% vs. 61%). Table 1 shows baseline characteristics of the DPS participants according to the FH of diabetes. With the exception of the 1-year difference in age ($P = 0.012$), the two groups (FH+ vs. FH–) did not differ significantly from each other. Furthermore, persons with FH+ and FH– were similar regarding their diet at baseline, but the total leisure time physical activity was greater in persons with FH–.

The 1-year changes in the main clinical and metabolic characteristics according to FH and randomization group (intervention vs. control group) are

Table 1—Baseline characteristics, diet, and physical activity of the DPS participants by family history of type 2 diabetes

	FH+	FH−	P value
N, men/women	327, 95/231	195, 76/119	
Age, years	55 (7)	56 (7)	0.012
Men, BMI kg/m ²	30.1 (3.8)	29.6 (3.3)	0.365
Women, BMI kg/m ²	32.1 (5.0)	31.4 (4.3)	0.185
Fasting glucose, mmol/L	6.1 (0.7)	6.2 (0.8)	0.737
2-h glucose, mmol/L	8.9 (1.4)	8.9 (1.6)	0.897
Fasting insulin, mU/L	15 (7)	14 (8)	0.381
2-h insulin, mU/L	96 (60)	94 (73)	0.282
HOMA-IR	4.2 (2.3)	4.0 (2.3)	0.250
HOMA-B	120 (67)	115 (67)	0.217
Drug treatment for hypertension, %	28.8	30.4	0.692
CVD at baseline	7.9	8.6	0.866
Energy intake, kcal/day	1,788 (529)	1,705 (511)	0.079
Fat, E%	36.6 (6.6)	36.4 (6.6)	0.724
Saturated fats, E%	16.6 (4.2)	16.5 (4.2)	0.784
Carbohydrates, E%	43.5 (6.9)	43.2 (7.4)	0.664
Protein, E%	17.5 (3.5)	17.8 (3.3)	0.364
Dietary fiber, g/1,000 kcal	11.6 (3.7)	11.9 (4.4)	0.305
Total LTPA, h/week	6.6 (5.6)	8.1 (6.5)	0.007
Moderate-vigorous LTPA, h/week	2.6 (3.0)	2.9 (3.2)	0.279

Means (SD) are shown for continuous variables. Boldface data indicate the significance of *P* value ($P < 0.05$ or less). CVD, cardiovascular disease; LTPA, leisure time physical activity.

shown in Supplementary Table 1. As shown previously, weight reduction was greater and glycemic control improved more in the intervention group than in the control group (17,18). In the intervention group, persons with FH+ achieved significantly greater reduction in 2-h plasma glucose than did persons with FH−. However, no significant interactions between FH and control/intervention groups were found in the changes in body weight, fasting plasma glucose, 2-h plasma glucose, homeostasis model assessment (HOMA) of insulin resistance, HOMA of insulin sensitivity, or energy intake. In addition, no major differences were found in the distribution of macronutrients or physical activity between FH+ and FH− groups after 1 year of intervention (data not shown).

Incidence of type 2 diabetes by family history

Incidence of type 2 diabetes in the intervention and control group by FH of diabetes is shown in Fig. 1 (data in Supplementary Table 2). During the original randomized trial period of 4 years on average, the incidence of diabetes seemed to be lower in the intervention group than in the control group in persons with FH+ ($P = 0.0002$), but not in those with FH−

($P = 0.61$). After adjustment for age, sex, baseline BMI, fasting glucose, and study center, the HR for diabetes in the intervention group compared with the control group was 0.42 (95% CI 0.26–0.70, $P = 0.0008$) in persons with FH+, whereas it was 0.61 (95% CI 0.33–1.12, $P = 0.11$) in persons with FH−. During the entire follow-up, in the adjusted model, the effect of intervention was, however, significant in both FH+ ($P = 0.002$) and FH− ($P = 0.006$) groups, and there was no significant interaction between the FH and randomization group ($P = 0.19$ for the follow-up during intervention, $P = 0.97$ for the entire follow-up).

Effect of gene variants and genetic risk score on the incidence of type 2 diabetes

We did not find any significant effects of the 19 risk variants on the incidence of type 2 diabetes (data not shown). Similarly, combined type 2 diabetes risk alleles of 19 SNPs (presented as GRS) did not have a significant effect on the incidence of diabetes during the entire follow-up period ($P = 0.784$ in the adjusted model). GRS based on eight SNPs influencing insulin secretion (20) (GRS_{SECR}) also did not have a significant effect ($P = 0.459$). The persons with FH+ and FH− did not

differ in the GRS (17.5 ± 2.7 vs. 17.6 ± 2.8 , $P = 0.726$). No statistical evidence for an interaction between GRS (or GRS_{SECR}) and randomization group on the incidence of type 2 diabetes was found ($P = 0.656$ or 0.340 for the interaction).

Predictors of the incidence of type 2 diabetes

In the Cox regression analysis, including GRS (19 SNPs), FH, and randomization group, adjusted for age, BMI, sex, and center, only the intervention group had a significant effect on the incidence of diabetes (Table 2). A further Cox regression analysis including age, sex, BMI, fasting and 2-h glucose and fasting and 2-h insulin at baseline, GRS (as a continuous variable), FH, randomization group, and study center in the model was performed to determine the predictors of the incidence of type 2 diabetes during the entire follow-up period (Table 2). It showed that fasting and 2-h plasma glucose, fasting insulin, and the randomization group significantly predicted the development of diabetes. Fasting glucose was the strongest predictor ($P = 2.2 \times 10^{-10}$). This could be explained by the inclusion criteria of the study, comprising only subjects with IGT. However, when the 1-year changes of metabolic variables were added in the model baseline, fasting and 2-h glucose, baseline fasting insulin, and changes in 2-h glucose and insulin predicted the incidence of diabetes (Table 2). Neither FH nor GRS was a significant predictor of the development of type 2 diabetes, and the effect of the intervention became nonsignificant (HR 0.74, $P = 0.106$) because the effect of lifestyles surely was mediated through glucose and insulin metabolism.

CONCLUSIONS—The current study aimed to investigate whether the FH+ per se, or the genetic risk variants and GRS based on 19 known type 2 diabetes-risk SNPs, modulated the effects of lifestyle intervention in the DPS participants. FH did not affect the result of lifestyle intervention during the entire follow-up. We did not observe any aggregation of known genetic risk variants in persons with FH+, nor did genetic risk variants modify the incidence of diabetes. On the basis of different analyses, in addition to the intervention, fasting and 2-h plasma glucose and fasting insulin at baseline, and the 1-year changes of 2-h plasma glucose and 2-h insulin were the main determinants of the development of diabetes

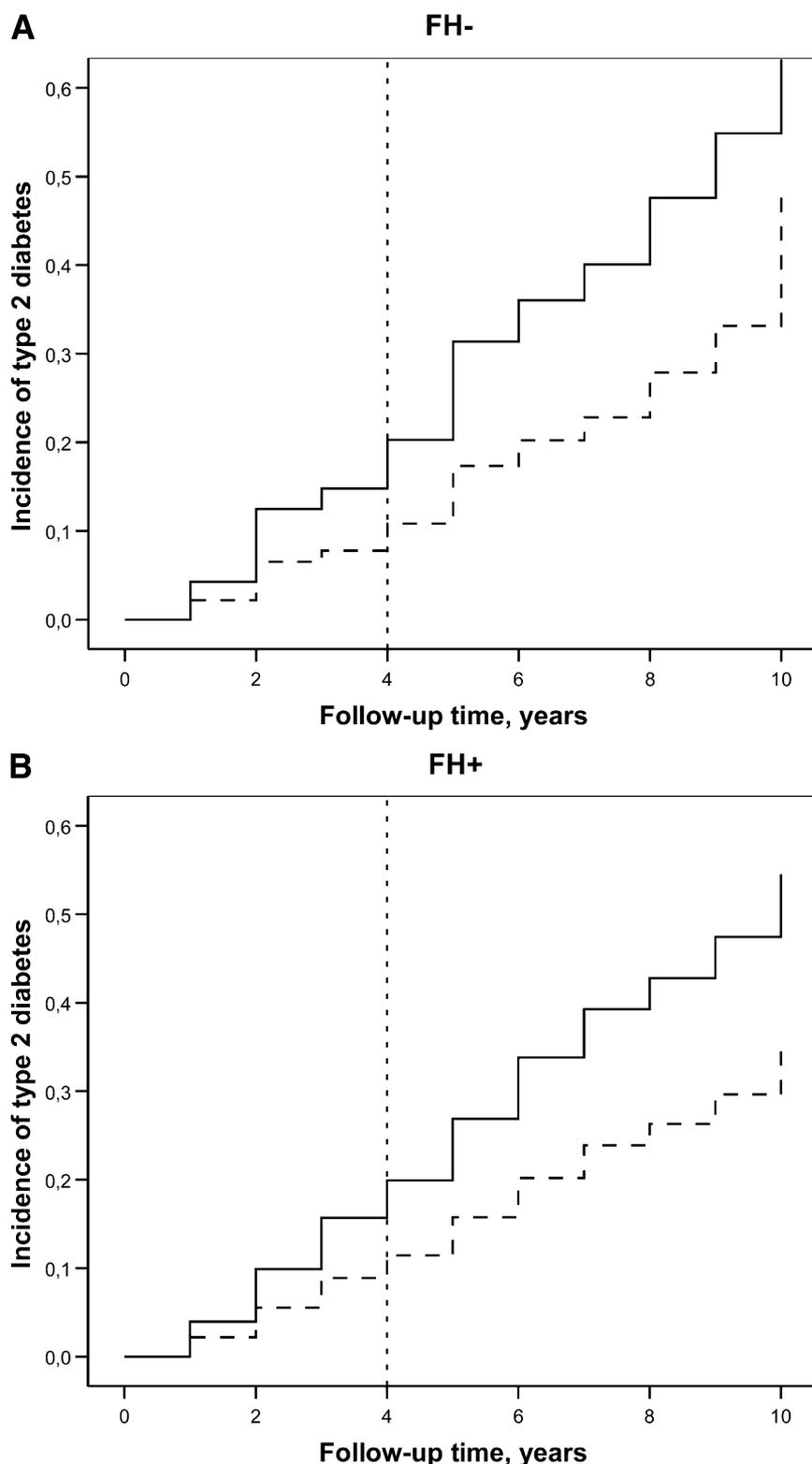


Figure 1—Incidence of type 2 diabetes during the intervention period of 4 years (A) (end indicated by a vertical line) and during the entire follow-up period (B) by FH and randomization group (intervention vs. control) in the DPS. Solid line is for the control group. During the intervention follow-up of 4 years on average, intervention had significant effect on the incidence of type 2 diabetes in the FH+ group ($P = 0.0002$, $*P = 0.0008$) but not in the FH- group ($P = 0.61$, $*P = 0.11$). During the entire follow-up, intervention had an effect in both FH+ ($P = 0.0004$, $*P = 0.002$) and FH- ($P = 0.13$, $*P = 0.006$) groups. P is from Kaplan-Meier analysis, $*P$ after adjustment for age, sex, baseline BML, baseline fasting glucose, and study center in Cox regression model.

during the follow-up, independently of the effects of genetic risk variants and FH.

Although the participants with FH+ seemed to have a lower incidence of diabetes than those with FH- during the first 4 years of follow-up when the active intervention was carried out, this early difference disappeared during the entire follow-up. The seemingly better early response could be explained by the fact that individuals with FH+ may be more aware of the risk of diabetes than others (21) and thus more motivated, as suggested by their greater decrease in total caloric intake during the first year of intervention ($P = 0.012$). In addition, the mean 1-year change in the 2-h plasma glucose values was greater among the participants with FH+ in the lifestyle intervention group. It should be noticed that at baseline no differences were found in any clinical or biochemical measurements, which could explain the present findings of the differences during the intervention phase in the incidence of diabetes between individuals with FH+ and FH-.

The known genetic risk variants were not associated with the FH of diabetes. However, this may not be an unexpected finding because it is known that risk loci confer only 10% of the risk of type 2 diabetes (2,22). Furthermore, all participants in the DPS had screened IGT based on two OGTTs and >60% had an FH+, which also might indicate an aggregation of genetic risk variants. In the general population, FH+ varies from 25% to 40% depending on selection of populations in different studies (4,12–14). It could be argued that a small sample size could explain why no significant association between genetic risk variants and FH or the type 2 diabetes risk was found. However, this may not be the case, because in regression analyses not even a trend to an association with the diabetes risk was found. It is of note that the total number of diabetes cases was 185 during the entire follow-up. This figure is almost comparable to 255 cases in the Framingham Offspring Study (5), including 2,377 participants with 28 years of follow-up. In that study, the adjusted C-statistic was 0.595 without the genotype score and 0.615 with the score ($P = 0.11$). In a larger study on Swedish and Finnish cohorts, including 18,831 individuals (4), of whom 2,201 developed diabetes during a median follow-up of 23.5 years, the addition of specific genetic information to clinical factors slightly improved the prediction of

Table 2—Effect of family history of diabetes, genetic risk score, intervention, and clinical variables on the incidence of type 2 diabetes

	HR	95% CI	P value
A			
Family history of T2DM	0.78	(0.57–1.06)	0.118
GRS (19 SNPs)	1.04	(0.90–1.20)	0.617
Intervention vs. control group	0.55	(0.41–0.75)	1.2 × 10⁻⁴
B			
Family history of T2DM	0.80	(0.57–1.11)	0.180
GRS (19 SNPs)	1.02	(0.87–1.18)	0.840
Intervention vs. control group	0.52	(0.38–0.72)	5.9 × 10⁻⁵
Fasting glucose (baseline)	1.69	(1.44–1.99)	2.2 × 10⁻¹⁰
2-h glucose (baseline)	1.35	(1.14–1.60)	0.0005
Fasting insulin (baseline)	1.25	(1.03–1.53)	0.025
2-h insulin (baseline)	0.81	(0.63–1.02)	0.076
BMI (baseline)	1.17	(0.98–1.39)	0.077
C			
Family history of T2DM	0.92	(0.65–1.29)	0.609
GRS (19 SNPs)	1.02	(0.88–1.18)	0.797
Intervention vs. control group	0.74	(0.52–1.06)	0.106
Fasting glucose (baseline)	1.93	(1.57–2.38)	3.5 × 10⁻¹⁰
Δ Fasting glucose (1-year change)	1.15	(0.96–1.38)	0.129
2-h glucose (baseline)	1.69	(1.39–2.05)	9.1 × 10⁻⁸
Δ 2-h glucose (1-year change)	1.62	(1.32–1.98)	3.4 × 10⁻⁶
Fasting insulin (baseline)	1.35	(1.06–1.73)	0.015
Δ Fasting insulin (1-year change)	1.18	(0.97–1.44)	0.103
2-h insulin (baseline)	1.05	(0.79–1.39)	0.755
Δ 2-h insulin (1-year change)	1.36	(1.05–1.75)	0.018
BMI (baseline)	1.18	(0.99–1.40)	0.061
Δ BMI (1-year change)	1.19	(0.98–1.44)	0.084

For dichotomous variables, HRs are shown for the intervention group, FH+ of T2DM, and male subjects. For continuous variables, HRs are expressed as unit change per 1 SD. A, B, C represent alternative models: A = effects of FH, GRS, and intervention without clinical variables. B = including clinical variables at baseline. C = including 1-year changes in these variables (Cox regression, all models are adjusted for age, sex, baseline BMI, and study center). Boldface data indicate the significance of P value ($P < 0.005$ or less). T2DM, type 2 diabetes mellitus.

future diabetes, from 0.74 to 0.75 (the area under the receiver operating characteristic curve); however, the P value was significant ($P = 1.0 \times 10^{-4}$). These results are in line with the Health Professionals Follow-up Study and Nurses' Health Study (6) applying a case-control study design, in which GRS based on 10 polymorphisms in nine loci increased the predictive value from 0.78 to 0.79 ($P < 0.001$). In the latter study, however, glucose values were not included in the analyses (6). In both the DPP and DPS, in which gene–lifestyle interactions have been examined, lifestyle changes abolished the increased risk of type 2 diabetes in the carriers of the risk allele at *TCF7L2* locus (9,10). No other studies have used a similar approach. Thus, lifestyle intervention per se, at least in part, seems to abolish the genetic risk associations observed in observational cross-sectional and longitudinal studies.

The main predictors of the incidence of type 2 diabetes in our study were the lifestyle intervention, fasting and 2-h glucose, fasting insulin at baseline, and 1-year change in 2-h glucose and 2-h insulin. The finding that the 1-year changes in the 2-h glucose and insulin levels were powerful predictors of diabetes, whereas the 1-year change in fasting glucose level, which primarily reflects insulin secretion, did not contribute to the success rate of prevention, suggests a significant role of an improvement of insulin sensitivity along with weight reduction. Indeed, in a substudy of DPS, there was a marked improvement of insulin sensitivity based on intravenous glucose tolerance test along with weight loss, but only small changes were found in insulin secretion (23). Overall, these results show that an elevation of fasting glucose with poor insulin secretion capacity and the degree of insulin resistance and obesity remain the main predictive factors

among known risk factors for type 2 diabetes. We cannot exclude the possibility that the known genetic risk variants could have been operative in an earlier phase of development of diabetes, but along with this line, the changes in lifestyle also might be more effective in earlier phases of this disease.

Because insulin secretion and insulin sensitivity are not independent of each other, both mechanisms could be operative when searching biological explanations for the markedly decreased risk of diabetes in prevention trials such as the DPS. It has been hypothesized that lifestyle intervention may have beneficial effects on insulin secretion avoiding the exhaustion of β -cells and thus delaying the progression of disturbed insulin secretion capacity. Because the decrease in the 2-h glucose and insulin had a marked impact on the risk reduction of diabetes, we believe that an improvement in insulin sensitivity and perhaps concomitant recovery of β -cell sensitivity to glucose (24) could mainly explain the observed beneficial effects of changing lifestyles on the diabetes risk.

To conclude, conventional risk factors and lifestyle changes known to decrease the risk of diabetes are the most important predictors of type 2 diabetes in persons with IGT, and lifestyle changes overcome the impact of the known genetic and familial risk. This information is important both for health professionals and for persons at increased risk for type 2 diabetes. Our results in conjunction with some former population-based studies and the DPP genetic studies indicate that genetic risk testing at this point may not offer much additional information applicable to prevention strategies of type 2 diabetes to that obtained from patients' FH and the well-known clinical risk markers.

Acknowledgments—This study has been financially supported by grants from the Academy of Finland (117844 and 40758, 211497, and 118590 [to M.I.U.]; 38387 and 46558 [to J.T.]; 206310 and 73566 [to S.K.-K.]); 128315 and 129330 [to J.L.]; the Juho Vainio Foundation [to J.L.]; the Novo Nordisk Foundation [to J.L.]; The EVO-fund of Kuopio University Hospital (5106, 5168, and 5254 [to M.I.U.]); The Ministry of Education of Finland; The Finnish Diabetes Research Foundation; Sigrid Juselius Foundation; The Graduate School of Molecular Medicine; Nordic Centre of Excellence on “Systems biology in controlled dietary interventions and cohort studies” (SYSDIET;

project number 070014); TEKES 70103/06 and 40058/07; and INTERACT.

No other potential conflicts of interest relevant to this article were reported.

M.I.U. and J.T. are the principal investigators of the DPS. M.I.U. and A.S. wrote the article. A.S. and M.P. analyzed the data. J.T., J.L., M.I.U., S.K.-K., S.A., P.I.-P., and J.G.E. participated in the data collection and interpretation of the results. M.L. was responsible for genetic analyses and contributed to the interpretation of the results. All authors have seen the final version of the article and have commented on it before the acceptance of the article.

Part of these results were presented at the 28th International Symposium on Diabetes and Nutrition, Oslo, Norway, 1–4 July 2010.

References

- McCarthy MI, Zeggini E. Genome-wide association studies in type 2 diabetes. *Curr Diab Rep* 2009;9:164–171
- Grant RW, Hivert M, Pandiscio JC, Florez JC, Nathan DM, Meigs JB. The clinical application of genetic testing in type 2 diabetes: a patient and physician survey. *Diabetologia* 2009;52:2299–2305
- Voight BF, Scott LJ, Steinthorsdottir V, et al.; MAGIC Investigators; GIANT Consortium. Twelve type 2 diabetes susceptibility loci identified through large-scale association analysis. *Nat Genet* 2010;42:579–589
- Lyssenko V, Jonsson A, Almgren P, et al. Clinical risk factors, DNA variants, and the development of type 2 diabetes. *N Engl J Med* 2008;359:2220–2232
- Meigs JB, Shrader P, Sullivan LM, et al. Genotype score in addition to common risk factors for prediction of type 2 diabetes. *N Engl J Med* 2008;359:2208–2219
- Cornelis MC, Qi L, Zhang C, et al. Joint effects of common genetic variants on the risk for type 2 diabetes in U.S. men and women of European ancestry. *Ann Intern Med* 2009;150:541–550
- Uusitupa M. Gene-diet interaction in relation to the prevention of obesity and type 2 diabetes: evidence from the Finnish Diabetes Prevention Study. *Nutr Metab Cardiovasc Dis* 2005;15:225–233
- Weyrich P, Stefan N, Häring HU, Laakso M, Fritsche A. Effect of genotype on success of lifestyle intervention in subjects at risk for type 2 diabetes. *J Mol Med* 2007;85:107–117
- Florez JC, Jablonski KA, Bayley N, et al.; Diabetes Prevention Program Research Group. TCF7L2 polymorphisms and progression to diabetes in the Diabetes Prevention Program. *N Engl J Med* 2006;355:241–250
- Wang J, Kuusisto J, Vanttinen M, et al. Variants of transcription factor 7-like 2 (TCF7L2) gene predict conversion to type 2 diabetes in the Finnish Diabetes Prevention Study and are associated with impaired glucose regulation and impaired insulin secretion. *Diabetologia* 2007;50:1192–1200
- Kaprio J, Tuomilehto J, Koskenvuo M, et al. Concordance for type 1 (insulin-dependent) and type 2 (non-insulin-dependent) diabetes mellitus in a population-based cohort of twins in Finland. *Diabetologia* 1992;35:1060–1067
- Lyssenko V, Almgren P, Anevski D, et al.; Botnia study group. Predictors of and longitudinal changes in insulin sensitivity and secretion preceding onset of type 2 diabetes. *Diabetes* 2005;54:166–174
- Hilding A, Eriksson AK, Agardh EE, et al. The impact of family history of diabetes and lifestyle factors on abnormal glucose regulation in middle-aged Swedish men and women. *Diabetologia* 2006;49:2589–2598
- Hemminki K, Li X, Sundquist K, Sundquist J. Familial risks for type 2 diabetes in Sweden. *Diabetes Care* 2010;33:293–297
- Moore AF, Jablonski KA, McAteer JB, et al.; Diabetes Prevention Program Research Group. Extension of type 2 diabetes genome-wide association scan results in the diabetes prevention program. *Diabetes* 2008;57:2503–2510
- Eriksson J, Lindström J, Valle T, et al. Prevention of type II diabetes in subjects with impaired glucose tolerance: the Diabetes Prevention Study (DPS) in Finland. Study design and 1-year interim report on the feasibility of the lifestyle intervention programme. *Diabetologia* 1999;42:793–801
- Tuomilehto J, Lindström J, Eriksson JG, et al.; Finnish Diabetes Prevention Study Group. Prevention of type 2 diabetes mellitus by changes in lifestyle among subjects with impaired glucose tolerance. *N Engl J Med* 2001;344:1343–1350
- Lindström J, Ilanne-Parikka P, Peltonen M, et al.; Finnish Diabetes Prevention Study Group. Sustained reduction in the incidence of type 2 diabetes by lifestyle intervention: follow-up of the Finnish Diabetes Prevention Study. *Lancet* 2006;368:1673–1679
- Uusitupa M, Peltonen M, Lindström J, et al.; Finnish Diabetes Prevention Study Group. Ten-year mortality and cardiovascular morbidity in the Finnish Diabetes Prevention Study—secondary analysis of the randomized trial. *PLoS ONE* 2009;4:e5656
- Stancáková A, Kuulasmaa T, Paananen J, et al. Association of 18 confirmed susceptibility loci for type 2 diabetes with indices of insulin release, proinsulin conversion, and insulin sensitivity in 5,327 non-diabetic Finnish men. *Diabetes* 2009;58:2129–2136
- Baptiste-Roberts K, Gary TL, Beckles GL, et al. Family history of diabetes, awareness of risk factors, and health behaviors among African Americans. *Am J Public Health* 2007;97:907–912
- Florez JC. Clinical review: the genetics of type 2 diabetes: a realistic appraisal in 2008. *J Clin Endocrinol Metab* 2008;93:4633–4642
- Uusitupa M, Lindi V, Louheranta A, Salopuro T, Lindström J, Tuomilehto J; Finnish Diabetes Prevention Study Group. Long-term improvement in insulin sensitivity by changing lifestyles of people with impaired glucose tolerance: 4-year results from the Finnish Diabetes Prevention Study. *Diabetes* 2003;52:2532–2538
- Mari A, Tura A, Natali A, et al.; RISC Investigators. Impaired beta cell glucose sensitivity rather than inadequate compensation for insulin resistance is the dominant defect in glucose intolerance. *Diabetologia* 2010;53:749–756