Contribution of the Nurses' Health Studies to Uncovering Risk Factors for Type 2 Diabetes: Diet, Lifestyle, Biomarkers, and Genetics

Sylvia H. Ley, PhD, RD, Andres V. Ardisson Korat, MS, Qi Sun, ScD, Deirdre K. Tobias, ScD, Cuilin Zhang, MD, PhD, Lu Qi, MD, PhD, Walter C. Willett, MD, DrPH, JoAnn E. Manson, MD, DrPH, and Frank B. Hu, MD, PhD

Objectives. To review the contribution of the Nurses' Health Study (NHS) and the NHS II to addressing hypotheses regarding risk factors for type 2 diabetes.

Methods. We carried out a narrative review of 1976 to 2016 NHS and NHS II publications.

Results. The NHS and NHS II have uncovered important roles in type 2 diabetes for individual nutrients, foods, dietary patterns, and physical activity independent of excess body weight. Up to 90% of type 2 diabetes cases are potentially preventable if individuals follow a healthy diet and lifestyle. The NHS investigations have also identified novel biomarkers for diabetes, including adipokines, inflammatory cytokines, nutrition metabolites, and environmental pollutants, offering new insights into the pathophysiology of the disease. Global collaborative efforts have uncovered many common genetic variants associated with type 2 diabetes and improved our understanding of gene–environment interactions. Continued efforts to identify epigenetic, metagenomic, and metabolomic risk factors for type 2 diabetes have the potential to reveal new pathways and improve prediction and prevention.

Conclusions. Over the past several decades, the NHS and NHS II have made major contributions to public health recommendations and strategies designed to reduce the global burden of diabetes. (*Am J Public Health.* 2016;106:1624–1630. doi:10.2105/AJPH.2016.303314)

EDITOR'S NOTE: Because of space restrictions and the large volume of references relevant to the Nurses' Health Study, additional references are provided in a supplement to the online version of this article at http://www.ajph.org.

Worldwide, 415 million adults are living with diabetes, and this estimate is projected to rise to 642 million by 2040. Nearly 12% of global health expenditures are devoted to diabetes-related treatments, and the United States alone accounted for $348 billion in 2015. Type 2 diabetes has become an important public health priority in recent decades, and considerable efforts have been made to identify effective preventive strategies.[1]

Prospective cohort studies have contributed significantly to the understanding of modifiable type 2 diabetes risk factors.[2] Research on novel biomarkers and intermediate phenotypes associated with diabetes risk has provided new insights into disease etiology and progression. Heterogeneity in individuals' responses to behavioral and lifestyle risk factors might be explained by differences in their metabolism, their intervention adherence, and complex gene–environment interactions.[3]

The Nurses' Health Study (NHS; initiated in 1976) and the NHS II (initiated in 1989) followed more than 200 000 participants during the decades contemporaneous with the evolving type 2 diabetes epidemic, making these studies ideally positioned to investigate type 2 diabetes and its risk factors. Our approach to identifying, confirming, and validating incident type 2 diabetes cases has been described in an earlier article.[4] The NHS cohorts have generated substantial scientific data and played an important role in elucidating the complex behavioral, metabolic, environmental, and genetic factors influencing type 2 diabetes risk (see the online appendix, available as a supplement at http://www.ajph.org, for relevant publications).[5]

ADIPOSITY, DIET, AND LIFESTYLE FACTORS

The NHS investigations have contributed to understanding behavioral risk factors for type 2 diabetes such as adiposity, diet, and other lifestyle factors.

Obesity

In the NHS cohorts, excess adiposity was the strongest type 2 diabetes risk factor.[6] Type 2 diabetes risk rose as excessive body fat increased, starting from the lower end of a healthful body mass index (BMI) or waist circumference.[7] Central adiposity (high waist

ABOUT THE AUTHORS

Sylvia H. Ley, Andres V. Ardisson Korat, Qi Sun, Lu Qi, Walter C. Willett, and Frank B. Hu are with the Department of Nutrition, Harvard T. H. Chan School of Public Health, Boston, MA. Deirdre K. Tobias and JoAnn E. Manson are with the Division of Preventive Medicine, Department of Medicine, Brigham and Women's Hospital and Harvard Medical School, Boston. Cuilin Zhang is with Epidemiology Branch, Division of Intramural Population Health Research, Eunice Kennedy Shriver National Institute of Child Health and Human Development, National Institutes of Health, Bethesda, MD.

Correspondence should be sent to Frank B. Hu, MD, PhD, Harvard T. H. Chan School of Public Health, 665 Huntington Ave, Boston, MA 02115 (e-mail: frank.hu@channing.harvard.edu). Reprints can be ordered at http://www.ajph.org by clicking the "Reprints" link.

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circumference or waist-to-hip ratio) was associated with type 2 diabetes risk in the NHS, even after adjustment for BMI. Duration of overweight/obesity was also an important predictor, as each 2 extra years of being obese increased an individual's type 2 diabetes risk by 14%. Although weight at age 18 years was initially associated with type 2 diabetes risk, this association was eliminated after adjustment for current adulthood BMI. Adulthood weight gain (after the age of 18 years) was an important type 2 diabetes risk factor.

Weight cycling, the repeated loss and regain of body weight, was also associated with type 2 diabetes risk initially, but the association was not independent of current BMI. Adiposity has been shown to interact with physical inactivity to augment type 2 diabetes risk, and adiposity was an important mediator of the relationship between a family history of diabetes and incident type 2 diabetes.

Diet

Diet has long been presumed to have a role in the development and progression of type 2 diabetes, and a vast amount of evidence from prospective studies evaluating diet in relation to type 2 diabetes incidence has accumulated in the past couple of decades.[8] With repeated dietary measures taken every 4 years, the NHS cohorts have played a vital role in understanding the relationship between various dietary factors and type 2 diabetes risk.

Nutrients. Although higher total fat intake was initially hypothesized to contribute to diabetes by inducing insulin resistance and promoting weight gain, the NHS did not reveal an association between total fat intake and type 2 diabetes risk.[9] Diets that favor plant-based oils over animal fats were associated with a lower type 2 diabetes risk.[9] Greater intake of *n*-6 polyunsaturated fatty acids was associated with a lower risk as well, whereas greater intake of trans fatty acids was associated with a higher risk independent of other fats.[10] Replacing trans fatty acids or saturated fat with *n*-6 polyunsaturated fatty acids was related to a lower type 2 diabetes risk.[9,10]

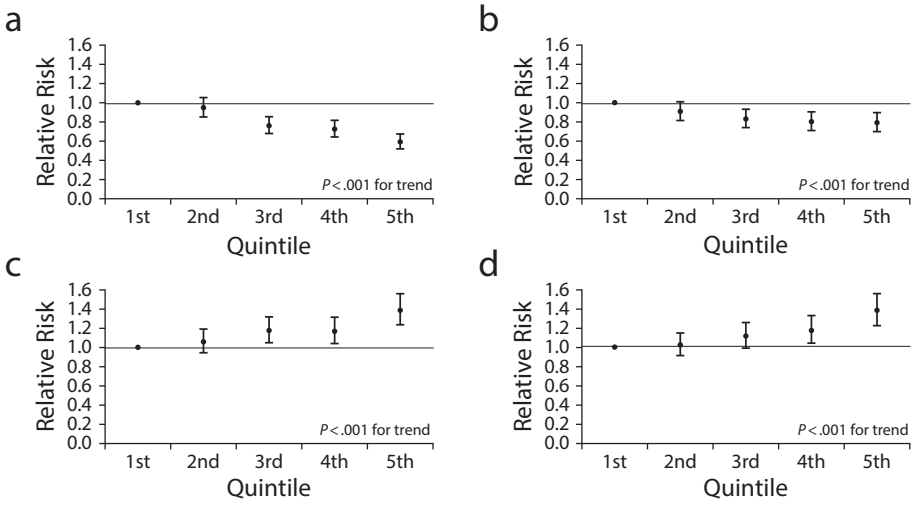
A diet rich in fiber, especially fiber from cereal products, has been associated with a lower type 2 diabetes risk.[11] Higher carbohydrate quality, evaluated via the glycemic index and glycemic load, which measure an individual's glycemic response to carbohydrate-rich foods, was associated with a lower risk[12] independent of the amount of cereal fiber in a person's diet. Higher starch consumption, low fiber consumption, and a high starch-to-cereal-fiber ratio were associated with a higher type 2 diabetes risk. Figure 1 summarizes key nutrient factor findings from the NHS,[7] underscoring the importance of overall quality of fats and carbohydrates in reducing type 2 diabetes risk.

Higher intake of magnesium and zinc was associated with a lower type 2 diabetes risk, whereas higher heme iron intake was associated with a greater risk. Higher levels of plasma 25-hydroxyvitamin D and toenail selenium were associated with a lower type 2 diabetes incidence. The NHS data suggest that suboptimal micronutrient intakes may also contribute to type 2 diabetes risk. However, these single-nutrient-based findings may have been confounded by other correlated nutrients and dietary factors.

Foods and beverages. Findings from analyses of individual foods or food groups have direct relevance for dietary recommendations. Greater whole grain intake was associated with a lower type 2 diabetes risk in the NHS cohorts.[13] Substitution of whole grains for other grains, such as 50 grams per day of cooked brown rice for the same amount of white rice, was associated with a 16% lower type 2 diabetes risk.[14] Greater intake of potatoes, especially french fries, was associated with a higher type 2 diabetes risk,[15] whereas substitution of 1 serving of whole grains for the same amount of potatoes was associated with a lower risk.

Frequent consumption of red meats, especially processed red meats such as bacon, sausages, and hot dogs, was strongly associated with a higher type 2 diabetes risk in the NHS cohorts.[16] Increasing red meat consumption over a 4-year period was associated with an increased subsequent 4-year type 2 diabetes risk.[17] In addition, greater red meat intake was associated with increased fasting insulin, hemoglobin A1c, and inflammatory biomarkers among healthy individuals. Substituting one serving of nuts, low-fat dairy, or whole grains per day for the same amount of red meat was associated with a 16% to 35% lower risk of type 2 diabetes.[16]

Although there was no association between risk of type 2 diabetes and total intake



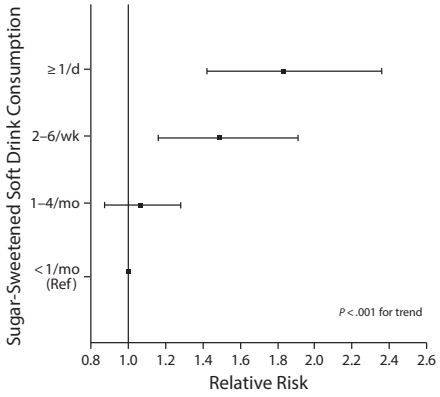
Note. Whiskers indicate 95% confidence intervals. Each of the relative risks was adjusted for the other 3 dietary variables and for age, time, the presence or absence of a family history of diabetes, menopausal status, use or nonuse of postmenopausal hormone therapy, smoking status, body mass index, weekly frequency of moderate to vigorous exercise, and daily alcohol consumption.

Source. Adapted with permission from Hu et al.[7]

FIGURE 1—Multivariate Relative Risks for Type 2 Diabetes According to Ascending Quintiles of Intake of (a) Cereal Fiber, (b) the Ratio of Polyunsaturated-Fat Intake to Saturated-Fat Intake, (c) Intake of Trans Fat, and (d) Glycemic Load: Nurses' Health Study, United States, 1980–1996

of fruits and vegetables in the NHS cohorts, greater intake of green leafy vegetables was associated with lower risk. Greater consumption of specific whole fruits rich in anthocyanin, such as blueberries, grapes, apples, and pears, was associated with a lower type 2 diabetes risk.[18] Regular consumption of nuts was also inversely related to type 2 diabetes risk. Higher intake of yogurt was associated with a lower type 2 diabetes risk, although total dairy consumption was not associated with incident type 2 diabetes.[19]

Greater intake of sugar-sweetened beverages (SSBs) has been associated with a higher type 2 diabetes risk (Figure 2).[20] In our analyses, this association remained significant even after adjustment for BMI, suggesting that the deleterious effects of SSBs are not entirely mediated by body weight. Substitution of plain water, coffee, or tea for SSBs was associated with a lower type 2 diabetes risk. Regular coffee consumption was also associated with a lower risk.[21] A U-shaped relationship between alcohol consumption and type 2 diabetes risk was observed, with the lowest risk in the moderate range of consumption (1–2 US standard drinks per day).[22] Moderate alcohol consumption may attenuate the positive association between dietary glycemic load and type 2 diabetes risk.



Note. Whiskers indicate 95% confidence intervals. The sample size was n = 91 249 women. Relative risks were adjusted for age, alcohol intake, physical activity, family history of diabetes, smoking, menopausal hormone use, oral contraceptive use, intake of cereal fiber, magnesium, trans fat, and ratio of polyunsaturated to saturated fat.

Source. Adapted with permission from Schulze et al.[20]

FIGURE 2—Relative Risks for Type 2 Diabetes According to Frequency of Sugar-Sweetened Beverage Consumption: Nurses' Health Study II, United States, 1991–1999

Dietary patterns. In addition to individual foods and nutrients, the NHS and NHS II have involved extensive analyses of various dietary patterns and type 2 diabetes risk. Dietary patterns that were characterized by higher intakes of fruits, vegetables, whole grains, and legumes and lower intakes of red meats, refined grains, and SSBs were associated with a lower type 2 diabetes risk.[23,24] A Western dietary pattern during adolescence, characterized by higher intakes of red and processed meats, refined grains, and sweets, was associated with a higher risk of developing type 2 diabetes in adulthood.

In the NHS, the Alternate Healthy Eating Index was developed as a measure of adherence to dietary guidelines based on the foods and nutrients most consistently associated with lower risk of chronic disease. This index, consisting of 11 components (with a higher quality diet indicated by greater intake of vegetables, fruits, nuts and legumes, long-chain fats, and whole grains; lower intake of SSBs, red and processed meat, trans fat, and sodium; and moderate alcohol consumption), was strongly associated with a lower type 2 diabetes risk.

Several other characteristics of eating patterns and overall diet quality were associated with diabetes risk in the NHS. For example, skipping breakfast and frequently consuming fried foods were associated with a higher risk of type 2 diabetes, and these associations were partially explained by elevated BMIs.

Physical Activity

Physical inactivity is now a well-accepted risk factor for type 2 diabetes, and the NHS cohorts have provided strong supporting evidence. For example, moderate- to high-intensity exercise such as brisk walking was inversely associated with type 2 diabetes risk in the NHS, even after adjustment for BMI,[4] and faster walking pace was independently associated with a lower risk as well.[25] By contrast, sedentary behavior, including TV viewing, was associated with a higher type 2 diabetes risk (Figure 3).[26] In the NHS cohorts, engagement in both moderate and vigorous aerobic physical activity and muscle-strengthening activity such as toning, yoga, and resistance training was associated with a lower type 2 diabetes risk.[27]

Smoking

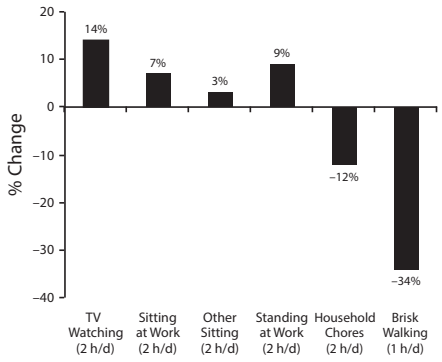
Exposure to both passive and active smoking was associated with a higher type 2 diabetes risk in the NHS,[28] with current smokers having the highest risk of type 2 diabetes in a dose-dependent manner with increased numbers of cigarettes smoked.[28] Although the risk of incident type 2 diabetes diminished with increased time since quitting, some elevation in risk remained even 20 to 29 years later.[28]

Sleep Quantity and Quality

In the NHS cohorts, quantity and quality of sleep were associated with type 2 diabetes risk. Both long (≥ 9 hours per day) and short (≤ 5 hours per day) sleep durations were associated with a higher risk of type 2 diabetes.[29] Furthermore, increases in sleep duration were associated with increased weight gain and type 2 diabetes risk, and extended periods of rotation night shift work were associated with a higher type 2 diabetes risk. Other measures of sleep quality were associated with type 2 diabetes risk as well, including regular snoring and difficulty falling or staying asleep. Lower melatonin secretion (measured from first morning urine samples), an indicator of sleep disruption, was independently associated with a higher risk of type 2 diabetes.[30]

Combined Role of Adiposity, Diet, and Lifestyle Factors

The data from the NHS suggest that more than 90% of type 2 diabetes cases are potentially preventable if individuals follow a healthful diet, have a BMI of 25 kilograms per meters squared or less, exercise for at least 30 minutes a day, avoid smoking, and consume alcohol in moderation.[7] These data, together with those from randomized controlled trials conducted among high-risk individuals, indicate that diet and lifestyle modification is of paramount importance in preventing type 2 diabetes (Table 1).



Note. Data were adjusted for age, smoking, alcohol consumption, family history of diabetes, and dietary covariates. All sedentary behavior variables were included simultaneously in the model. Other sitting includes reading, eating meals, and time spent sitting at a desk.

Source. Adapted with permission from Hu et al.[26]

FIGURE 3—Percent Changes in Risk of Developing Type 2 Diabetes Associated With TV Viewing, Other Sedentary Behaviors, and Walking: Nurses' Health Study, United States, 1992–1998

BIOMARKERS

The NHS investigations have identified novel biomarkers for incident type 2 diabetes and offered new insights into the pathophysiology of the disease.

Cytokines, Adipokines, and Insulin-Like Growth Factors

Higher levels of pro-inflammatory biomarkers, including tumor necrosis factor-α, interleukin-6, interleukin-18, and C-reactive protein, were associated with a higher risk of type 2 diabetes in the NHS,[31] independent of BMI. Endothelial dysfunction biomarkers, such as E-selectin and intercellular adhesion molecule 1, were associated with type 2 diabetes risk as well. Higher levels of adiponectin, an anti-inflammatory adipokine, were associated with a lower type 2 diabetes risk. The high-molecular-weight to total adiponectin ratio was also related to lower risk, independent of total adiponectin.

Higher fetuin-A, a glycoprotein secreted by the liver, was associated with a higher type 2 diabetes risk independent of liver enzymes (i.e., gama-glutamyl transferase and alanine aminotransferase). Lower levels of fetuin-A and insulin explained a significant proportion of the inverse association between moderate alcohol consumption and type 2 diabetes.

Laboratory models have shown that insulin-like growth factor (IGF)-1, which shares structural homology with insulin, and its binding proteins IGFBP-1 and IGFBP-2 have potentially beneficial effects on diabetes risk, whereas IGFBP-3 may have adverse effects. In the NHS, total IGF-1 was not significantly associated with type 2 diabetes risk, but free IGF-1 was inversely associated with type 2 diabetes risk among women with higher insulin concentrations and positively associated with risk among those with lower insulin concentrations. Lower IGFBP-1 and IGFBP-2 levels were associated with a lower type 2 diabetes risk, and higher IGFBP-3 levels were associated with a higher risk.

Biomarkers of Dietary Bioactive Compounds

In the NHS cohorts, urinary excretion of polyphenol metabolites was investigated as a biomarker of polyphenol intake from fruits, vegetables, grains, coffee, and other plant-based foods in relation to type 2 diabetes risk. Specific flavonoid subclasses such as flavanones and flavonols, in addition to caffeic acid, were associated with a lower type 2 diabetes risk over a median follow-up period of 4.6 years.[32] Urinary isoflavones were also associated with a lower risk, especially among postmenopausal women who did not use hormone therapy. Urinary lignan metabolites, especially entrerolactone, were associated with a lower risk as well. Additional investigations are warranted to confirm these findings and to explore potential mechanisms underlying the associations observed.

GENETIC FACTORS

Earlier efforts to identify genetic variants of type 2 diabetes heritability in epidemiological studies involved genome-wide linkage and candidate gene approaches. With the introduction of genome-wide association studies (GWASs) involving high-throughput genotyping technology, the field advanced rapidly in identifying and replicating novel loci associated with type 2 diabetes and diabetes-related traits. Through use of the GWAS approach, the NHS has identified several novel loci for type 2 diabetes and for diabetes-related biomarkers such as leptin receptor and interleukin-18, although these loci did not add clinically significant prediction beyond traditional type 2 diabetes risk factors.[3]

Because of small effects of common variants,[3] cumulative genetic risk scores were used in the NHS, and their relations with type 2 diabetes risk were assessed. For example, on the basis of established loci for blood lipids, a genetic predisposition to dyslipidemia was estimated according to a genotype score focusing on lipids such as low-density lipoprotein cholesterol, high-density lipoprotein cholesterol, and triglycerides. These scores were used to relate a genetic predisposition to low levels of high-density lipoprotein cholesterol or high levels of triglycerides to a higher risk of type 2 diabetes.[33]

Furthermore, the NHS was active in collaborative efforts through its contributions of GWAS and phenotype data to international consortia. For example, the NHS was part of a global collaboration of 23 studies involving populations of European ancestry comprising 27 206 type 2 diabetes cases and 57 574 controls, leading to the identification and mapping of numerous new loci for type 2 diabetes.

Gene–environment interaction studies have also faced methodological challenges in investigating small effects of common gene variants,[3] and genetic risk scores, which represent accumulative genetic effects, are widely used to investigate gene–environment interactions. In a nested case–control investigation conducted as part of the NHS, a type 2 diabetes genetic risk score was calculated on the basis of 10 polymorphisms in 9 loci.[34] The results showed a stronger association between genetic risk score and type 2 diabetes among individuals with higher BMIs.[34]

The NHS provided important data for several landmark studies in the field of gene–environment interactions. For example, an interaction between genetic predisposition and SSB intake was investigated in relation to BMI by means of a genetic predisposition score calculated on the basis of 32 BMI-associated loci.[35] Higher SSB intake was associated with a more pronounced genetic predisposition to a higher BMI and an increased risk of obesity.[35] In an

TABLE 1—Role of Lifestyle Factors in Type 2 Diabetes Risk: The Nurses' Health Studies, United States, 1976–2016

Category	Protective Factors	Predisposing Factors
Body fat	Maintaining a healthy body weight; weight loss	Excessive body fat
Nutrients	N-6 polyunsaturated fatty acids; fiber; magnesium; zinc; vitamin D; selenium	Trans fatty acids; heme iron; high glycemic index and glycemic load; high starch-to-cereal-fiber ratio
Foods and beverages	Whole grains; nuts; yogurt; green leafy vegetables; whole fruits rich in anthocyanin (e.g., blueberries, grapes, apples, pears); coffee; moderate alcohol consumption	White rice; potatoes and French fries; red/processed meat; sugar-sweetened beverages; fruit juices
Dietary patterns	Adherence to healthy eating recommendations	Western dietary pattern
Physical activity	Moderate- to high-intensity exercise; brisk walking	Sedentary behavior (prolonged TV viewing, sitting)
Smoking	Smoking cessation	Active and passive smoking
Sleep	6–8 h/d of sleep	Long and short sleep durations; extended periods of rotation night shift work

investigation involving a similar approach, another interaction was reported between fried food consumption and genetic predisposition to adiposity,[36] indicating that genetic influences on adiposity are amplified by regular consumption of fried foods.

There have also been collaborative cross-study efforts to investigate gene–environment interactions (e.g., the Cohorts for Heart and Aging Research in Genomic Epidemiology Consortium). For example, a meta-analysis of 14 cohort studies comprising approximately 48 000 participants of European descent investigated interactions between the *GCKR* (rs780094) variant and whole grain intake with respect to fasting insulin. In this analysis, greater whole grain intake was associated with smaller reductions in fasting insulin among those with the insulin-raising allele.

Together, the NHS cohorts have contributed substantially to our understanding of the pathophysiology of type 2 diabetes. Continued advances in knowledge of gene–environment interactions and identification of epigenetic, metagenomic, and metabolomic factors will be important for precision in predicting, preventing, and intervening in type 2 diabetes.

LIFE COURSE AND REPRODUCTIVE FACTORS

The NHS investigations have contributed to understanding life course and reproductive risk factors for type 2 diabetes among women.

Prenatal and Early Life Factors

In meta-analyses, including those focusing on the NHS data,[37] a U-shaped relationship has been reported between birth weight and risk of developing type 2 diabetes later in life. In the NHS, birth weights below 2500 grams and above 4000 grams were associated with a higher type 2 diabetes risk than normal birth weights (2500–4000 g). A higher type 2 diabetes risk occurring at low birth weights could be explained by fetal undernutrition during critical periods of development leading to the disease later in life; a higher risk at higher birth weights might be explained by overnutrition during this period leading to later glucose intolerance. Although birth weight is associated with type 2 diabetes risk, evidence from the NHS cohorts suggests that most type 2 diabetes cases can be prevented by adoption of a healthier lifestyle later in life.[38]

In comparison with the reference age of 13 years, early age at menarche (12 years or younger) was associated with a higher type 2 diabetes risk later in life. Larger body size during childhood, assessed via recall and pictorial diagrams, was associated with a higher type 2 diabetes risk in adulthood, although this association was not evident among those who became lean in adulthood.

Pregnancy and Reproductive Factors

Women with a very preterm birth (20–32 weeks of gestation) had a higher type 2 diabetes risk in the decade after their pregnancy. Furthermore, delivering a macrosomic infant was associated with a higher type 2 diabetes risk among mothers in the first 5 years after their pregnancy. Higher parity was not associated with type 2 diabetes risk after adjustment for BMI and other confounders. Longer duration of lactation was associated with a lower type 2 diabetes risk.

Current oral contraceptive use did not substantially influence type 2 diabetes risk in the NHS, although a marginally positive association was observed between past use and diabetes. After adjustment for BMI, current users of postmenopausal hormone therapy had a lower type 2 diabetes risk than those who had never used postmenopausal hormone therapy. Type of hormone therapy (estrogen alone, progesterone alone, or combination) did not influence risk.

DEPRESSION AND PSYCHOSOCIAL FACTORS

The relationship between depression and diabetes appears to be bidirectional.[39] Use of antidepressant medications was associated with a higher type 2 diabetes risk. Increased symptoms of posttraumatic stress disorder were associated with a higher type 2 diabetes risk in the NHS II,[40] and severe psychological violence from an intimate partner was associated with a higher risk as well. Higher phobic anxiety symptom scores were also associated with type 2 diabetes risk. Low socioeconomic status in both childhood and

adulthood was associated with a higher type 2 diabetes risk, which may have been partially mediated through psychosocial vulnerability and mental stress.

ENVIRONMENTAL POLLUTANTS

The NHS has contributed to a growing body of literature supporting a role of endocrine-disrupting chemicals in type 2 diabetes risk. A meta-analysis of the NHS and 6 other prospective studies showed that higher urinary levels of persistent organic pollutants were associated with a higher type 2 diabetes risk. Higher urinary levels of bisphenol-A and phthalate metabolites were associated with type 2 diabetes risk among middle-aged but not older women.[41] Exposure to varying degrees of particulate matter during the 12 months before type 2 diabetes diagnosis was not associated with risk of the disease among NHS participants living in metropolitan areas. However, living less than 50 meters from a major road, as a proxy for particulate matter exposure, was associated with a higher type 2 diabetes risk than living more than 200 meters from a major road.

RISK FACTORS FOR GESTATIONAL DIABETES

Gestational diabetes, a common pregnancy complication, is a key type 2 diabetes risk factor. Advanced maternal age, family history of diabetes, non-White ethnicity, higher prepregnancy BMI, weight gain in early adulthood, and cigarette smoking are well-documented gestational diabetes risk factors.[42] Several modifiable gestational diabetes risk factors were reported in the NHS II, and most of them were similar to the risk factors for type 2 diabetes. For example, regular prepregnancy physical activity was associated with a lower gestational diabetes risk, whereas prepregnancy unhealthy dietary patterns and diets high in glycemic load, heme iron, animal fat and protein, potatoes, and SSBs were associated with a higher risk. Collectively, approximately 47% of gestational diabetes cases may be preventable through diet and lifestyle modifications.[43]

Furthermore, early life exposures such as maternal cigarette smoking during pregnancy and early age at menarche were associated with a higher gestational diabetes risk. Maintaining healthy lifestyles remains important with respect to lowering type 2 diabetes risk after a gestational diabetes pregnancy.[44,45]

SUMMARY AND PUBLIC HEALTH PERSPECTIVES

The prevalence of type 2 diabetes has increased rapidly in recent decades, and the disease has become a major public health concern. The NHS and the NHS II, which followed a large number of participants during the evolution of the diabetes epidemic, have provided critical data to quantify the roles of diet, lifestyle, biomarkers, and genetics in the development of type 2 diabetes. There is compelling evidence that excess adiposity is the single most important risk factor for type 2 diabetes; thus, maintaining a healthy body weight and avoiding excess weight gain during adulthood are the cornerstones of diabetes prevention. Diet quality can contribute to diabetes prevention independent of body weight. Higher consumption of coffee, whole grains, fruits, and nuts is associated with a lower type 2 diabetes risk, whereas regular consumption of refined grains, red and processed meats, and SSBs is associated with a higher risk.

The NHS data have contributed substantially to current dietary guidelines and policies that promote healthy eating patterns and limit consumption of SSBs, refined grains, and red and processed meats as a means of preventing chronic diseases such as type 2 diabetes. However, translating scientific evidence into practice requires fundamental changes in public policies, the food industry, built environments, and health care systems. AJPH

CONTRIBUTORS

S. H. Ley and F. B. Hu drafted the article. All of the authors participated in critical revisions of the article.

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Note. The authors assume full responsibility for the analyses and interpretation of the data described in this article.

HUMAN PARTICIPANT PROTECTION

The study protocol was approved by the institutional review boards of Brigham and Women's Hospital and the Harvard School of Public Health. Participants provided written informed consent.

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