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Trends in the Incidence of Type 2 Diabetes Mellitus From the 1970s to the 1990s

The Framingham Heart Study

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Background—Recent studies indicate that the prevalence of type 2 diabetes mellitus is increasing in the United States; less is known about trends in the incidence of type 2 diabetes mellitus.

Methods and Results—Participants free of diabetes mellitus (n=3104; mean age 47 years; 1587 women) from the Framingham Offspring Study who attended a routine examination in the 1970s, 1980s, or 1990s were followed up for the 8-year incidence of diabetes mellitus. Diabetes was defined as a fasting plasma glucose ≥7.0 mmol/L or treatment with either insulin or a hypoglycemic agent. Pooled logistic regression was used to compare diabetes incidence across decades for participants between 40 and 55 years of age in each decade. The age-adjusted 8-year incidence rate of diabetes was 2.0%, 3.0%, and 3.7% among women and 2.7%, 3.6%, and 5.8% among men in the 1970s, 1980s, and 1990s, respectively. Compared with the 1970s, the age- and sex-adjusted odds ratio (OR) for diabetes was 1.40 (95% confidence interval [CI], 0.89 to 2.22) in the 1980s and 2.05 (95% CI, 1.33 to 3.14) in the 1990s (*P* for trend=0.0006). Among women, the OR was 1.50 (95% CI, 0.75 to 2.98) in the 1980s and 1.84 (95% CI, 0.95 to 3.55) in the 1990s (*P* for trend=0.07) compared with the 1970s, whereas among men, the OR was 1.33 (95% CI, 0.72 to 2.47) in the 1980s and 2.21 (95% CI, 1.25 to 3.90) in the 1990s (*P* for trend=0.003). Most of the increase in absolute incidence of diabetes occurred in individuals with body mass index ≥30 kg/m^2 (*P* for trend=0.03).

Conclusions—In the present community-based sample of middle-aged adults, we observed a doubling in the incidence of type 2 diabetes over the last 30 years. Careful surveillance of changes in diabetes incidence may be necessary if current trends of excess adiposity continue. (*Circulation*. 2006;113:2914-2918.)

Key Words: diabetes mellitus ■ epidemiology ■ obesity ■ population ■ prevention

Obesity[1,2] and weight gain[3] are leading risk factors for the development of diabetes mellitus. Several epidemiological reports indicate that the prevalence[4–10] and incidence[8,10] of diabetes are increasing. The prevalence of diabetes has increased up to 50%,[7,11] and crude incidence rates were reported to have tripled over the past decade among Hispanic participants in the San Antonio Heart Study.[8]

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However, there are limitations to prior work, including the use of relatively short time periods to document trends,[4–9] the use of self-reported diabetes status,[4–6] changing definitions of diabetes, use of cases derived from a pharmacoepidemiological database,[9] and the limited use of incidence data.[8–10] Furthermore, it is unclear how relative changes in body weight have contributed to changes in the incidence of diabetes. Thus, we sought to examine trends in the incidence of diabetes in the Framingham Offspring Study, in which routine screening for diabetes has been performed since the study's inception. We also examined trends by categories of body mass index (BMI) to determine the relative contribution of changes in body weight to changes in incidence of diabetes.

Methods

Study Sample

Individuals with diabetes were identified during the entirety of follow-up of Framingham Heart Study offspring participants. Beginning in 1948, 5209 men and women aged 28 to 62 years were enrolled in the original cohort of the Framingham Heart Study. Offspring and spouses of the offspring of the original cohort were enrolled in the Offspring Study starting in 1971. Original cohort subjects were invited to attend examinations every 2 years, and offspring subjects were invited to attend examinations every 4 years,

with the exception of an 8-year interval between the first and second offspring examinations.

Selection criteria and study design have been described in detail.[12,13] Briefly, the standard clinic examination included a physician interview, a physical examination, and laboratory tests. The study sample consisted of offspring participants free of diabetes at the following index examinations: the first (1971 to 1975; the 1970s), second (1979 to 1983; the 1980s), or fourth (1987 to 1991; the 1990s) examination cycle. Participants were followed up for 8 years for the development of diabetes. Incident diabetes cases were diagnosed after 8 years of follow-up for consistency within these 3 time periods. The present study sample was defined a priori as participants attending 2 Framingham Heart Study examinations 8 years apart. Thus, participants lost to follow-up between examinations were not eligible for the present analysis. In the 1980s and 1990s, there was an intermediate examination 4 years after baseline; however, because no such intermediate examination occurred in the 1970s, we did not consider any data from these examinations in the 1980s and 1990s. Participants were able to contribute to more than 1 time period as long as they remained free of diabetes. Overall, there were 69 unique individuals with incident diabetes among 1587 unique women and 93 unique individuals with incident diabetes among 1517 unique men.

Incidence rates were examined across the 3 time periods. To reduce the influence of aging in the study's closed cohort and to ensure that age distributions across all decades overlapped, we restricted our analysis to subjects between ages 40 and 55 years at baseline for each index examination. This age range was represented in all decades.

The authors had full access to the data and take full responsibility for its integrity. All authors have read and agree to the manuscript as written.

Diabetes Ascertainment

Diabetes was defined as a fasting plasma glucose ≥ 7.0 mmol/L at a Framingham Offspring Study examination or treatment with either insulin or a hypoglycemic agent. Fasting plasma glucose was measured in fresh specimens. Chart review was conducted to identify participants with type 1 diabetes mellitus; those individuals were excluded from the analyses (n=9).

Risk Factor Assessment

BMI was defined as weight (kilograms) divided by the square of height (meters) and was measured at each index examination.

Statistical Analysis

We compared the decade-specific 8-year incidence rates for diabetes for 3 time periods: 1970s, 1980s, and 1990s. The 1970s were used as the referent time period, and the odds of developing diabetes in the 1980s and 1990s were compared with pooled logistic regression.[14] Models were adjusted first for age and sex and then additionally for BMI; sex-specific analyses were performed as well. Additionally, we calculated age-adjusted, sex-specific diabetes incidence rates with 95% confidence intervals (CIs) for each time period on the basis of the pooled logistic regression modeling. A secondary analysis was conducted in which diabetes incidence was recomputed relying solely on fasting plasma glucose.

In descriptive analyses, we investigated the influence of BMI on the incidence of diabetes by calculating the 8-year incidence of diabetes for each decade and BMI category (<25, 25 to 29.9, and ≥ 30 kg/m²). SAS version 8.0 software (SAS Institute, Inc, Cary, NC) was used to perform all computations.[15]

Results

Overall, 1587 women and 1517 men free of diabetes at baseline attended examination cycles 1, 2, or 4 of the Framingham Offspring cohort. These 3104 unique individuals contributed to 4523 total person-examinations of observation. The mean age was 47 years old (Table 1). From the

TABLE 1. Baseline Characteristics of Study Sample (Women and Men Aged 40 to 55 Years) Free of Diabetes by Decade of Examination

	1970s	1980s	1990s
Women			
Person-examinations, n*	656	786	862
Age, y	46±4	47±5	47±4
BMI, kg/m²	25.3±4.3	25.1±4.5	25.7±5.3
Men			
Person-examinations, n*	653	765	801
Age, y	46±4	47±5	47±4
BMI, kg/m²	27.2±3.2	27.3±3.5	27.9±3.9

Values are mean±SD or n.
*Examinations included 1587 unique women and 1517 unique men.

1970s to the 1990s, mean BMI ranged from 25.3 to 25.7 kg/m² in women and from 27.2 to 27.9 kg/m² in men, with higher values in the later decades (age-and-sex–adjusted P for trend=0.0006).

The 8-year incidence rate of diabetes was 2.0% in the 1970s in women, increasing to 3.0% in the 1980s and 3.7% in the 1990s (Table 2). In men, the incidence rate was 2.7% in the 1970s, 3.6% in the 1980s, and 5.8% in the 1990s.

In age-and-sex–adjusted logistic regression models (Table 3), the odds of incident diabetes increased by 40% in the 1980s compared with the 1970s and doubled in the 1990s (P for trend=0.0006). Sex-specific analyses demonstrated a nonsignificant 50% increase in women in the 1980s and an 80% increase in diabetes incidence in the 1990s (P for trend=0.07). In men, diabetes increased by 33% in the 1980s and slightly more than doubled in the 1990s (P for trend=0.003). The observed gender difference was not statistically significant ($P=0.50$). Adjustment for BMI attenuated but did not diminish the significance of these findings (Table 3). In a secondary analysis in which trends in diabetes incidence over time were recomputed based solely on fasting plasma glucose status, results were unchanged (data not shown).

To explore the contribution of body weight to increases in diabetes, we examined 8-year incidence rates of diabetes by BMI category(Figure). Most of the absolute increase in diabetes incidence occurred among the obese group (P for trend=0.03); trends in the normal and overweight groups were not significant ($P=0.13$ and 0.16, respectively).

TABLE 2. Age-Adjusted 8-Year Incidence Rates of Diabetes With 95% CIs in Framingham Offspring Study Participants by Decade of Examination

	1970s	1980s	1990s
Women, n	656	786	862
Incident diabetes, n	13	24	32
Incidence rate, %	2.0 (1.1–3.6)	3.0 (1.9–4.7)	3.7 (2.4–5.5)
Men, n	653	765	801
Incident diabetes, n	17	28	48
Incidence rate, %	2.7 (1.6–4.5)	3.6 (2.4–5.4)	5.8 (4.2–8.1)

Study subjects consisted of women and men aged 40 to 55 years.

TABLE 3.   ORs of Incident Diabetes in the 1980s and 1990s in Participants Aged 40 to 55 Years Free of Diabetes at Baseline, Compared With the 1970s

	Age- and Sex-Adjusted OR (95% CI)	*P*	OR With BMI Adjustment (95% CI)	*P*
Overall cohort				
1970s	1.0	...	1.0	...
1980s	1.40 (0.89–2.22)	0.15	1.38 (0.87 to 2.2)	0.17
1990s	2.05 (1.33 to 3.14)	0.001	1.73 (1.11 to 2.68)	0.01
Women				
1970s	1.0	...	1.0	...
1980s	1.50 (0.75–2.98)	0.25	1.50 (0.74–3.04)	0.26
1990s	1.84 (0.95–3.55)	0.07	1.56 (0.79–3.06)	0.20
Men				
1970s	1.0	...	1.0	...
1980s	1.33 (0.72–2.47)	0.36	1.30 (0.70–2.41)	0.41
1990s	2.21 (1.25–3.90)	0.006	1.83 (1.03–3.27)	0.04

Results are age-sex adjusted and then additionally adjusted for BMI.
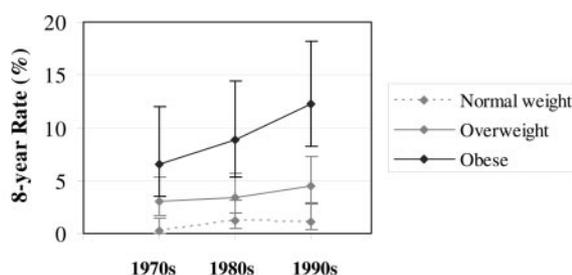
Discussion

In the community-based Framingham Offspring Study cohort, we observed a 2-fold increase in the odds of developing diabetes over the last 30 years for individuals between the ages of 40 and 55 years. This corresponds to an absolute increase in the incidence of diabetes of ≈2.5% during the 1990s compared with the 1970s. Absolute rates of diabetes have increased most prominently among obese individuals; nonsignificant increases were observed among those who were overweight or normal weight at baseline. Adjustment for BMI reduced the odds of incident diabetes by ≈30%, but the temporal effect remained significant, which suggests that increases in BMI account for some but not all of the observed increase in diabetes incidence. To the best of our knowledge, these data are among the first to show trends in incidence rates of diabetes in a community-based, long-term, epidemiological study.

Few other studies of changes in diabetes incidence exist. Investigators analyzing data from Rochester, Minn, that consisted of medical record review for incident cases of diabetes between 1960 and 1965 compared with 1985 to 1989 reported that the age-adjusted incidence of diabetes increased

Age- and sex-adjusted 8-year incidence rate of diabetes (% developing diabetes in 8 years) stratified by category of BMI and decade among participants aged 40 to 55 years. Error bars represent 95% confidence intervals. Numbers of participants at risk in normal weight, overweight, and obese categories in the 1970s were 540, 566, and 203; in the 1980s, the numbers were 671, 633, and 247; and in the 1990s, the numbers were 661, 656, and 346.

by 26% among women and by 47% among men.[10] Potential methodological differences compared with the present study include the use of cases derived from medical chart review, because such cases are subject to changes in screening practices and to the effects of temporal changes in the definition of diabetes. The San Antonio Heart Study examined the change in diabetes incidence from 1987 to 1996 and noted that among Mexican Americans and non-Hispanic whites, crude incidence rates nearly tripled, increasing from 5.7% to 15.7% and from 2.6% to 9.4%, respectively; however, the increase in incidence among non-Hispanic whites was only of borderline significance (*P*=0.07) because of the very small number of people with incident diabetes in that group.[8] Differences from the present study that might explain the higher relative increase in diabetes incidence observed in the San Antonio study include the use of rates that were unadjusted for age, different age and gender distributions, a shorter duration of follow-up than in the present study, and the different ethnic composition of the study sample. Nonetheless, these data, combined with those presented here, support the contention that the incidence of diabetes has risen in the United States during the past few decades.

Most of the prior data documenting increases in diabetes are based on prevalence data; however, increases in prevalence may not solely reflect the accumulation of more cases, because increases may also reflect differences in the survival of affected individuals over time. For example, results from a Danish database found that although the prevalence of diabetes was increasing, the actual incidence remained unchanged, which suggests that declines in overall mortality may be responsible for the observed increases in prevalence.[9] However, these data were derived from a pharmacoepidemiological database and therefore only represent individuals with pharmacologically treated diabetes. Prior studies in the United States have consistently demonstrated the increasing prevalence of diabetes. The Behavioral Risk Factor Surveillance System, which relies on self-reported diagnosis of diabetes, documented an increase in diabetes prevalence from 4.9% to 6.5% (a 33% increase) from 1990 to 1998[4] and an additional 6% increase, from 6.5% to 6.9%, from 1998 to

1999.[5] Compared with the Second National Health and Nutrition Examination Survey (NHANES II; 1976 to 1980), data from NHANES in 1999 to 2000 showed that the prevalence of diabetes increased from 5.3% to 8.1%, a 53% increase.[11] When the prevalence of diabetes is compared between NHANES III (1988 to 1994) and NHANES 1999 to 2000, a significant change in the prevalence of diabetes is not observed.[16] However, an oral glucose tolerance test was used for NHANES III but not for NHANES 1999 to 2000. Oral glucose tolerance tests will identify a larger subset of the study sample with diabetes[17] and may explain the discrepancies in this single study.

The cause of the increase in diabetes incidence is likely related to changes in obesity and lifestyle. Obesity[1,2] and weight gain[3] are leading risk factors for the development of diabetes. Among women, overweight increases the risk of diabetes 3-fold, and obese individuals are at a 9-fold increased risk.[18] A recent examination of 40-year secular trends in prevalence of cardiovascular disease risk factors from NHANES demonstrated improvements in all risk factors except diabetes, despite increasing levels of adiposity.[11] Data from the National Health Examination Study (1960 to 1962) and the NHANES studies (1971 to 1974, 1976 to 1980, and 1988 to 1994) demonstrated increases in the prevalence of obesity from 12.8% in the earlier time period to 22.5% in the later time period,[19] and overweight prevalence increased from 25.4% to 33.3% between 1976 to 1980 and 1988 to 1994.[20] These findings are confirmed when more contemporary data are included.[21] In addition to increases in obesity, changes in energy intake and expenditure may also be contributing to observed increases in diabetes incidence. National data show an increase in the number of kilocalories consumed per day.[22] An ecological analysis of nutrient consumption found a direct correlation with increasing intake of corn syrup and increasing prevalence of type 2 diabetes,[23] which suggests that changes in dietary composition over time independent of absolute caloric intake may also be contributing to the increasing prevalence of diabetes. Physical activity has declined over time, with increases in sedentary activities such as television watching and declines in occupational-related activities, activity in the home, and travel.[24] An increase in sedentary activities has been found to be associated with incident diabetes.[25] Taken together, these data suggest that increasing body weight and changes in lifestyle may have fueled increases in diabetes incidence.

Therefore, it is notable that, after we adjusted for BMI, the odds of developing diabetes in the 1990s were only attenuated by ≈30%, and the temporal trends were still present. There are several potential explanations for these findings. First, adjustment for BMI in this way assumes a linear relation between BMI and diabetes risk; however, when we introduced squared terms or categories of BMI into our models, we did not observe significant changes in our results. Second, BMI may not be the best overall measure of adiposity to reflect diabetes risk. Measures of central adiposity, specifically waist circumference and visceral adipose tissue compartments, are more closely related to diabetes risk.[26–28] However, we do not have measures of waist circumference in the earlier decades of our study and are unable to adjust for changes in waist size over time. Furthermore, we were unable to account for antecedent weight gain as a potential mechanism, because weight gain before study entry for our initial examination was unknown. Finally, changes in dietary and physical activity patterns that are independent of changes in body weight may also contribute to the present findings. Data from the Nurses Health Study demonstrated that consumption of sugar-sweetened beverages is an independent risk factor for diabetes, even after adjustment for weight gain.[29] Thus, declines in physical activity and changes in diet are unmeasured in the present study and are factors that could contribute to an increased risk for diabetes independently of the direct effect of weight gain.

Strengths and Limitations

Strengths of the present study include regular screening for diabetes with fasting plasma glucose, which enabled documentation of incident diabetes. Furthermore, we were able to quantify diabetes incidence over 3 time periods. We did not rely on self-reported diabetes status, which may be influenced by changing definitions of diabetes, screening practices of physicians,[30] and an increasing tendency to treat diabetes at lower fasting plasma glucose thresholds. Because of the longstanding nature of the Framingham Heart Study, we had adequate follow-up to explore long-term trends in diabetes incidence. Limitations of these data include uncertainties about their generalizability to ethnic groups other than those in the study, to other geographic regions of the country, and to individuals younger or older than 40 to 55 years at baseline. Results from the Behavioral Risk Factor Surveillance System study demonstrate increases in self-reported diabetes prevalence of 26% among blacks, 29% among whites, and 38% among Hispanic individuals between 1990 and 1998.[4] Among Native Americans and Alaskan Natives, diabetes prevalence rose 29% between 1990 and 1997. Trends data for other ethnic groups, including Asian Americans, that are at high risk[31] are lacking. Therefore, additional studies examining trends in diagnosed and undiagnosed diabetes by ethnicity are needed. Lastly, we were not able to fully account for all potential covariates, including changes in physical activity, diet, and body composition, including waist circumference and body fat distribution.

Implications and Conclusions

The proportion of obese individuals with diabetes continues to increase.[32] How this increase will affect the subsequent morbidity and mortality associated with diabetes is currently unknown. The incidence of diabetes has significantly increased over the last 30 years in middle-aged adults. Careful surveillance of changes in diabetes incidence may be necessary if current trends of excess adiposity continue.

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Disclosures

None.

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CLINICAL PERSPECTIVE

Recent studies indicate that the prevalence of type 2 diabetes mellitus is increasing in the United States; less is known about trends in incidence of type 2 diabetes. Participants free of diabetes from the Framingham Offspring Study who attended a routine examination in the 1970s, 1980s, or 1990s, were followed up for 8-year incidence of diabetes. Compared with the 1970s, the incidence of diabetes increased by 40% in the 1980s and 2-fold in the 1990s. Among women, the odds of developing diabetes increased by 50% in the 1980s and by 84% in the 1990s, whereas among men, the odds of developing diabetes increased by 30% in the 1980s and by more than 2-fold in the 1990s. Most of the increase in absolute incidence of diabetes has occurred in individuals with body mass index ≥ 30 kg/m^2, although adjustment for body mass index did not attenuate the observed increase in incidence of diabetes mellitus. Changes in dietary and physical activity patterns that are independent of changes in body weight may have contributed to our findings, but we were not able to assess these factors in the present study. In the present community-based sample of middle-aged adults, we observed a doubling in the incidence of type 2 diabetes over the last 30 years. Careful surveillance of changes in diabetes incidence may be necessary if current trends of excess adiposity continue. How these current trends will affect the subsequent morbidity and mortality associated with diabetes is currently unknown.