



## Relative Contributions of Incidence and Survival to Increasing Prevalence of Adult-Onset Diabetes Mellitus: A Population-based Study

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This population-based retrospective study investigates temporal trends in adult-onset diabetes mellitus prevalence, incidence, and survival. The complete community-based medical records, including laboratory results, of all Rochester, Minnesota, residents with a clinical diagnosis of diabetes or diabetes-like condition were reviewed to identify incidence cases aged 30 years or more from 1945 to 1989 ( $n = 1,847$ ) and prevalence cases aged 45 years or more on January 1, 1970 ( $n = 465$ ), January 1, 1980 ( $n = 689$ ), or January 1, 1990 ( $n = 973$ ). Glucose values and case definitions were standardized throughout. Observed 10-year survival for 1970 and 1980 prevalence cases was compared with that expected for Minnesota white populations in 1970 and 1980, respectively. Age-adjusted prevalence rose 65% for men and 37% for women between 1970 and 1990. There were marked differences among prevalence groups in treatment type, the proportion diagnosed using glucose tolerance tests, and the proportion categorized as obese. Relative survival for 1980 prevalence cases was not greater than that for 1970 prevalence cases. Age-adjusted incidence rates rose 47% for men and 26% for women between 1960 and 1965 and 1985 and 1989. These findings emphasize the need for heightened surveillance and intervention to reduce the burden of illness from adult-onset diabetes mellitus in the population. *Am J Epidemiol* 1997;146:12-22.

diabetes mellitus, non-insulin-dependent; incidence; mortality; obesity; prevalence

Estimate from consecutive National Health Interview Surveys reveal that the prevalence of self-reported diabetes rose 50 percent between 1973 and 1993, from 20.4 to 30.7 per 1,000 population (1). Studies from other countries have also reported a rise in the prevalence of adult-onset diabetes mellitus in recent decades (2-5). The reasons for this rise are not clear. Increasing prevalence could result from more new cases of diabetes (i.e., higher incidence rates) and/or longer duration of disease (i.e., better survival) among persons with diabetes. The extent to which either or both of these factors are operating is unknown due to a paucity of population-based data on secular trends in diabetes incidence and survival. Available information, drawn largely from self-report, health insurance claims, and death certificate data, is difficult to interpret because of temporal changes in diagnostic criteria as well as changes in disease detection and reporting practices.

Temporal trends in diabetes incidence and duration are investigated in this population-based study, using the resources of the Rochester Epidemiology Project (REP) (6). The study compares the age- and sex-adjusted prevalence of adult-onset diabetes mellitus among Rochester, Minnesota, residents aged 45 years or more on January 1, 1970, 1980, and 1990. Each of the three cohorts is characterized according to age, duration and severity of diabetes, type of treatment, and body mass index at prevalence. Ten-year survival estimates for the 1970 and 1980 prevalence cohorts, along with data on the incidence of diabetes among Rochester residents for the period 1945 through 1989, are then presented to help explicate observed differences in prevalence.

### MATERIALS AND METHODS

The opportunity for population-based research in Rochester is the result of an unusual set of circumstances: Rochester is relatively isolated from other population centers and is home of one of the world's largest tertiary care medical centers, the Mayo Clinic. Therefore, the majority of the medical care received by local residents is provided by the Clinic, along with its two affiliated hospitals, and a second group practice and its affiliated hospital (Olmsted Medical Center).

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Abbreviations. CI, confidence interval; GTT, glucose tolerance tests; NDDG, National Diabetes Data Group; REP, Rochester Epidemiology Project.

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Information from every Mayo Clinic contact, including hospital inpatient or outpatient care, office visits, emergency room, and nursing home care as well as death certificate and autopsy information, is contained within a single dossier for each patient. The diagnoses assigned and surgical procedures performed at each visit are coded and entered into continuously updated computer files. With funding from the National Institutes of Health, the Clinic's indexing system was expanded to include the small number of other providers of care to local residents, primarily the Olmsted Medical Center.

### Identification of the diabetes cohort

This system, the REP, was used to identify all Rochester residents with a diagnosis of diabetes or a diabetes-like condition from January 1, 1945, through December 31, 1989. The complete medical records for each potential case were then retrieved and reviewed by trained nurse abstractors, under the direction of an endocrinologist (P. J. P.). The diagnosis was confirmed with review of all laboratory results. The identification of the cohort has been an ongoing process, initiated over 2 decades ago. For the most recent update, 1980–1989, cases were identified using criteria that approximated National Diabetes Data Group (NDDG) recommendations (7), i.e., two consecutive fasting glucose levels of 140 mg/dl or more or 1- and 2-hour levels of 200 mg/dl or more obtained during a standard oral glucose tolerance test (GTT). Prior identification of the 1945–1979 cohort used less-stringent criteria, i.e., 120 mg/dl or more fasting and 180 mg/dl or more GTT (8–11). For purposes of this study, the laboratory values for these individuals were reviewed, and NDDG criteria were applied; thus, diagnostic criteria were standardized throughout the entire period 1945–1989. Similarly, using the method of West (12), adjustments were made for temporal changes in laboratory methods. The values of 140 mg/dl for fasting and 200 mg/dl for GTT were based on the Auto-Analyzer (Technicon, New York, New York) ferrocyanide reductase technique for plasma, the method used at the Mayo Clinic since May 1972. The values for 1945–1958 (Folin-Wu method) were 130 mg/dl or more fasting and 200 mg/dl or more GTT, and for 1959 through April 1972 (Auto-Analyzer ferrocyanide reductase technique for whole venous blood), values were 120 mg/dl or more fasting and 180 mg/dl or more GTT. Glucose values from other institutions were interpreted in light of the method being used.

Persons who failed to meet the above criteria, but for whom oral agents or insulin were used for at least 2 weeks or until death, also qualified as cases. Date of diagnosis was the earliest date for which any of the

above criteria, alone or in combination (e.g., one elevated glucose level followed by treatment), were met. Persons diagnosed elsewhere who were on medication or whose first glucose values in the record met diagnostic criteria were considered prevalence cases only; date of diagnosis for these individuals was the first recorded date provided by the patient in the medical record.

Information on residency at diagnosis and at prevalence was available from continuously updated registration files of both the Mayo Clinic and Olmsted Medical Center. It was also obtained from correspondence (with dates and addresses on billing, insurance, and follow-up mailings) in the medical record, review of telephone and city directories for the period 1945 to present, and telephone calls and mailings, if necessary. In an effort to exclude persons who may have moved to Rochester seeking medical treatment at the Mayo Clinic, incidence cases were limited to persons who had resided in Rochester for 1 year prior to meeting diagnostic criteria. Similarly, prevalence cases were limited to persons who had resided in Rochester 1 year prior to the prevalence dates. The effect of this restriction was minimal, however; fewer than 3 percent of cases were excluded on the basis of the 1-year residency rule.

This analysis was limited to adult-onset diabetes mellitus, i.e., persons for whom age at diagnosis was 30 years or more. In previous REP publications, 94 percent of the diabetic individuals in this age group were categorized as non-insulin-dependent diabetes by using an algorithm based on age, body mass index, treatment type, and evidence of ketosis; the remainder represented either insulin-dependent (<4 percent) or secondary (<3 percent) diabetes (8, 9). Prevalence cases were limited to persons aged 45 years or more as of January 1, 1970, 1980, or 1990. This decision resulted from time and financial constraints, given the extensive effort required to establish residency on those dates. Residency at prevalence was confirmed for 99 percent of potential cases age 45 years or more on any of the three dates.

Data on clinical characteristics at prevalence, including fasting glucose levels, mention of glycosuria or ketonuria, treatment type (insulin, oral medication, or diet alone), and body mass index (height (m)/weight (kg)<sup>2</sup>) were obtained from medical record review. Vital status as of January 1, 1992, and date of death for those who died were obtained from review of the medical record and active telephone and mail follow-up, if necessary. Vital status as of January 1, 1992, was confirmed for 97 percent of the 1945–1989 incidence cohort and 98 percent of the prevalence cases. Date of death was available for all decedents.

## Analysis

Prevalence was estimated in 10-year age groups, with the number of adult-onset diabetes mellitus cases as the numerator and decennial census data (1970, 1980, and 1990) as the denominator (13). Rates were age- and sex-adjusted to the 1980 United States white population by the direct method. Ninety-five percent confidence intervals were estimated based on the Poisson distribution. Characteristics of the 1970, 1980, and 1990 prevalence cohorts were summarized using descriptive statistics. Of the 1,697 prevalence cases, 384 (23 percent) belonged to more than one prevalence cohort; because the assumption of independent observations did not hold, statistical tests of differences among the three cohorts were not performed.

Adult-onset diabetes mellitus incidence rates were calculated for each sex and age group (30–44, 45–54, 55–64, 65–74, 75–84, and 85 or more years) for successive quinquennia, with newly diagnosed cases as the numerator and Rochester person-years at risk as the denominator. The denominator was based on decennial census data with linear interpolation for intercensus years (13). Incidence rates were directly age- and sex-adjusted as described above for prevalence. Poisson regression was used to evaluate associations between incidence and age, sex, and calendar year of diagnosis (14). The significance of two-way interaction terms and higher-order polynomials was examined. Previous REP studies of trends in diabetes incidence over the period 1945–1969 found a marked increase in incidence associated with the addition of blood glucose to the Auto-Analyzer in the late 1950s (9). To minimize the impact of this potential detection bias on temporal trends in diabetes incidence, we limited the regression analysis in this study to person-years of observation after December 31, 1959. Observations used for the regression analysis were the crude incidence rates formed by all combinations of sex, 5-year age groupings, and calendar year of diagnosis. The midpoints of the age groupings were used in the analysis.

The contribution of changes in survival to temporal trends in diabetes prevalence was investigated by comparing survival for individuals in the 1970 prevalence cohort with that for individuals in the 1980 prevalence cohort. Survival was measured from date of prevalence until the earliest of death or 10 years. Consequently, while some of the same individuals may have been in both cohorts, there was independence in the person-years of observation within each cohort for the survival analysis. Crude survival curves were estimated using the Kaplan-Meier product-limit method (15). Observed survival was estimated relative to that expected using the sex-, age-, and prevalence year-

appropriate survival experience of the Minnesota white population (13). The 10-year survival experience for each prevalence cohort was also evaluated using Cox proportional hazards modeling (16). The models included sex, age at prevalence, and duration of diabetes, with consideration of two-way interaction terms and higher-order polynomials. Tests for nonproportionality of hazards were performed (17).

## RESULTS

There was a 51 percent increase in the crude prevalence of adult-onset diabetes mellitus among Rochester residents aged 45 years or more between 1970 and 1990. Aging of the population accounted for only a small proportion of this increase, as the age- and sex-adjusted prevalence rose 48 percent, from 34.6 per 1,000 population on January 1, 1970 to 51.4 per 1,000 population on January 1, 1990 (table 1). The age-adjusted increase was greater for men (65 percent) than for women (37 percent). There was a general increase in prevalence with age, and the increase over time was apparent for each age group, with the exception of the oldest age groups.

The clinical characteristics of each prevalence cohort are provided in table 2. The three cohorts were remarkably similar with respect to age, duration of diabetes, and standardized fasting glucose levels at prevalence. The cohorts differed markedly in the proportion diagnosed with oral glucose tolerance tests. Among persons for whom values at diagnosis were available, the proportion who met criteria based on an oral GTT was 23 percent (82 of 354), 17 percent (89 of 537), and 6 percent (49 of 803) in the 1970, 1980 and 1990 cohorts, respectively. Although mean fasting glucose levels differed between persons diagnosed with and those diagnosed without oral GTT ( $147 \pm 60$  vs.  $222 \pm 88$  mg/dl,  $p < 0.01$ ), standardized fasting glucose levels at diagnosis were very similar among the three prevalence cohorts (table 2).

There were also marked differences in the type of treatment at prevalence. Consistent with the 1971 recommendations of the University Group Diabetes Program (18), the proportion of prevalence cases using oral agents dropped from 43 to 12 percent between 1970 and 1980, whereas the proportion using insulin rose from 27 to 42 percent. The shift reversed somewhat in the next decade; as of 1990, 36 percent of individuals were using insulin, and 36 percent were using oral agents. The proportion of prevalence cases on either insulin or oral agents increased from approximately half in 1980 to nearly three quarters in 1990 (table 2).

The proportion of individuals with mention of glycosuria was higher in 1990 than in 1980 or 1970; the

**TABLE 1. Prevalence of adult-onset diabetes mellitus among Rochester, Minnesota, residents aged  $\geq 45$  years on January 1, 1970, 1980, and 1990**

Age (years)	1970						1980						1990					
	Women		Men		Both sexes		Women		Men		Both sexes		Women		Men		Both sexes	
	No	Rate*	No.	Rate*	No.	Rate*	No.	Rate*	No.	Rate*	No.	Rate*	No.	Rate*	No.	Rate*	No.	Rate*
45-54	24	9.5	34	15.2	58	12.2	49	19.0	56	23.2	105	21.0	66	19.3	75	23.5	141	21.3
55-64	57	24.7	56	33.9	113	28.5	77	33.3	102	52.1	178	41.9	109	42.5	130	56.7	239	49.2
65-74	106	57.9	74	71.5	180	62.8	96	46.7	91	77.9	187	58.0	140	63.4	167	103.1	307	80.2
75-84	69	58.7	17	29.8	86	49.3	101	67.2	64	102.6	165	77.5	137	74.2	75	92.1	212	79.7
$\geq 85$	18	49.0	10	75.2	28	56.0	47	77.7	6	34.9	53	68.2	52	53.9	22	81.2	74	59.9
Total	274	33.4	191	34.0	465	33.6	370	40.8	319	50.4	689	44.8	504	45.8	469	57.3	973	50.7

Prevalence rate	1970		1980		1990	
	Rate*	95% confidence interval	Rate*	95% confidence interval	Rate*	95% confidence interval
Age-adjusted						
Women	32.0	28.2-35.8	37.1	33.1-41.0	43.8	39.8-47.8
Men	37.3	32.0-42.7	53.9	47.9-59.8	61.4	55.8-67.0
Age- and sex-adjusted	34.6	31.4-37.8	44.6	41.2-48.0	51.4	48.1-54.7

\* Rates are per 1,000 population

extent to which this difference was associated with more complete documentation in recent time periods could not be determined. There were also substantial increases in the proportion of persons categorized as obese (body mass index  $\geq 27.8$  for men and  $\geq 27.3$  for women). In 1970, approximately one third of the prevalence cases were obese, but by 1990, 48 percent of men and 58 percent of women with diabetes were obese. The proportion of obese persons was similar between the sexes on January 1, 1970 ( $p = 0.543$ ) but was significantly higher for women than for men on January 1, 1990 ( $p = 0.004$ ).

The increase in prevalence between 1970 and 1990 did not result from greater in-migration of persons with diabetes. The proportion of prevalence cases that were diagnosed elsewhere was similar among the cohorts from 1970 (88 of 465 = 19 percent), 1980 (133 of 689 = 19 percent), and 1990 (176 of 973 = 18 percent). The proportion of prevalence cases diagnosed elsewhere and not residing in Rochester on the prior prevalence date (i.e., those who had moved to Rochester in the preceding decade) was 15 percent for both the 1980 cohort (106 of 689) and the 1990 cohort (142 of 973).

The rise in prevalence between 1970 and 1990 was attributable in part to an increase in the incidence of diabetes. As shown in figure 1, there was a marked increase in age-adjusted incidence rates among Rochester residents aged 30 years or more between 1945-1959 and 1960-1969 for both sexes. Age-adjusted rates rose 58 percent for women (1945-1959 = 1.35 per 1,000 person-years, 95 percent confidence interval (CI) 1.15-1.59 vs. 1960-1969 = 2.14 per 1,000 person-years, 95 percent CI 1.87-2.44) and 45 percent

for men (1945-1959 = 1.74 per 1,000 person-years, 95 percent CI 1.48-2.04 vs. 1960-1969 = 2.52 per 1,000 person-years, 95 percent CI 2.19-2.90). Age-adjusted incidence rates continued to rise, from 2.82 per 1,000 person-years (95 percent CI 2.50-3.18) in 1970-1979 to 3.31 per 1,000 person-years (95 percent CI 3.00-3.66) in 1980-1989 for men and from 2.08 per 1,000 person-years (95 percent CI 1.85-2.35) in 1970-1979 to 2.39 (95 percent CI 2.16-2.65) in 1980-1989 for women.

Poisson regression analysis of incidence rates for the period 1960-1989 showed that calendar year, age, and sex each contributed significantly to the model (table 3). The risk of adult-onset diabetes mellitus was 43 percent higher for men than women. The absence of a significant sex  $\times$  calendar year interaction suggests that temporal trends in incidence rates did not differ between men and women. There was a nonlinear effect of age on incidence, and the effect of calendar year was not constant across all age groups. As shown in the graphs of predicted incidence for 1960, 1965, 1970, 1975, 1980, and 1985 by 5-year age groups for women and men (figure 2), the effect of calendar year on incidence diminished with increasing age, such that the rise in incidence over time was not apparent for the age group 80 or more years.

The rise in prevalence from 1970 to 1990 did not appear to be attributable to increased duration of diabetes mellitus. There was little difference among cohorts in duration of diabetes at prevalence, and the 10-year crude survival experiences for the 1970 and 1980 prevalence cohorts were similar: 54 percent (251 of 465) of the persons in the 1970 cohort died compared with 53 percent (368 of 689) in the 1980 cohort.

**TABLE 2. Characteristics of Rochester, Minnesota, residents aged  $\geq 45$  years with adult-onset diabetes mellitus on January 1, 1970, 1980, and 1990**

	1970	1980	1990
No of persons	465	689	973
% male	41	46	48
Age at diagnosis (years)			
Men (mean (SD*))	57.6 (11.0)	56.7 (10.9)	57.5 (11.0)
Women (mean (SD))	60.6 (11.6)	60.6 (13.3)	60.1 (13.1)
Duration of diabetes (years)			
Men (median)	5.8	6.6	6.8
Women (median)	7.2	8.2	7.5
Fasting glucose (mg/dl)†,‡			
At diagnosis (mean (SD))	213 (85)	208 (93)	211 (84)
At prevalence (mean (SD))	172 (76)	175 (69)	178 (74)
Glycosuria (%)	31	27	39
Ketonuria (%)	4	4	4
Treatment (%)†			
Insulin	27	42	36
Oral	43	12	36
Neither	30	46	28
Obese (%)†,§			
Men	33	34	48
Women	36	45	58

\* SD, standard deviation.

† Analysis considered only persons on whom data were available. For 1970, 1980, and 1990, respectively, fasting glucose was available at diagnosis for 76%, 78%, and 82% and at prevalence for 88%, 95%, and 97%; treatment was available for 88%, 95%, and 97%; body mass index was available on men for 88%, 95%, and 98%; and body mass index was available on women for 90%, 95%, and 98%.

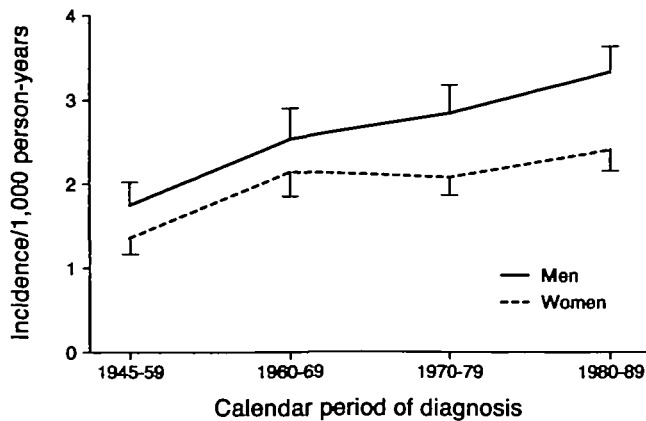
‡ Fasting glucose values included those drawn with oral glucose tolerance tests. Glucose values obtained prior to 1972 were transformed into their post-1972 equivalents.

§ Obesity was defined as body mass index  $\geq 27.8$  for men and  $\geq 27.3$  for women.

To address further the question of whether temporal trends in survival contributed to the increased prevalence of diabetes, one must consider contemporaneous survival trends for the general population. Ten-year survival rates for the 1970 and 1980 Rochester diabetes prevalence cohorts, relative to that expected based on 1970 and 1980 Minnesota white populations, respectively, are graphed in figure 3 for women and men. The graphs reveal that survival for both men and women with diabetes was substantially poorer than that expected in both time periods. However, men with diabetes experienced improvement in survival between 1970 and 1989 similar to that experienced by Minnesota white men during that time period, while survival among women with diabetes did not keep pace with the improvements experienced by Minnesota white women.

The effects of age, sex, and duration of diabetes on risk of mortality were estimated using Cox propor-

tional hazards models for the 1970 and 1980 prevalence cohorts separately (table 4). Greater age at prevalence was associated with higher mortality in both models, with an approximately twofold increase in hazard with each decade of age above 45 years. In the 1970 model, there was a sex  $\times$  duration interaction; each 10-year increase in duration was associated with a 70 percent increase in the hazard of mortality for women (relative hazard = 1.7, 95 percent CI 1.4–2.1) but only a 10 percent increase for men (relative hazard = 1.1, 95 percent CI 0.8–1.5). There was no duration  $\times$  sex interaction in the 1980 model; each 10-year increase in duration was associated with a 15 percent increase in hazard for both men and women. As a consequence of these differences, predicted survival for women with diabetes duration of 10 years was better for members of the 1980 cohort compared with those in the 1970 cohort. However, for women with shorter duration of diabetes, e.g., 5 years, pre-



**FIGURE 1.** Age-adjusted, sex-specific incidence rates and 95 percent confidence intervals (denoted by bars) for adult-onset diabetes mellitus among residents of Rochester, Minnesota, aged 30 years or more for 1945–1959 through 1980–1989.

dicted survival was actually poorer in 1980 than in 1970. Predicted survival for men in the 1980 cohort was better than that for men in the 1970 cohort, irrespective of duration of diabetes. These results are displayed graphically in figure 4 (duration = 10 years) and figure 5 (duration = 5 years). It is important to note that the between-cohort differences in predicted survival displayed in figures 4 and 5 do not consider differences relative to the Minnesota white population discussed above. For purposes of comparison, estimated life expectancy at age 70 years for the Minnesota white population increased between 1969–1971 and 1979–1981 from 11.5 to 12.6 years for men and from 14.6 to 16.5 years for women (10).

## DISCUSSION

The age- and sex-adjusted prevalence of adult-onset diabetes mellitus among Rochester residents aged 45 years or more rose 48 percent between 1970 and 1990. The increase was greater for men than for women. Analysis of characteristics at prevalence showed little change in average duration of diabetes or mean glu-

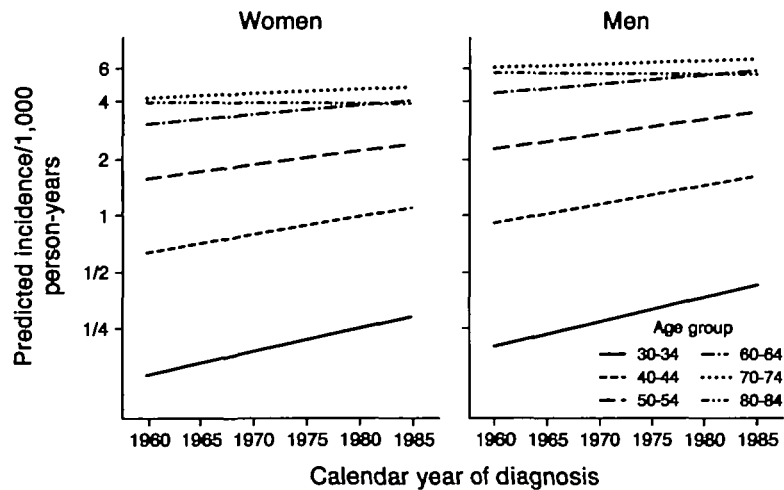
**TABLE 3.** The contribution of age, sex, and calendar year to incidence of adult-onset diabetes mellitus among Rochester, Minnesota, residents aged  $\geq 30$  years, as modeled by Poisson regression, 1960–1989

Variable	Beta $\pm$ standard error	<i>p</i> value
Intercept	-18.747 $\pm$ 1.178	<0.001
Age (years)	0.309 $\pm$ 0.023	<0.001
Calendar year of diagnosis	-0.005 $\pm$ 0.014	<0.001
Sex (female = 1)	-0.359 $\pm$ 0.48	<0.001
Age <sup>2</sup>	-0.002 $\pm$ 0.000	<0.001
Age $\times$ calendar year	-0.001 $\pm$ 0.000	0.005

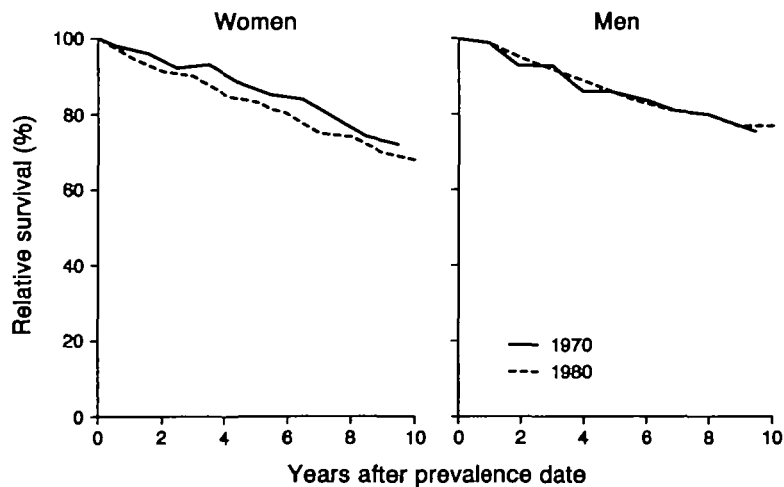
cose levels but marked changes over time in treatment type and in the proportion of persons who were obese. The increase in prevalence was accompanied by a rise in age-adjusted incidence and was not attributable to changing migration patterns or improvements in relative survival. Improvements in 10-year survival among men with diabetes between 1970 and 1980 generally mirrored those of Minnesota white males. Women with diabetes did not share in the improved survival exhibited by Minnesota white females during this time period.

There are few datasets with sufficient longitudinal information on diabetes prevalence, incidence, and survival with which our findings can be compared. Rochester is 96 percent white (6). Comparison with data from Native American (19) or Pacific Island (5) populations is confounded by marked differences in genetic, sociodemographic, and environmental characteristics. A Canadian study, using Manitoba Health Insurance data, found a 49 percent increase in age- and sex-adjusted prevalence over the 5-year period from 1986 to 1991, greater than the 48 percent increase in age- and sex-adjusted prevalence rates for Rochester over the 20-year period from 1970 to 1990 (15 percent between 1980 and 1990) (4). Both studies differ from US National Health Interview Survey findings, which show that age-adjusted prevalence for white men and women were essentially unchanged between 1980 and 1990 (1, 20). Reported trends in diabetes incidence from National Health Interview Survey data for 1935–1969 are very similar to those observed for Rochester over the period 1945–1969. However, while Rochester rates rose 15 percent for women and 17 percent for men between 1970–1979 and 1980–1989, National Health Interview Survey data show no change in incidence since 1968 (1). The Canadian study found that annual incidence rates of diabetes were unchanged, after an initial decline from 1986 through 1989 (4).

These discrepancies could relate either to actual geographic differences in risk, including genetic, environmental, and lifestyle factors (5, 21) or to differences in study design (22). Ascertainment of cases and designation as an incidence case in the Manitoba Health Insurance study were based on an algorithm for number, timing, and type of visits with a discharge diagnosis code for diabetes (4). The use of administrative data for ascertaining trends in disease incidence is problematic (23). Information on diabetes in the National Health Interview Survey was collected by asking survey respondents whether they or anyone in the household had ever been told by a physician that they had diabetes. If the answer was yes, the respondent was counted as a prevalence case and asked when the condition was first noticed; if this was within the



**FIGURE 2.** Predicted incidence rates of adult-onset diabetes for women and men in Rochester, Minnesota, aged 30–34, 40–44, 50–54, 60–64, 70–74, and 80–84 years in 1960, 1965, 1970, 1975, 1980, and 1985 from Poisson regression model.



**FIGURE 3.** Kaplan-Meier estimated observed survival relative to that expected using the age-, sex-, and prevalence year-appropriate survival experience of the Minnesota white population for female and male members of the 1970 and 1980 Rochester, Minnesota, adult-onset diabetes mellitus prevalence cohorts aged 45 years or more at prevalence.

previous 12 months, the respondent was also considered an incidence case. The limitations of this approach are apparent from prospective screening studies, such as the National Health and Nutrition Examination Surveys, that reveal that 14 percent of persons who said they had diabetes did not test positive for diabetes in oral glucose tolerance tests (24). Likewise, earlier Rochester Epidemiology Project studies showed that 15 percent of persons with physician-diagnosed diabetes between 1945 and 1969 did not meet NDDG criteria at the time of diagnosis (10), although this proportion probably declined after the widespread application of NDDG criteria in clinical practice.

Our study was based on retrospective review of medical records of all Rochester residents ever as-

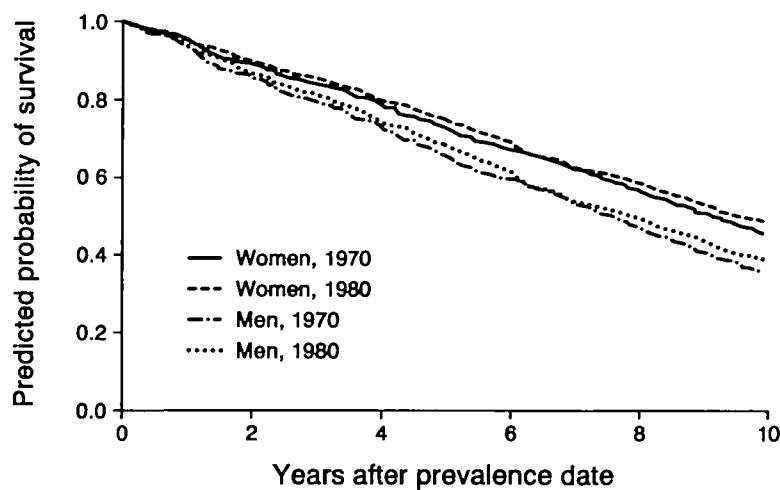
signed a diagnosis of diabetes by a physician between 1945 and the present. The complete community-based medical records, including laboratory values, were reviewed using NDDG criteria to confirm the diagnosis. In order to minimize temporal changes in detection bias, the retrospective application of NDDG criteria in our study was intentionally strict. Persons with a single elevated fasting glucose in the absence of subsequent elevated values or hypoglycemic medication were not considered cases; neither were women who qualified during pregnancy but who never met NDDG criteria afterward. Thus, prevalence and incidence rates reported here are typically lower than those reported in other studies, especially in the younger age groups. For example, published National Health Interview Survey estimates for the percent of the US white

**TABLE 4.** Risk of death among members of the 1970 and 1980 diabetes mellitus prevalence cohorts as modeled by Cox proportional hazards

Variable	Beta $\pm$ standard error	Relative hazard	95% confidence interval	<i>p</i> value
1970 prevalence cohort				
Age*	0.590 $\pm$ 0.069	1.8	1.6–2.1	<0.001
Sex†	–0.701 $\pm$ 0.220			0.002
Duration*	0.093 $\pm$ 0.173			0.590
Duration* $\times$ sex	0.422 $\pm$ 0.204			0.038
1980 prevalence cohort				
Age*	0.734 $\pm$ 0.054	2.08	1.9–2.3	<0.001
Sex†	–0.273 $\pm$ 0.111	0.76	0.6–0.9	0.014
Duration*	0.139 $\pm$ 0.069	1.15	1.005–1.3	0.042

\* Per 10-year increase

† 0 = male; 1 = female

**FIGURE 4.** Predicted survival using Cox proportional hazards models for members of the 1970 and 1980 Rochester, Minnesota, adult-onset diabetes mellitus prevalence cohorts aged 70 years at prevalence with diabetes duration of 10 years.

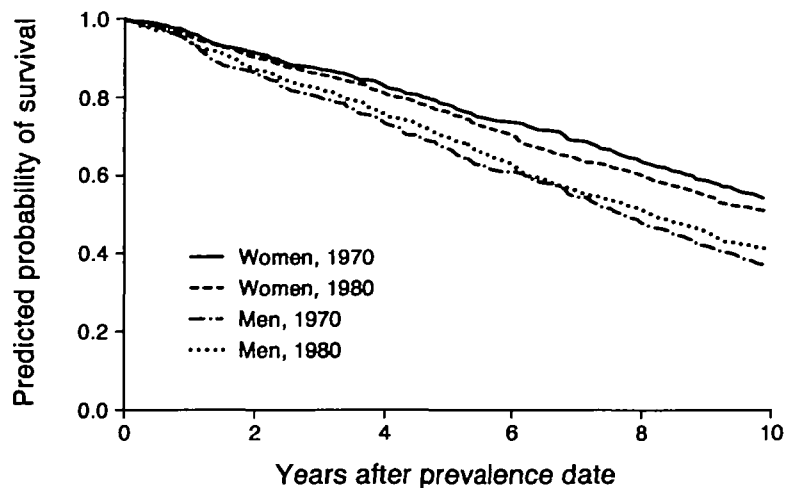
population with diagnosed diabetes in 1990 of 4.5, 9.6, and 7.4 for persons aged 45–64, 65–74, and 75 years or more, respectively (1), compare with 1990 Rochester percentages of 3.3 (95 percent CI 3.0–3.7), 8.0 (95 percent CI 7.2–9.0), and 7.3 (95 percent CI 6.5–8.3) for corresponding age groups. It is important to note that rates reported in most other studies include women with gestational diabetes only. The contribution of gestational diabetes to female prevalence rates is arguably substantial. Published figures show that 31 percent of the average annual number of newly diagnosed cases of diabetes in 1990–1992 among women occurred in the age group 25–44 years, compared with only 18 percent among men (1).

Prevalence rates reported here are lower than point estimates from studies based on prospective screening (24–27), in part because persons never assigned a diagnosis of diabetes or diabetes-like condition are not identified in the Rochester study. Data from national

population samples in Israel and the United States demonstrated that 50 percent of individuals who met NDDG criteria when screened with oral GTT reported that they did not recall ever having received a diagnosis of diabetes (28).

The extent to which temporal trends reported here are confounded by the absence of persons never assigned a diagnosis depends on 1) whether the proportion of individuals who came to medical attention and received a diagnosis changed over time and 2) whether the study design was able to account for such changes. Because the REP database affords access to the original records, it is possible to examine associations between patient characteristics at diagnosis and temporal changes in technology, practice style, and diagnostic criteria. Previous REP comparisons of the 1945–1959 and 1960–1969 Rochester incidence cohorts showed that the later cohort exhibited less-severe disease at onset, a higher proportion with mildly ele-





**FIGURE 5.** Predicted survival using Cox proportional hazards models for members of the 1970 and 1980 Rochester, Minnesota, adult-onset diabetes mellitus prevalence cohorts aged 70 years at prevalence with diabetes duration of 5 years.

vated glucose or abnormal glucose tolerance tests alone, and earlier age at onset (8, 9). These findings suggest that some of the increase in incidence between 1945 and 1969 was attributable to earlier disease detection.

Changes since 1970 that could have affected the completeness of case ascertainment include the adoption of NDDG criteria; a marked decline in the use of oral GTT; and potential changes in access to care, frequency of testing, and patterns of documentation. The introduction of NDDG criteria was largely accounted for in this study by review of the actual laboratory values and the application of standardized glucose criteria throughout. The impact of changes in documentation and access to care on ascertainment was examined in a previous study of hospitalization rates among residents of Olmsted County for 1970, 1976, 1980, and 1985 (11). These authors reported that the rate of hospitalizations with diabetes coded as one of the first three discharge diagnoses was similar between 1970 and 1976, rose in 1980, and declined in 1985, a pattern roughly similar to that observed for the general population. Thus, the opportunity for detection likely decreased with general declines in hospitalization that accompanied the introduction of the Prospective Payment System in the early 1980s. Any decrease in detection was probably offset, however, by an increase in the number of discharge diagnosis codes over the same time period and the finding that the 1985 hospital discharge rate for diabetes based on 15 discharge diagnoses (36.4 of 1,000 person-years) was greater than that based on five discharge diagnoses (28.4 of 1,000 person-years) (11). The effects of such changes on temporal trends reported here are likely less, given that this study also reviewed independently assigned outpatient diagnoses.

The impact of the declining use of oral GTT on ascertainment is not straightforward. The oral GTT is a more sensitive measure than fasting glucose (9, 28). If the decline in GTT resulted in a smaller proportion of persons coming to medical attention, the increases in diabetes incidence and prevalence seen for Rochester since 1970 are likely underestimates. With this line of reasoning, it might be argued that the negligible improvements in relative survival since 1970 reported here are due to reduced detection of less-severe cases in recent time periods. The fact that incidence rates increased while patient characteristics for the 1970, 1980, and 1990 prevalence groups did not change, however, argues against differential detection as a primary explanation for the temporal trends in diabetes prevalence, incidence, or survival observed for this community since 1970. Age at diagnosis, age at prevalence, duration of diabetes, and disease severity, as manifest by fasting glucose at prevalence and at diagnosis (including fasting values obtained during the oral GTT), were remarkably similar among the three prevalence cohorts.

Studies based on health insurance claims and self-report reveal little change in diabetes incidence in recent decades; therefore, the increase in prevalence has been attributed to declines in mortality among persons with diabetes (1). The age-adjusted rate for diabetes as a cause of death on death certificates declined between 1970 and 1980. A rise in rates since 1985 is attributed to changes in the death certificate form (29). The limitations of death certificate data are well recognized, however (30, 31). In our study, underlying causes for deaths through 1989 were available from the Minnesota Department of Health. Among members of the 1970 or 1980 cohorts who died between January 1, 1970 and December 31, 1989,

the proportions with diabetes listed as the underlying cause were 9 percent (12 of 138), 11 percent (12 of 110), 12 percent (27 of 228), and 17 percent (26 of 156) in 1970–1974, 1975–1979, 1980–1984, and 1985–1989, respectively. The small percentage reported and the potential changes in that percentage over time suggest that trends in deaths due to diabetes are a poor indicator of patterns of all-cause mortality among the diabetic population.

More fundamentally, however, improvement in survival among persons with diabetes only translates to increased prevalence if it exceeds improvements experienced by the general population. In the United States between 1970 and 1990, life expectancy at birth increased from 70.8 years to 75.4 years, with much of the increase attributable to improved survival at older ages (32). Because these improvements in survival resulted largely from declines in cardiovascular disease mortality and because cardiovascular disease mortality is particularly high among persons with diabetes, it is conceivable that the diabetic population may have exhibited greater improvement in survival than the general population. The results of our study do not support this hypothesis.

Perhaps our most important finding from a clinical or public policy perspective is the marked increase in the proportion of persons with diabetes who are categorized as obese. While we cannot exclude the possibility that this is due to greater sensitivity among clinicians regarding the need to screen such persons, the trends in obesity observed for the Rochester diabetic population mirror the dramatic increases in obesity reported for the US population generally (33). Additional research is needed to elucidate the relation between patterns of obesity among adult-onset diabetes mellitus prevalence cohorts and temporal trends in diabetes incidence and survival.

In conclusion, longitudinal data on diabetes prevalence, incidence, and survival from Rochester, Minnesota, emphasize the need for heightened awareness, both to detect new cases of diabetes and to monitor the potentially fatal complications among those who have been diagnosed. The findings presented here should be interpreted with some caution. The data are from a single, predominantly white US population; persons who would qualify if prospectively screened, but who never came to clinical attention, are missing, and although the analysis showed significant calendar-year effects, there was wide fluctuation from year to year. However, to the extent that the temporal trends reported here are real and generalizable, the findings have important methodological and public policy implications.

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