Temporal Trends in BMI Among Adults With Diabetes

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OBJECTIVE — Increasing obesity within the general population has been accompanied by rising rates of diabetes. The extent to which obesity has increased among people with diabetes is unknown, as are the potential consequences for diabetes outcomes.

RESEARCH DESIGN AND METHODS — Community medical records (hospital and ambulatory) of all Rochester, Minnesota, residents aged ≥30 years who first met standardized research criteria for diabetes from 1970 to 1989 (n = 1,306) were reviewed to obtain data on BMI and related characteristics as of the diabetes identification date (±3 months). Vital status as of 31 December 1999 and date of death for those who died were obtained from medical records, State of Minnesota death tapes, and active follow-up.

RESULTS — As of the identification date, data on BMI were available for 1,290 cases. Of the 272 who first met diabetes criteria in 1970–1974, 33% were obese (BMI ≥30), including 5% who were extremely obese (BMI ≥40). These proportions increased to 49% ($P < 0.001$) and 9% ($P = 0.012$), respectively, for the 426 residents who first met diabetes criteria in 1985–1989. BMI increased significantly with increasing calendar year of diabetes identification in multivariable regression analysis. Analysis of survival revealed an increased hazard of mortality for BMI ≥41, relative to BMI of 23–25 (hazard ratio 1.60, 95% CI 1.09–2.34, $P = 0.016$).

CONCLUSIONS — The prevalence of obesity and extreme obesity among individuals at the time they first met criteria for diabetes has increased over time. This is disturbing in light of the finding that diabetic individuals who are extremely obese are at increased risk of mortality compared with their nonobese diabetic counterparts.

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The prevalence of obesity within the U.S. population increased markedly in recent decades (1–5). Obesity is a well-recognized risk factor for type 2 diabetes; as revealed by studies from Rochester, Minnesota, and elsewhere (6–8), increases in obesity within the general population were accompanied by rising diabetes incidence rates. The increase in diabetes incidence is disconcerting, largely because of the increased risk for morbidity and mortality associated with diabetes (9). Studies of the general population (10–19) have shown that obesity is also a risk factor for morbidity and mortality. Thus, if obesity is a risk factor for mortality among people with diabetes, and if people with diabetes experienced the same temporal increases in obesity as those observed in the general population, it is likely that increases in the number of individuals with diabetes will be exacerbated by an increased likelihood of adverse events among those individuals. However, few studies have examined the association between BMI and mortality in people with diabetes, and the results of those studies are conflicting (11,20,21). There is also a paucity of data on temporal trends in obesity among people with diabetes. The present study uses the population-based longitudinal resources of the Rochester Epidemiology Project (REP) to investigate temporal patterns in BMI and the association between BMI and mortality among people with diabetes.

RESEARCH DESIGN AND METHODS

— REP resources include a computerized diagnostic index and a medical records linkage system that has been demonstrated to capture >95% of the medical care delivered to Rochester residents (22). The diagnostic index includes all diagnoses assigned to local residents by REP providers since 1945. The medical records include detailed information from all encounters with these providers, including office and nursing home visits; hospital inpatient, outpatient, and emergency room admissions; all laboratory, pathology, and procedure results; death certificates; and autopsy reports (22).

These resources were used to construct the Rochester diabetes cohort. Details are provided elsewhere (8,23,24), but in general, cohort members were identified using a two-stage process. Candidate cases were identified from a listing of all residents ever assigned any diagnosis in the REP diagnostic index that was suggestive of diabetes (e.g., diabetes, elevated blood glucose, impaired glucose tolerance, rule-out diabetes, diabetic nephropathy). The length of medical history available for review is extensive, and the list of diagnoses is very broad. In a study of all Rochester residents who died at an age of ≥45 years in 1979–1994, the median time from first contact with an REP provider until death was 43 years (interquartile range 24–58). A total of 25% of decedents had a diagnosis in the REP diagnostic index that qualified them as a candidate case (25).

In the second stage of the identification process, the complete provider-linked medical records of each candidate

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Abbreviations: HR, hazard ratio; NDDG, National Diabetes Data Group; NHANES, National Health and Nutrition Examination Survey; OR, odds ratio; REP, Rochester Epidemiology Project.

A table elsewhere in this issue shows conventional and Système International (SI) units and conversion factors for many substances.

Table 1—*Characteristics of members of the Rochester, Minnesota, incident diabetes cohort aged ≥30 years, as of the date they were identified as first meeting standardized case criteria for diabetes, by quinquennia*

	1970–1974	1975–1979	1980–1984	1985–1989	*P*
n	265	283	321	421	
Men (%)	43	56	49	53	0.07
Age (years)					
Men	62 ± 14	59 ± 12	62 ± 13	60 ± 13	0.23
Women	64 ± 13	66 ± 13	64 ± 14	63 ± 15	0.17
Fasting glucose level* (mg/dL)					
Men	216 ± 93	219 ± 96	216 ± 82	221 ± 86	0.59
Women	215 ± 87	217 ± 106	220 ± 92	214 ± 82	0.95
Smokers (%)					
Men	39	42	29	30	0.01
Women	19	12	20	16	0.88
BMI (%)					0.004
<18.5	4	2	2	1	
18.5–24.9	23	28	22	19	
25.0–29.9	40	31	36	31	
30.0–39.9	28	34	34	39	
≥40	5	4	6	9	

Data are means ± SD unless otherwise indicated. *Values for fasting glucose were available for 1,139 (88%) of individuals.

case were retrospectively reviewed from the date of first contact with an REP provider until the date of last contact, death, or the end of the study period for all laboratory glucose values (available since 1930) and evidence of any antidiabetic medication. The records were reviewed by trained nurse abstractors under the direction of an endocrinologist (P.J.P.) to identify individuals who met standardized case criteria for diabetes, to assign the date they first met these criteria, and to determine whether they were Rochester residents on that date. The criteria approximated the National Diabetes Data Group (NDDG) recommendations (i.e., two consecutive fasting glucose levels ≥7.8 mmol/l or both 1- and 2-h levels ≥11.1 mmol/l, obtained during a standard oral glucose tolerance test) (26). Individuals who failed to meet glycemic criteria but who used oral agents or insulin for ≥2 weeks or until their death also qualified as cases.

The present study was limited to individuals identified as having first met criteria for diabetes between 1 January 1970 and 31 December 1989 and who were aged ≥30 years and residing in Rochester for ≥1 year as of the date they first met criteria (*n* = 1,330). In accordance with a Minnesota state statute (27), 24 individuals who declined to authorize the use of their medical records in research were excluded from further review.

Data collection

After approval from the Mayo Medical Center and Olmsted Medical Center institutional review boards, the complete medical records of each of the 1,306 remaining members of the diabetes incident cohort were retrospectively reviewed for sex, age, fasting glucose level, current smoking status, and BMI (kg/m^2) as of the diabetes identification date (±3 months). The study was limited to the 1,290 (99%) individuals for whom data on BMI at identification were available. BMI was categorized as <18.5 = underweight, 18.5–24.9 = normal, 25.0–29.9 = overweight, 30.0–39.9 = obese, ≥40 = extremely obese) (28). Data on 10-year survival were obtained by following each individual from their diabetes identification date forward, using medical records, State of Minnesota death tapes, and active follow-up through 31 December 1999. Vital status as of 10 years and date of death for those who died was confirmed for all but 11 individuals. Follow-up for these 11 individuals was censored as of the most recent date for which they were known to be alive.

Statistical analysis

Subject characteristics as of the identification date were compared across quinquennia (1970–1974 through 1985–1989) using Kruskal-Wallis test for trend for categorical variables and Pearson correlation for continuous variables. Multivariable regression was used to test for a significant effect of calendar year on BMI after controlling for age, sex, smoking status, and fasting glucose as of the identification date. The modeling process included consideration of all main effects. For significant main effects, backward stepwise regression was then used to investigate all two-way interactions and quadratic terms for continuous variables. Standard diagnostic tests for assessing the effect of outliers on β-coefficients were used. Cox proportional hazards analysis was used to assess the effect of BMI at identification on survival, controlling for the variables described above. BMI was entered as multiple dummy variables (<17, 17–19, 20–22, 26–28, 29–31, 32–34, 35–37, 38–40, and ≥41), with BMI 23–25 as the referent, in a backward stepwise fashion. The assumptions of nonproportionality were examined. All values were considered significant at $P < 0.05$.

RESULTS — Comparison of characteristics at diabetes identification for cohort members who first met diabetes criteria in 1970–1974, 1975–1979, 1980–1984, and 1985–1989 revealed no significant differences across quinquennia in the percent male, mean age, or mean fasting glucose level (Table 1). The proportion of individuals who were cigarette smokers at diabetes identification decreased significantly over time for men, and there was no significant trend for women.

There were marked differences across successive quinquennia in the distribution of BMI at diabetes identification (Table 1), with a significant decrease in the proportion of individuals categorized as either underweight or normal ($P = 0.008$) and a significant increase in the proportion who were either obese or extremely obese ($P = 0.001$). One-third of individuals identified as first meeting diabetes criteria in 1970–1974 were either obese or extremely obese. By 1985–1989, the proportion had risen to nearly one-half (49%). The proportion categorized as extremely obese rose significantly ($P = 0.012$), from 5% in 1970–1974 to 9% in

1985–1989. Temporal trends in mean BMI are graphed for men and women by age-group in Fig. 1. Visual inspection reveals an increase for women in every age-group (Fig. 1*A*) and for men in all but the oldest age-group, in which there were ≤25 individuals in each quinquennium (Fig. 1*B*).

The final multivariable regression model is provided in Table 2. The association between BMI and fasting glucose did not reach conventional statistical significance (β-coefficient −0.004, P = 0.06). On average, BMI was 1.04 units (95% CI 0.26–1.83) lower for cigarette smokers than for nonsmokers. BMI was higher for women than men, but the difference between the sexes diminished with increasing age (e.g., the between-sex difference in mean BMI was 6.5 units at 30 years of age and only 1.2 units at 70 years of age). BMI was higher for individuals who met diabetes criteria at younger compared with older ages, and the difference increased with age. For example, the mean BMI for women aged 30 years was 0.9 units greater than that for women aged 40 years, whereas the mean BMI for women aged 70 years was 2.9 units greater than that for women aged 80 years. There was a significant effect of calendar year, with a model-predicted increase in mean BMI over the full 20-year period of 2.9 units (95% CI 1.8–4.0). The absence of significant interactions between calendar year and smoking status (P = 0.95), age (P = 0.08), and sex (P = 0.12) suggests that trends did not differ between smokers and nonsmokers and reinforces the observation shown in Fig. 1 that trends were similar for men and women and across all ages.

There were 689 deaths among the 1,290 diabetic individuals in the 10 years after their diabetes identification date. The final Cox proportional hazards model of the association between characteristics at diabetes identification and mortality is provided in Table 3. The hazard of death increased with increasing age and fasting glucose level. The hazard of death associ-

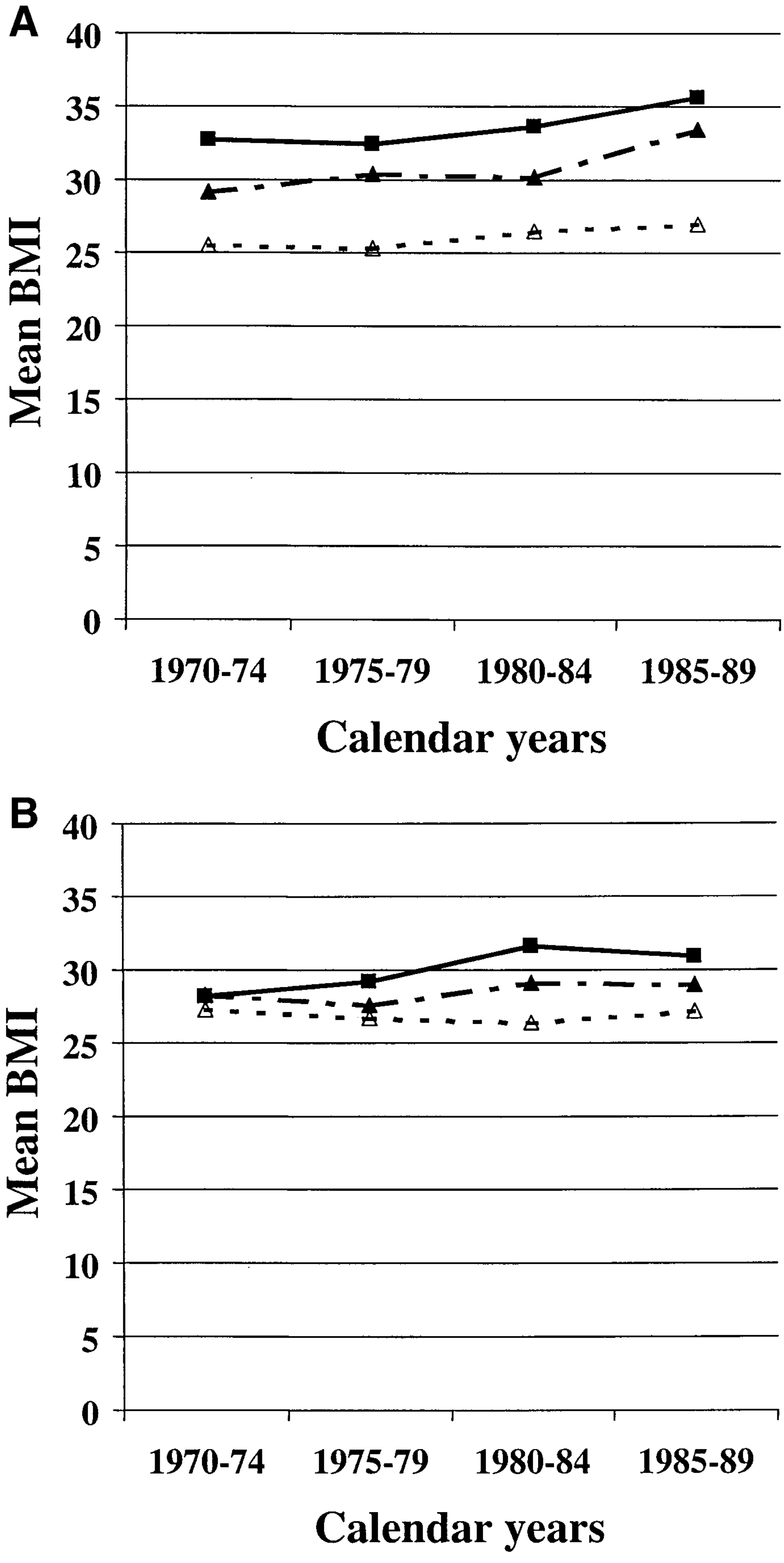

Figure 1—*Mean BMI values as of the date members of the 1970–1989 Rochester, Minnesota, incident diabetes cohort aged ≥30 years were identified as first meeting standardized case criteria for diabetes, by quinquennia for women (1A) and men (1B) at specified ages.* ■, *30–54 years of age;* ▲, *55–74 years of age;* △, *≥75 years of age.*

Table 2—*The final regression model of the association between investigated variables and BMI, as of the date members of the 1970–1989 Rochester, Minnesota, incident diabetes cohort were identified as first meeting case criteria for diabetes*

Variable	β-coefficient	SE	*P*
Intercept	34.558	3.056	<0.001
Age	0.083	0.097	0.392
Age^2	−0.002	0.001	0.001
Male sex	−10.427	1.608	<0.001
Current smoker	−1.045	0.399	0.009
Male sex × age	0.132	0.025	<0.001
Calendar year	0.145	0.029	<0.001

ated with male sex varied as a function of smoking status. Among nonsmokers, men were at increased risk of death relative to women (hazard ratio [HR] 1.42, 95% CI 1.18–1.71). But among individuals who smoked, men were no longer at increased risk (HR 0.90, 95% CI 0.65–1.23). When BMI was entered as 3-unit dummy variables, with BMI of 23–25 as the referent, the only category for which there was a significantly increased risk of death was that for people with BMI ≥41.

CONCLUSIONS— There was a significant increase in BMI among Rochester residents who first met criteria for diabetes between 1970 and 1989. The model-predicted increase of 2.9 BMI units over the 20-year period translates, for individuals of average height (men 175 cm and women 163 cm), to an increase of 8.9 kg (20 lbs) for men and 7.7 kg (17 lbs) for women. Between 1970–1974 and 1985–1989, the proportion of individuals who were obese or extremely obese at diabetes identification increased from one-third to nearly one-half, and the proportion who were extremely obese increased from 5 to 9%. The latter is especially disturbing in light of our finding that individuals who were extremely obese at diabetes identification had a 60% greater risk of death compared with their nonobese diabetic peers.

We compared BMI values observed here with those obtained in the 1976–1980 National Health and Nutrition Examination Survey (NHANES) (29). Despite between-study differences (NHANES subjects were volunteers, diabetes was identified using self-report and glucose tolerance testing, and BMI was measured prospectively), age- and sex-specific mean BMI values for diabetic individuals observed in the 1976–1980 NHANES are very similar to those we observed for 1975–1979 (Fig. 1). The results of Table 2 are consistent with the NHANES observations that the likelihood of obesity among individuals with diabetes was greater for women versus men and for younger versus older individuals (29). Published comparisons between the 1976–1980 NHANES and the 1989 National Health Interview Survey revealed a 4.8% increase in mean self-reported BMI among subjects aged 20–75 years with self-reported history of diabetes (29). Interpretation of these findings is limited by the introduction of new criteria for assigning a clinical diagnosis of diabetes in 1979 (26) and marked discrepancies between self-reported and measured BMI (29). These limitations were minimized in our study by using standardized glycemic criteria for defining diabetes and by using direct measures of height and weight for calculating BMI. Our finding that the mean BMI increased 7.8% between 1975–1979 and 1985–1989 confirms that BMI values for individuals with diabetes increased over the past few decades and suggests that the magnitude of the increase was greater than that indicated by self-report.

Table 3—*The final Cox proportion hazards model of the association between investigated variables, as of the date members of the 1970–1989 Rochester, Minnesota, incident diabetes cohort were identified as first meeting case criteria for diabetes and survival free of death*

Variable	β-coefficient	SE	*P*	HR (95% CI)
Age	0.085	0.004	<0.001	1.089 (1.080–1.098)
Male sex	0.351	0.093	<0.001	—
Current smoker	0.652	0.149	<0.001	—
Fasting glucose	0.002	0.000	<0.001	1.001 (1.001–1.002)
Male sex × smoker	−0.460	0.186	<0.01	—
BMI ≥ 41	0.471	0.194	0.02	1.601 (1.094–2.344)

One possible explanation for the temporal increase in BMI is greater ascertainment of diabetes among obese individuals in recent times. This does not, however, appear to be the case. There was no evidence that the association between BMI and fasting glucose level varied over time (test for interaction between glucose and calendar year, with glucose added to the model in Table 2, $P = 0.54$). To the extent that fasting glucose level is a marker for diabetes severity, this observation argues against temporal increases in ascertainment (i.e., at milder stages of the disease) among obese individuals. To further assess trends in ascertainment, we reviewed the medical records of a random sample of 200 members of the 1970–1989 diabetes cohort for the frequency of glucose measures. Of this sample, 35% had at least one glucose measurement in the year before diabetes identification, and the likelihood did not differ as a function of the calendar year of identification (odds ratio [OR] 0.96, 95% CI 0.90–1.02). Interestingly, the proportion of all Rochester residents aged ≥30 years who had at least one glucose measurement in any year was also ~35%, and that proportion also did not change over time (30). Thus, the relatively high and similar levels of surveillance among potential cases and the population in general, as well as the constancy of surveillance over time, indicate that ascertainment bias was unlikely to have accounted for the observed temporal increases in BMI.

The extent to which the findings of the present study are generalizable to the U.S. population is limited by the fact that, during the years of study, the Rochester population was 95% white. Although measures of height and weight were those recorded during a medical encounter, the protocol was not standardized. No data were available for nondiabetic Rochester residents, and data on individuals with diabetes were not available beyond 1989. The criteria used for ascertaining incident diabetes cases were intentionally strict to minimize misclassification and to ensure a standardized definition throughout the study period. As a result, individuals whose glucose values never met NDDG criteria but did meet the more recently introduced American Diabetes Association criteria (31) were excluded. Individuals who never had a diagnosis suggestive of diabetes in the REP diagnostic index but who would have qualified if prospectively screened were also excluded. This proportion is likely to have been small, as evidenced by our previous finding that 25% of all Rochester decedents had such a diagnosis (see RESEARCH DESIGN AND METHODS). Importantly, the likelihood of having had such a diagnosis was unchanged over time (for each calendar year: OR 1.00, 95% CI 0.99–1.01).

In conclusion, the results of our study reinforce speculation that increasing BMI within the general population contributes not only to greater numbers of diabetic individuals, but also to a greater proportion of diabetic individuals who are extremely obese and, thus, to a greater proportion who are at risk of adverse outcomes. Diabetes is a leading cause of mortality, and diabetes-related deaths are increasing (32). Both the likelihood of diabetes and diabetic complications can be reduced with lifestyle modifications. In the absence of such modifications, the declining mortality observed for the general population over the past several decades may slow or even reverse.

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