Estimated Number of Adults With Prediabetes in the U.S. in 2000

Opportunities for prevention

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OBJECTIVE — To estimate the percent and number of overweight adults in the U.S. with prediabetes who would be potential candidates for diabetes prevention as per the American Diabetes Association Position Statement (12).

RESEARCH DESIGN AND METHODS — We analyzed data from the Third National Health and Nutrition Examination Survey (NHANES III; 1988–1994) and projected our estimates to the year 2000. We defined impaired glucose tolerance (IGT; 2-h glucose 140–199 mg/dl), impaired fasting glucose (IFG; fasting glucose 110–125 mg/dl), and prediabetes (IGT or IFG) per American Diabetes Association (ADA) criteria. The ADA recently recommended that all overweight people (BMI ≥25 kg/m^2) who are ≥45 years of age with prediabetes could be potential candidates for diabetes prevention, as could prediabetic people aged >25 years with risk factors. In NHANES III, 2-h postload glucose concentrations were done only among subjects aged 40–74 years. Because we were interested in overweight people who had both the 2-h glucose and fasting glucose tests, we limited our estimates of IGT, IFG, and prediabetes to those aged 45–74 years.

RESULTS — Overall, 17.1% of overweight adults aged 45–74 years had IGT, 11.9% had IFG, 22.6% had prediabetes, and 5.6% had both IGT and IFG. Based on those data, we estimated that in the year 2000, 9.1 million overweight adults aged 45–74 had IGT, 5.8 million had IFG, 11.9 million had prediabetes, and 3.0 million had IGT and IFG.

CONCLUSIONS — Almost 12 million overweight individuals aged 45–74 years in the U.S. may benefit from diabetes prevention interventions. The number will be substantially higher if estimation is extended to individuals aged >75 and 25–44 years.

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Type 2 diabetes, which has devastating consequences on life expectancy, morbidity, and quality of life and imposes large economic costs, currently affects 16 million persons in the U.S.—a number that is projected to increase (1–3). Despite major advances in the treatment of glycemia, risk factors for cardiovascular disease (CVD), and other diabetes complications, type 2 diabetes remains a chronic degenerative condition that is difficult to treat (4). Prevention of diabetes is thus a worthy public health goal, especially because the diabetes pandemic is linked to contemporary lifestyle (5). Although literature from the last decade indicated that lifestyle interventions may reduce the incidence of type 2 diabetes, evidence from randomized controlled trials has been lacking (6).

Now four recent randomized controlled trials, performed across diverse countries, settings, and populations, have provided evidence that the progression from impaired glucose tolerance (IGT) to type 2 diabetes can be delayed or prevented (7–11). The most compelling evidence so far is from the recently published Diabetes Prevention Program (DPP) in the U.S. (9,10). The DPP was a 27-center, randomized controlled clinical trial that included a diverse group of 3,200 adults aged >25 years with a BMI ≥24 kg/m^2 and IGT. The trial found that modest weight loss and changes in lifestyle reduced the 3-year incidence of type 2 diabetes by 58%, and that the drug metformin reduced the risk by 31% (10). The DPP showed that it was possible to prevent or delay diabetes among individuals at high risk for diabetes, regardless of age, sex, and race/ethnicity.

The success of these major diabetes prevention trials is clearly a call for action (5). Although these trials focused on adults with IGT, the American Diabetes Association (ADA) has recently recommended that all overweight people (BMI ≥25 kg/m^2) aged ≥45 years with prediabetes (IGT or impaired fasting glucose [IFG]) be considered potential candidates for diabetes prevention, as well as overweight younger individuals with prediabetes and other risk factors (12). As a first public health step, we need to determine how many individuals in the U.S. may benefit from such interventions. These data will help assess resource needs, plan resource allocation, target the delivery of interventions, and provide baseline data for monitoring national diabetes prevention programs.

In our study, we wanted to estimate how many individuals in the U.S. could be eligible for diabetes prevention inter-

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Abbreviations: ADA, American Diabetes Association; CVD, cardiovascular disease; DPP, Diabetes Prevention Program; IFG, impaired fasting glucose; IGT, impaired glucose tolerance; NHANES III, Third National Health and Nutrition Examination Survey; OGTT, oral glucose tolerance test.

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

vention as per the recent ADA Position Statement (12). To do this, we projected total and strata-specific (e.g., age, sex, and race/ethnicity) estimates of IGT, IFG, and prediabetes for the year 2000 using data from the nationally representative Third National Health and Nutrition Examination Survey (NHANES III), which was conducted from 1988 through 1994, and year 2000 U.S. census estimates.

RESEARCH DESIGN AND METHODS

— NHANES III was a survey of the civilian, noninstitutionalized U.S. population that followed a complex sampling design, including oversampling of blacks and Mexican-Americans (13,14). Home interviews, physical examinations, and laboratory examinations were performed on ~34,000 persons aged ≥2 months. Adults were randomly assigned to either morning or afternoon sessions for physical and laboratory examinations. Only those who participated in the morning session were eligible for the oral glucose tolerance test (OGTT) and fasting glucose test; therefore, we limited our analyses to this population. Of the 6,974 participants aged ≥25 years who were randomly assigned to the morning, 572 reported a previous diagnosis of diabetes when not pregnant and 6,402 did not. After a 9- to 24-h fasting period, a blood sample was obtained from 5,830 (91.1%) of the participants without self-reported diabetes. Of the participants who gave a fasting blood sample, 2,426 were between ages 45 and 74 years, the age group to which OGTT was restricted. After a 2-h (±15 min) 75-g glucose challenge, a second blood sample was obtained from 2,269 (93.5%) participants in that age group.

We assessed other information from the participants, including demographics and risk factors for CVD. Being overweight was defined as having a BMI ≥25 kg/m^2 (12). Dyslipidemia was defined as an HDL concentration <45 mg/dl in men or <55 mg/dl in women, a total cholesterol concentration ≥200 mg/dl, an LDL concentration ≥100 mg/dl, or a fasting triglyceride concentration ≥200 mg/dl or as having ever been prescribed medication for high cholesterol (15,16). Hypertension was classified as having an elevated blood pressure (systolic ≥140 mmHg or diastolic ≥90 mmHg) or as having ever been prescribed medication for hypertension (17). Microalbuminuria was determined by a urinary albumin concentration ≥30 μg/ml (18). Smoking meant being a current smoker and having smoked ≥100 cigarettes during one's lifetime.

Aside from adults with self-reported diabetes, all analyses were conducted among overweight adults aged 45–74 years who received both the fasting glucose test and a 2-h glucose challenge. Adults without self-reported diabetes were classified as having undiagnosed diabetes if their 2-h glucose concentration was ≥200 mg/dl and/or their fasting glucose concentration was ≥126 mg/dl (19,20). We used the term "prediabetes" to identify adults without diabetes who had IGT (2-h glucose concentration of 140–199 mg/dl) or IFG (fasting glucose concentration 110–125 mg/dl) (12,19,20). The prevalence of IGT, IFG, prediabetes, and IGT plus IFG was estimated among overweight adults aged 45–74 years. A comparison of people with prediabetes with people meeting DPP criteria for IGT (IGT plus fasting glucose of 95–125 mg/dl) (9) across several demographic and clinical characteristics was also performed. To project 1988–1994 NHANES III estimates to the year 2000, we applied the respective prevalences of self-reported diabetes and being overweight, undiagnosed diabetes and being overweight, and prediabetes and being overweight to year 2000 population estimates (21). SUDAAN software was used to account for the complex sampling design of the survey (22). All analyses accounted for the clustered sampling design and oversampling and were adjusted for differential noncoverage and nonresponse (13,14).

RESULTS

— Among overweight adults aged 45–74 years, 12.5% had self-reported diabetes (the corresponding U.S. population projection for 2000 is 6.7 million persons), 10.8% (5.7 million) had undiagnosed diabetes, 22.6% (11.9 million) had prediabetes, 17.1% (9.1 million) had IGT, 11.1% (5.8 million) had IFG, 5.6% (3.0 million) had both IGT and IFG (Table 1), and 54.1% (38.4 million) had normal glucose metabolism. In all, 14.4% or 7.3 million people met DPP IGT criteria. Among the overweight adults aged 45–74 years with prediabetes, >50% had IGT only; <25% had IFG only or IGT and IFG combined (Fig. 1).

The prevalence of impaired metabolism states was similar by sex and by race/ethnicity, with two exceptions (Table 1). Mexican-American men were more than twice as likely as Mexican-American women to have IFG (16.5 vs. 7.6%), and the prevalence of prediabetes was higher among Mexican-Americans than among non-Hispanic blacks (27.3 vs. 18.9%).

There were a few differences in characteristics across the metabolic states (Table 2). Among overweight adults aged 45–74 years, a higher proportion of men than women had IFG (55.4 vs. 44.6%). Compared with adults with IFG, adults with IGT had a lower mean weight (83.5 vs. 87.3 kg) and a lower mean waist circumference (103.3 vs. 106.1 cm). Among adults with prediabetes, the prevalence of CVD risk factors was high: 94.9% had dyslipidemia, 56.5% had hypertension, 13.9% had microalbuminuria, and 16.6% were current smokers. People with prediabetes had characteristics that were remarkably similar to those with DPP IGT (IGT plus fasting glucose 95–125 mg/dl) across several demographic and clinical variables; the only exception was that people with prediabetes had lower 2-h glucose concentrations (149.7 vs. 164.1 mg/dl).

CONCLUSIONS

— Overall, ~25% of overweight adults aged 45–74 years had prediabetes, which translates into about 12 million persons in the U.S. in the year 2000. Recent controlled trials on diabetes prevention have confirmed that lifestyle changes such as diet, weight loss, and exercise as well as the drug metformin can substantially delay or prevent the progression from impaired metabolism to type 2 diabetes (7–10). Thus, several million individuals could benefit from diabetes prevention intervention. Furthermore, in the process of identifying those with prediabetes, we estimated that an additional 6.5 million persons with undiagnosed diabetes would be detected.

We compared the characteristics of individuals with IGT in the population represented by NHANES III with those of individuals with IGT recruited in the DPP (10,23). As previously reported (23), the DPP sample was younger and had a lower proportion of men, a lower proportion of nonminority groups, a higher mean BMI, lower mean lipid concentrations, a lower proportion of smokers, but roughly similar mean fasting glucose (106.5 vs. 104.2 mg/dl) and mean 2-h glucose concentra-

Table 1—*Prevalence of prediabetes, IGT, and IFG among overweight (BMI ≥25 kg/m^2) adults aged 45–74 years, by race and ethnicity and by sex*

	Using ADA criteria				Using DPP criteria
	Prediabetes (IGT or IFG)	IGT	IFG	IGT and IFG	IGT and fasting glucose 95–125 mg/dl
All races					
Both sexes	22.6 ± 1.7 (11.9)	17.1 ± 1.6 (9.1)	11.1 ± 1.1 (5.8)	5.6 ± 1.0 (3.0)	14.4 ± 1.4 (7.3)
Men	23.2 ± 2.2 (6.0)	16.6 ± 2.2 (4.3)	12.4 ± 1.6 (3.2)	5.9 ± 1.2 (1.5)	15.0 ± 2.1 (3.7)
Women	22.0 ± 1.6 (5.9)	17.7 ± 1.6 (4.8)	9.7 ± 1.4 (2.6)	5.4 ± 1.3 (1.5)	13.8 ± 1.5 (3.6)
Non-Hispanic white					
Both sexes	22.2 ± 1.8 (8.9)	16.7 ± 1.7 (6.7)	11.1 ± 1.1 (4.5)	5.6 ± 1.1 (2.3)	14.2 ± 1.4 (5.7)
Men	22.3 ± 2.5 (4.6)	15.9 ± 2.4 (3.3)	12.7 ± 1.7 (2.6)	6.3 ± 1.5 (1.3)	14.4 ± 2.2 (3.0)
Women	22.1 ± 1.8 (4.3)	17.6 ± 1.8 (3.4)	9.5 ± 1.4 (1.8)	4.9 ± 1.3 (1.0)	14.1 ± 1.7 (2.7)
Non-Hispanic black					
Both sexes	18.9 ± 1.8 (1.0)	13.7 ± 1.5 (0.8)	9.5 ± 1.4 (0.5)	4.2 ± 0.8 (0.2)	10.9 ± 1.3 (0.6)
Men	22.0 ± 4.0 (0.5)	15.0 ± 3.4 (0.3)	10.3 ± 2.3 (0.2)	3.2 ± 1.3 (0.1)	11.6 ± 2.6 (0.2)
Women	17.1 ± 1.8 (0.6)	12.9 ± 1.8 (0.4)	9.0 ± 1.5 (0.3)	4.8 ± 1.3 (0.2)	10.4 ± 1.6 (0.4)
Mexican-American					
Both sexes	27.3 ± 3.0 (0.7)	20.9 ± 2.5 (0.6)	11.8 ± 1.6 (0.3)	5.4 ± 0.9 (0.1)	18.2 ± 2.3 (0.5)
Men	28.5 ± 4.8 (0.4)	18.1 ± 3.1 (0.2)	16.5 ± 2.6 (0.2)	6.1 ± 1.6 (0.1)	15.1 ± 2.7 (0.2)
Women	26.3 ± 3.3 (0.4)	23.4 ± 3.5 (0.3)	7.6 ± 1.6 (0.1)	4.7 ± 1.2 (0.1)	21.1 ± 3.2 (0.3)

Data are % ± SEM (*n* in millions, calculated using the 2000 U.S. population). Adults with IGT (2-hour glucose concentration 140-199 mg/dl) and/or IFG (fasting glucose concentration 110–125 mg/dl were considered to have prediabetes (12). Also included in analysis were people meeting DPP criteria for IGT (9) *Estimates include those of racial and ethnic groups not listed separately.

tion (164.9 vs. 161.9 mg/dl). Although the DPP population had a higher proportion of minority groups, the DPP researchers found that lifestyle and metformin interventions worked equally well across all race/ethnic groups (10). Of interest is the fact that people with prediabetes had remarkably similar characteristics to those with IGT in the DPP trial (IGT plus fasting glucose 95–125 mg/dl) across several demographic and clinical variables.

To date, no diabetes prevention trial has been conducted solely among persons with IFG, although each of the recent trials included some persons with IGT who also had IFG. Both conditions indicate prediabetes (12), and the two states overlap somewhat, but are not identical. In our study, 25% of those with prediabetes had both IGT and IFG; yet we found that demographic and CVD risk factor profiles were similar between those with IGT and IFG except for some differences in gender distribution, mean weight, and mean waist circumference. In the Hoorn study (24), the conversion rate from IGT to diabetes and from IFG to diabetes was fairly similar (57.9/1,000 vs. 51.4/1,000 person-years).

The risk of diabetes is strongly linked to contemporary lifestyle, which is heavily influenced by socioeconomic and cultural factors; diabetogenic lifestyles are also ubiquitous (4,5). It is intuitive to argue that a diabetes prevention approach aimed at the entire population rather than one targeted at a high-risk group should be adopted. However, several factors support an aggressive, DPP-like approach targeting high-risk persons (defined by IGT or IFG in overweight adults). For example, in the total population serum glucose concentrations were bimodally distributed (19), and the threshold for diabetes risk coincided with the onset of prediabetes. Using data reported in the Hoorn study (24), we estimated that although 8% of that study population had IGT, 40% of incident cases of diabetes occurred among subjects with IGT, and although 10% had IFG, 42% of incident cases occurred among subjects with IFG. In addition, most, if not all, individuals who develop type 2 diabetes pass through IGT or IFG; this phase offers an opportunity to efficiently identify those at imminent risk of developing diabetes. Moreover, in our analysis, the prevalence of certain CVD risk factors (e.g., dyslipidemia and hypertension) among those with IGT or IFG was very high; lifestyle interventions in this group may help prevent CVD, in addition to delaying or preventing the development of diabetes.

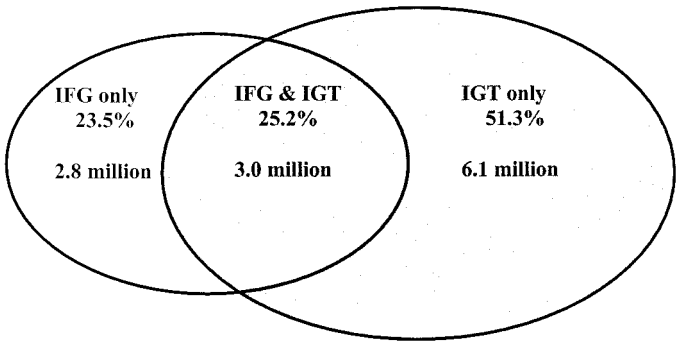

Figure 1—*Proportion of IFG, IGT, and IFG plus IGT among overweight (BMI ≥25 kg/m^2) prediabetic individuals aged 45–74 years.*

Table 2—*Characteristics of overweight (BMI ≥25 kg/m^2) adults ages 45–74 years with prediabetes, IGT, and IFG*

	Using ADA criteria				Using DPP criteria
	Prediabetes (IGT or IFG)	IGT	IFG	IGT and IFG	IGT and fasting glucose 95–125 (mg/dl)
Sex (%)					
Male	50.6 ± 2.7	47.8 ± 4.0	55.4 ± 4.5	51.4 ± 7.0	51.4 ± 4.5
Female	49.4 ± 2.7	52.2 ± 4.0	44.6 ± 4.5	48.6 ± 7.0	48.6 ± 4.5
Age					
45-59 years (%)	46.8 ± 3.4	44.6 ± 4.2	47.2 ± 4.6	41.0 ± 6.1	44.6 ± 5.0
60-74 years (%)	53.2 ± 3.4	55.4 ± 4.2	52.8 ± 4.6	59.0 ± 6.1	55.4 ± 5.0
Mean (years)	59.8 ± 0.6	60.1 ± 0.8	59.8 ± 0.8	60.8 ± 1.2	60.1 ± 0.9
Race or ethnicity (%)					
Non-Hispanic white	79.0 ± 3.0	78.4 ± 3.7	80.4 ± 3.1	80.0 ± 4.5	79.4 ± 3.8
Non-Hispanic black	7.3 ± 1.1	7.0 ± 1.2	7.5 ± 1.4	6.6 ± 1.8	6.6 ± 1.2
Mexican-American	4.8 ± 0.9	4.8 ± 1.0	4.2 ± 0.9	3.8 ± 1.1	5.0 ± 1.1
BMI					
25–29 kg/m^2 (%)	58.5 ± 3.0	58.0 ± 3.6	54.5 ± 4.2	49.1 ± 5.4	55.3 ± 4.3
≥30 kg/m^2 (%)	41.5 ± 3.0	42.0 ± 3.6	45.5 ± 4.2	50.9 ± 5.4	44.7 ± 4.3
Mean (kg/m^2)	30.2 ± 0.3	30.0 ± 0.3	30.8 ± 0.5	30.8 ± 0.6	30.3 ± 0.4
Family history of diabetes (%)	44.3 ± 3.5	46.1 ± 4.3	47.9 ± 4.8	56.7 ± 6.1	46.2 ± 4.5
Mean lipid concentration (mg/dl)					
Total cholesterol	224.6 ± 2.9	225.7 ± 3.4	224.9 ± 3.7	228.3 ± 5.7	227.3 ± 3.8
HDL cholesterol	46.1 ± 0.8	46.1 ± 0.9	45.6 ± 1.1	44.9 ± 1.4	44.7 ± 1.0
LDL cholesterol	141.8 ± 2.3	142.2 ± 2.8	143.6 ± 3.3	146.4 ± 5.1	144.7 ± 3.3
Triglycerides	184.3 ± 5.5	189.8 ± 6.2	178.1 ± 9.2	188.7 ± 12.4	192.6 ± 7.3
Cardiovascular risk factor (%)					
Dyslipidemia	94.9 ± 2.2	95.8 ± 1.5	94.3 ± 3.0	96.6 ± 2.2	95.9 ± 1.6
Hypertension	56.5 ± 3.2	58.5 ± 4.2	55.4 ± 4.1	60.7 ± 6.9	58.8 ± 4.2
Albuminuria	13.9 ± 1.9	14.2 ± 2.1	10.7 ± 3.2	8.6 ± 3.4	14.4 ± 2.3
Smoking	16.6 ± 2.9	15.3 ± 3.2	17.8 ± 4.5	15.3 ± 5.8	14.6 ± 3.7
Mean weight (kg)	84.4 ± 1.0	83.5 ± 1.1	87.3 ± 1.5	87.4 ± 2.2	84.9 ± 1.2
Mean waist circumference (cm)	104.0 ± 0.7	103.3 ± 0.8	106.1 ± 1.0	105.9 ± 1.2	104.1 ± 0.8
Mean fasting glucose concentration (mg/dl)	107.4 ± 0.7	105.0 ± 0.9	115.6 ± 0.5	116.1 ± 0.6	107.9 ± 0.9
Mean 2-hour glucose concentration (mg/dl)	149.7 ± 2.1	162.9 ± 1.2	137.0 ± 4.4	165.2 ± 2.7	164.1 ± 1.5
Mean HbA_{1c} (%)	5.5 ± 0.0	5.5 ± 0.0	5.6 ± 0.1	5.6 ± 0.1	5.6 ± 0.0

Data are % ± SEM or mean ± SEM. Adults with prediabetes included those with IGT (2-h glucose concentration 140–199 mg/dl) and/or IFG (fasting glucose concentration 110–125 mg/dl) (12). Also included in analysis were people meeting DPP criteria for IGT (9). See RESEARCH DESIGN AND METHODS for details.

The NHANES III data posed some advantages and disadvantages for our analyses. It was advantageous that the data were nationally representative and had standardized laboratory, clinical, and physical measurements. However, the fact that limited data were available on racial/ethnic groups at high risk for diabetes (e.g., Native Americans), and that no 2-h glucose data from adults ages <40 years and ≥75 years were available was disadvantageous. In addition, we might have underestimated the true size of the U.S. population at risk for diabetes because the proportions of overweight and diabetic adults have increased since the NHANES III was conducted (25). We have estimated that in 2000, among overweight Americans aged 45–74 years, 9.1 million had IGT, 5.8 million had IFG, and 11.9 million had prediabetes.

There is strong evidence for substantially delaying or preventing diabetes among overweight adults with IGT. The ADA has recommended that all overweight people aged ≥45 years with prediabetes are potential candidates for diabetes prevention (12). To what extent other people with abnormal glucose tolerance (e.g., those with IFG) would respond similarly to subjects that participated in the clinical trials of prevention (7–11) is not clear. In any case, our estimates suggest that very large numbers of people at risk for diabetes may benefit from diabetes prevention interventions; our estimates may also be conservative, because data were not available for all age groups. The immediate challenge is to translate research evidence for diabetes prevention into practice and policy. Questions remain about which groups may benefit and by how much from diabetes interventions, the most efficient means to identify these groups, and the most effective ways to deliver and sustain interventions.

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