Full Accounting of Diabetes and Pre-Diabetes in the U.S. Population in 1988–1994 and 2005–2006

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OBJECTIVE — We examined the prevalences of diagnosed diabetes, and undiagnosed diabetes and pre-diabetes using fasting and 2-h oral glucose tolerance test values, in the U.S. during 2005–2006. We then compared the prevalences of these conditions with those in 1988–1994.

RESEARCH DESIGN AND METHODS — In 2005–2006, the National Health and Nutrition Examination Survey included a probability sample of 7,267 people aged ≥12 years. Participants were classified according to glycemic status by interview for diagnosed diabetes and by fasting and 2-h glucoses measured in subsamples.

RESULTS — In 2005–2006, the crude prevalence of total diabetes in people aged ≥20 years was 12.9%, of which ~40% was undiagnosed. In people aged ≥20 years, the crude prevalence of impaired fasting glucose was 25.7% and of impaired glucose tolerance was 13.8%, with almost 30% having either. Over 40% of individuals had diabetes or pre-diabetes. Almost one-third of the elderly had diabetes, and three-quarters had diabetes or pre-diabetes. Compared with non-Hispanic whites, age- and sex-standardized prevalence of diagnosed diabetes was approximately twice as high in non-Hispanic blacks ($P < 0.0001$) and Mexican Americans ($P = 0.0001$), whereas undiagnosed diabetes was not higher. Crude prevalence of diagnosed diabetes in people aged ≥20 years rose from 5.1% in 1988–1994 to 7.7% in 2005–2006 ($P = 0.0001$); this was significant after accounting for differences in age and sex, particularly in non-Hispanic blacks. Prevalences of undiagnosed diabetes and pre-diabetes were generally stable, although the proportion of total diabetes that was undiagnosed decreased in Mexican Americans.

CONCLUSIONS — Over 40% of people aged ≥20 years have hyperglycemic conditions, and prevalence is higher in minorities. Diagnosed diabetes has increased over time, but other conditions have been relatively stable.

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Diabetes and its complications remain major causes of morbidity and mortality in the U.S. (1). Estimated economic costs of diabetes in medical expenditures and lost productivity total $174 billion in the U.S. in 2007 (2). In 1999–2002, the crude prevalence of diabetes (diagnosed and undiagnosed) in the U.S. was 9.3%, of which 30% was undiagnosed based on fasting plasma glucose (FPG) (3). A further 26% had impaired fasting glucose (IFG). IFG increases the risk of diabetes (4), and both undiagnosed diabetes and IFG are associated with diabetes complications and risk factors (4,5). These prevalence data came from the National Health and Nutrition Examination Survey (NHANES), the only national survey that captures information on diabetes and pre-diabetes from an interview and FPG.

In 2005–2006, an oral glucose tolerance test (OGTT) was added to NHANES, which had not been performed since NHANES 1988–1994. Whereas elevated FPG is determined more by impaired hepatic insulin resistance, elevated 2-h plasma glucose from an OGTT is determined predominantly by peripheral insulin resistance (4,6). The OGTT aids in detecting the total burden of diabetes and also impaired glucose tolerance (IGT). Two-hour plasma glucose values are more sensitive in the elderly (7), an increasing proportion of the U.S. population. IGT also predicts diabetes and is more commonly associated with cardiovascular disease risk factors and events than IFG (4,8).

In this report, we analyze the prevalence of diagnosed diabetes, undiagnosed diabetes based on fasting and 2-h plasma glucose from an OGTT, and pre-diabetes (IFG or IGT) in people aged ≥12 years using data from NHANES 2005–2006. Results are presented by age, sex, and race/ethnicity. We compare these estimates with those from NHANES 1988–1994.

The addition of the OGTT also allowed assessment of the agreement between diagnostic categories defined by fasting and 2-h plasma glucose. Although this was examined in NHANES 1988–1994 in those aged 40–74 years (9), a reexamination is appropriate given *1)* the measurements in a wider age range in NHANES 2005–2006, *2)* the change in criteria for IFG (lowered from 110 to 100 mg/dl) since that report (8), and *3)* the rising prevalence of glucose abnormalities (3) and obesity (10).

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RESEARCH DESIGN AND METHODS

— NHANES 2005–2006 was conducted by the National Center for Health Statistics (11). NHANES is designed to be representative of the U.S. civilian noninstitutionalized population using a complex, multistage probability sample. Participants are interviewed in their homes and subsequently receive a physical and laboratory examination in a mobile examination center. Among eligible subjects in 2005–2006, 77.7% were interviewed and 74.9% were examined (11).

In 2005–2006, 7,267 individuals aged ≥12 years completed the household interview (online appendix Figure A1 [available at http://dx.doi.org/10.2337/dc08-1296]). Questions covered demographic characteristics and medical conditions. Individuals were asked whether, other than during pregnancy for women, a doctor or health care professional had ever told them that they have diabetes. There were 516 individuals aged ≥12 years classified as having diagnosed diabetes.

Households were randomized to either a morning or afternoon/evening examination session. There were 3,107 individuals aged ≥12 years without diagnosed diabetes examined during a morning session, and plasma glucose values were obtained from 2,662 (86%) of them after they fasted for 8 to <24 h. This group is subsequently referred to as the FPG subsample. Pregnant women (n = 162) were included, none of whom had undiagnosed diabetes based on FPG.

Individuals assigned to the morning examination underwent an OGTT (11). A 75-g glucose-equivalent oral glucose challenge (Trutol) was given, and a blood sample was drawn 2 h (±15 min) later. Exclusion criteria included use of insulin or oral medications for diabetes, known pregnancy, hemophilia, chemotherapy, refusal of phlebotomy, and inability/refusal to drink all of the Trutol. The 2-h glucose value was obtained for 2,290 (86%) of those in the FPG sample. This group is subsequently referred to as the OGTT subsample.

Procedures for blood collection and processing are described elsewhere (11). Plasma glucose was measured at a central laboratory using a hexokinase enzymatic method (11), with a coefficient of variation of 1.3–2.2% (11). A1C was measured by a high-performance liquid chromatographic assay (11). Because there were changes to the equipment and laboratory that measured glucose and A1C since the earlier NHANES surveys, conversion factors were applied to values from 2005–2006 to make them comparable with values from NHANES III (1988–1994) (11).

Standard diagnostic criteria were used to classify people without diagnosed diabetes as to whether they had undiagnosed diabetes (FPG ≥7.0 mmol/l and/or 2-h glucose ≥11.1 mmol/l) or pre-diabetes (IFG [FPG 5.6 to <7.0 mmol/l] and/or IGT [2-h glucose 7.8 to <11.1 mmol/l]) (12).

Estimates from NHANES 2005–2006 are compared with those from NHANES 1988–1994. NHANES 1988–1994 used similar interview questions on previous diagnosis of diabetes (13,14). Collection methods for blood specimens were the same across the surveys (13). In 1988–1994, the OGTT was only performed in individuals aged 40–74 years.

For NHANES 2005–2006, individuals with diagnosed diabetes from the interviewed sample were combined with individuals without diagnosed diabetes from the FPG subsample for estimates involving FPG, or the OGTT subsample for estimates involving 2-h glucose (online appendix Figure A1). Appropriate sampling weights were used so that the sum of the sample weights from the two groups (interview and FPG or OGTT subsample) added to the total U.S. population. For NHANES 1988–1994, prevalences of normal glucose and undiagnosed diabetes (based on FPG or 2-h glucose), IFG, and IGT in the subsamples of people without diagnosed diabetes were each adjusted for the prevalence of diagnosed diabetes from the interviewed sample so that the sum of all diagnostic categories added to the total U.S. population (15). This difference in approach for NHANES 1988–1994 was required because sampling weights provided for the FPG and OGTT subsamples for that survey did not account for some individuals having invalid or unknown fasting times or unknown plasma glucose values.

We standardized estimates to the U.S. 2000 Census population by age and sex using the direct method with age categories of 12–19, 20–39, 40–59, and ≥60 years for estimates in people aged ≥12 and ≥20 years and age categories of 40–59 and 60–74 years for estimates in those aged 40–74 years. The ratio of undiagnosed to total diabetes was also standardized to the total U.S. 2000 Census population. SUDAAN (16) was used to calculate SEs in NHANES 2005–2006 based on the Taylor series linearization method (17). For NHANES 1988–1994, variance estimates were based on Fay's modified balanced repeated replication (18), reflecting the method used to combine the interviewed and FPG/OGTT subsamples.

For NHANES 2005–2006, we used one-sample Student's t tests for testing whether differences between subgroups in proportions were significantly different from zero. Two-sample Student's t tests were used to test differences in proportions between the two surveys. A P value ≤0.05 was considered statistically significant. The degrees of freedom used reflect the complex sample design.

RESULTS

Prevalences in 2005–2006

Diagnosed diabetes. The crude prevalence of diagnosed diabetes in individuals aged ≥20 years was 7.7% (Table 1). Prevalence increased with age and peaked at age 60–74 years (crude 17.6%), falling slightly in older ages. Crude and standardized prevalences were similar in men and women. Crude prevalence was significantly higher in non-Hispanic blacks (12.8%) than in non-Hispanic whites (6.6%; $P < 0.0001$) and Mexican Americans (8.4%; $P = 0.008$); standardized prevalences were significantly higher in non-Hispanic blacks ($P < 0.0001$) and Mexican Americans ($P = 0.0001$) than in non-Hispanic whites.

Undiagnosed diabetes (FPG). The crude prevalence of undiagnosed diabetes based on FPG was 2.5% among individuals aged ≥20 years (Table 1). Prevalence was much higher in those aged ≥60 years than in people of younger ages. The higher prevalences of undiagnosed diabetes in men than in women were not significantly different (crude $P = 0.12$; standardized $P = 0.08$). There were no statistically significant differences between race/ethnic groups.

Undiagnosed diabetes (2-h OGTT glucose). The crude prevalence of undiagnosed diabetes based on 2-h glucose was 4.9% among people aged ≥20 years, approximately twofold higher than prevalences of undiagnosed diabetes based on FPG (Table 1). Similar to the case of undiagnosed diabetes based on FPG, prevalence based on 2-h glucose was much higher in those aged ≥60 years than in those of younger ages. No differences in prevalence were found by sex. Standardized prevalence of undiagnosed diabetes

Table 1—*Crude and standardized* prevalence of previously diagnosed diabetes, undiagnosed diabetes (based on FPG and 2-h glucose from an OGTT), total undiagnosed diabetes, total diabetes, and proportion of total diabetes that is undiagnosed by age, sex, and race/ethnicity, NHANES 2005–2006*

	Diagnosed diabetes	Undiagnosed diabetes			Total diabetes (diagnosed and undiagnosed by FPG or OGTT)	Proportion of total diabetes that is undiagnosed§
		FPG†	OGTT‡	Total (FPG or OGTT)		
n	3,178	3,178	2,806	2,806	2,806	2,806
Crude prevalence						
Combined age-groups (years)						
≥12	6.7 (5.8–7.7)	2.1 (1.1–3.2)	4.2 (3.0–5.5)	4.4 (3.1–5.7)	11.1 (9.3–13.0)	39.7 (32.8–46.6)
≥20	7.7 (6.7–8.8)	2.5 (1.2–3.7)	4.9 (3.4–6.4)	5.1 (3.6–6.6)	12.9 (10.8–14.9)	39.8 (32.9–46.6)
≥65	17.0 (14.9–19.0)	6.6 (2.7–10.5)	14.3 (9.6–19.0)	14.6 (10.0–19.2)	31.6 (25.7–37.6)	46.2 (39.3–53.1)
Age-specific groups (years)						
12–19	0.2‖ (0.0–0.5)¶	0.1‖ (0.0–0.1)¶	0.0	0.1‖ (0.0–0.2)¶	0.3‖ (0.0–0.6)¶	#
20–39	2.1 (1.5–2.8)	0.8‖ (0.2–1.3)	0.9 (0.4–1.4)	1.0 (0.4–1.6)	3.1 (2.4–3.9)	32.5 (16.7–48.2)
40–59	7.9 (6.3–9.5)	1.9‖ (0.4–3.4)	4.2 (1.8–6.5)	4.5 (2.1–6.9)	12.4 (9.0–15.8)	36.1 (24.5–47.8)
60–74	17.6 (14.9–20.3)	6.7‖ (2.1–11.4)	12.4 (6.7–18.2)	12.8 (7.1–18.4)	30.0 (23.0–37.0)	42.6 (32.1–53.1)
≥75	14.9 (11.1–18.8)	5.4‖ (1.1–9.8)	13.4 (9.3–17.5)	13.4 (9.3–17.5)	29.1 (24.8–33.3)	46.0 (34.6–57.5)
Sex by age (years)						
Men						
≥12	6.2 (4.9–7.5)	2.9 (1.1–4.6)	4.2 (2.3–6.0)	4.5 (2.6–6.4)	10.7 (8.1–13.2)	41.9 (30.9–53.0)
≥20	7.2 (5.7–8.7)	3.3 (1.3–5.3)	4.9 (2.8–7.0)	5.2 (3.0–7.4)	12.4 (9.6–15.2)	42.0 (31.2–52.8)
Women						
≥12	7.2 (5.7–8.7)	1.5‖ (0.5–2.4)	4.3 (2.9–5.7)	4.4 (2.8–5.9)	11.6 (9.1–14.1)	37.8 (29.1–46.5)
≥20	8.3 (6.5–10.0)	1.7‖ (0.6–2.8)	4.9 (3.3–6.5)	5.0 (3.3–6.8)	13.3 (10.5–16.1)	37.9 (29.1–46.6)
Race/ethnicity by age (years)						
Non-Hispanic white						
≥12	5.8 (4.6–7.1)	2.3‖ (0.8–3.7)	4.8 (3.0–6.6)	4.9 (3.0–6.8)	10.7 (8.2–13.3)	45.8 (36.4–55.3)
≥20	6.6 (5.3–7.9)	2.6‖ (0.9–4.2)	5.5 (3.4–7.5)	5.6 (3.5–7.7)	12.2 (9.4–15.0)	46.0 (36.7–55.2)
Non-Hispanic black						
≥12	10.6 (8.9–12.4)	2.6 (1.3–3.8)	2.9 (1.9–3.9)	3.4 (1.5–5.3)	14.1 (11.5–16.6)	24.2 (13.4–34.9)
≥20	12.8 (10.6–15.1)	3.1 (1.7–4.5)	3.5 (2.4–4.6)	4.1 (2.0–6.2)	17.0 (14.4–19.7)	24.2 (13.4–35.0)
Mexican American						
≥12	6.9 (5.1–8.8)	2.9‖ (1.1–4.8)	4.6 (1.8–7.5)	5.3 (2.4–8.1)	12.2 (8.0–16.4)	43.1 (32.2–54.1)
≥20	8.4 (6.3–10.6)	3.5‖ (1.1–5.8)	5.7 (2.2–9.2)	6.3 (2.7–9.9)	14.7 (9.5–20.0)	43.0 (31.5–54.6)
Standardized* prevalence						
Combined age-groups (years)						
≥12	6.6 (5.8–7.3)	2.1 (1.2–3.0)	4.1 (3.0–5.3)	4.3 (3.2–5.4)	10.9 (9.5–12.3)	#
≥20	7.6 (6.7–8.5)	2.4 (1.4–3.5)	4.8 (3.5–6.1)	5.0 (3.7–6.3)	12.6 (10.9–14.3)	34.2 (26.3–42.1)
≥65	16.9 (14.8–19.0)	6.6 (2.7–10.5)	14.1 (9.5–18.7)	14.4 (9.9–18.9)	31.4 (25.3–37.4)	45.6 (39.0–52.3)
Age-specific groups (years)						
12–19	0.2‖ (0.0–0.5)¶	0.1‖ (0.0–0.1)¶	0.0	0.1‖ (0.0–0.1)¶	0.3‖ (0.0–0.6)¶	#
20–39	2.1 (1.5–2.8)	0.7‖ (0.2–1.3)	0.9 (0.4–1.4)	1.0 (0.4–1.5)	3.1 (2.4–3.8)	25.9 (16.2–35.7)
40–59	7.9 (6.3–9.5)	1.9‖ (0.4–3.4)	4.2 (1.8–6.5)	4.5 (2.1–6.9)	12.4 (9.0–15.8)	36.1 (24.4–47.9)
60–74	17.5 (14.8–20.3)	6.8‖ (2.0–11.5)	12.4 (6.6–18.3)	12.8 (7.1–18.5)	29.9 (22.9–37.0)	42.7 (32.0–53.3)
≥75	14.8 (11.1–18.5)	5.7‖ (1.4–10.0)	13.2 (9.3–17.2)	13.2 (9.3–17.2)	28.8 (24.6–32.9)	45.8 (35.1–56.5)
Sex by age (years)						
Men						
≥12	6.3 (4.9–7.6)	2.9 (1.3–4.6)	4.3 (2.6–6.0)	4.6 (2.9–6.3)	10.9 (8.8–13.0)	#
≥20	7.3 (5.8–8.8)	3.4 (1.5–5.3)	5.0 (3.0–6.9)	5.3 (3.3–7.3)	12.6 (10.1–15.0)	45.1 (33.5–56.8)

Table 1—*Continued*

	Diagnosed diabetes	Undiagnosed diabetes			Total diabetes (diagnosed and undiagnosed by FPG or OGTT)	Proportion of total diabetes that is undiagnosed§
		FPG†	OGTT‡	Total (FPG or OGTT)		
Women						
≥12	6.8 (5.5–8.1)	1.4‖ (0.5–2.3)	3.9 (2.7–5.2)	4.0 (2.7–5.4)	10.8 (8.9–12.8)	#
≥20	7.9 (6.4–9.3)	1.6‖ (0.5–2.6)	4.6 (3.1–6.0)	4.7 (3.1–6.3)	12.5 (10.3–14.8)	**
Race/ethnicity by age (years)						
Non-Hispanic white						
≥12	5.2 (4.3–6.1)	2.0 (0.8–3.2)	4.2 (2.7–5.7)	4.3 (2.8–5.9)	9.5 (7.7–11.4)	#
≥20	6.0 (5.0–7.0)	2.3 (0.9–3.7)	4.9 (3.1–6.6)	5.0 (3.2–6.8)	11.0 (8.8–13.2)	37.5 (22.7–52.4)
Non-Hispanic black						
≥12	12.0 (10.4–13.7)	3.0 (2.0–4.0)	3.5 (2.5–4.6)	4.1 (2.3–5.8)	16.1 (14.7–17.6)	#
≥20	13.9 (12.0–15.9)	3.5 (2.3–4.7)	4.1 (2.9–5.3)	4.7 (2.7–6.8)	18.7 (17.0–20.4)	18.5 (9.8–27.2)
Mexican American						
≥12	10.9 (8.7–13.1)	3.2 (1.7–4.7)	6.0 (4.0–8.0)	6.5 (4.7–8.4)	17.4 (13.9–21.0)	#
≥20	12.6 (10.0–15.2)	3.7 (1.9–5.5)	7.0 (4.7–9.3)	7.5 (5.2–9.8)	20.1 (15.9–24.2)	35.9 (29.9–41.9)

Data are % (95% CI). Diagnosed diabetes determined by self-report on interview. Values by age alone and by sex include those of race/ethnic groups not listed separately. *Estimates for the total population aged ≥12 and ≥20 years and for race/ethnic groups were age and sex standardized, estimates for age-specific groups including those aged ≥65 years were sex standardized, and estimates for sex groups were age standardized (all using the 2000 U.S. Census population). †FPG ≥7.0 mmol/l. ‡2-h plasma glucose ≥11.1 mmol/l. §Estimates in this section have a denominator of total diabetes, whereas all other estimates have a denominator of the total population. ‖Relative SE >30%: the confidence interval is wide, relative to the size of the estimate. ¶Rounded to zero as method of calculating confidence intervals led to lower bounds that were slightly below zero. #Age group 12–19 years and age group ≥12 years standardized were excluded because few people aged 12–19 years had diabetes, resulting in unreliable estimates. **There was no undiagnosed diabetes in women aged 20–39 years; therefore, the standardized estimate and associated confidence interval are unreliable.

based on 2-h glucose was significantly higher in Mexican Americans compared with non-Hispanic blacks (7.0 vs. 4.1%; $P = 0.04$) but not compared with non-Hispanic whites (7.0 vs. 4.9%; $P = 0.14$).

Total undiagnosed diabetes. The combined crude prevalence of undiagnosed diabetes based on FPG or 2-h glucose was 5.1% in people aged ≥20 years (Table 1). Prevalence was much higher in people aged ≥60 years than in those of younger ages. Prevalence did not differ significantly by sex or race/ethnicity, even in Mexican Americans compared with non-Hispanic whites and non-Hispanic blacks (standardized, both $P = 0.07$).

Total diabetes. The combined crude prevalence of diabetes, based on diagnosed and undiagnosed diabetes detected by FPG or 2-h glucose, was 12.9% in people aged ≥20 years (Table 1). Total prevalence of diabetes increased steadily with age and peaked at about 30% in all age groups ≥60 years. Total diabetes prevalence was virtually the same in men and women. Compared with non-Hispanic whites aged ≥20 years, total diabetes prevalence was about 70% higher in non-Hispanic blacks ($P < 0.0001$) and 80% higher in Mexican Americans ($P = 0.0008$) after accounting for differences in age and sex distributions.

Proportion of undiagnosed total diabetes. The proportion of total diabetes that was undiagnosed was almost 40% in those aged ≥20 years and increased moderately with age (Table 1). The proportion of total diabetes that was undiagnosed was similar in men and women aged ≥20 years. A significantly higher proportion was undiagnosed in non-Hispanic whites aged ≥20 years (crude 46.0%) and Mexican Americans (crude 43.0%) than in non-Hispanic blacks (24.2%; both $P = 0.02$); racial differences were not explained by different age and sex distributions, as shown in the standardized ratios.

IFG. In individuals aged ≥20 years, 25.7% had IFG (Table 2). IFG increased with age, doubling between ages 20–39 and 40–59 years, and then remained constant at ≥60 years. IFG prevalence was significantly higher in men (crude 32.1%) than in women (crude 19.8%; both crude and standardized $P < 0.0001$). No statistically significant differences in prevalence were observed by race/ethnicity.

IGT. IGT was found in 13.8% of those aged ≥20 years, about half the prevalence of IFG (Table 2). Prevalence steadily increased with age, peaking at 35.1% in those aged ≥75 years. Prevalences did not differ significantly by sex or race/ethnicity.

Total pre-diabetes. The crude prevalence of either IFG or IGT was 29.5% among people aged ≥20 years (Table 2). Prevalence increased with age, peaking at age ≥75 years (crude 46.7%). Prevalence was much higher in men than in women (aged ≥20 years crude 36 vs. 23.4% and standardized 35.7 vs. 22.8%; both $P = 0.0002$). The somewhat higher prevalence in Mexican Americans than in non-Hispanic whites or non-Hispanic blacks was not significantly different.

Total diabetes (diagnosed and undiagnosed) and pre-diabetes (IFG and IGT). The total combined crude prevalence of diabetes and pre-diabetes was 42.3% in people aged ≥20 years (Table 2 and online appendix Figures A2 and A3). Prevalence rose steadily with age, with crude prevalence reaching 75.7% in people aged ≥75 years. Prevalence of any hyperglycemic condition was much higher in men than in women (aged ≥20 years crude 48.4 vs. 36.7%, $P = 0.0002$; standardized 48.3 vs. 35.4%, $P = 0.0001$), explained largely by the higher preva-

Table 2—*Crude and standardized* prevalence of IFG, IGT, total pre-diabetes, and total diabetes and pre-diabetes, NHANES 2005–2006*

	IFG	IGT	Total pre-diabetes (IFG or IGT)	Total diabetes and pre-diabetes
n	3,178	2,806	2,806	2,806
Crude prevalence				
Combined age-groups (years)				
≥12	23.9 (20.7–27.2)	12.4 (10.0–14.8)	27.6 (24.5–30.7)	38.7 (34.5–43.0)
≥20	25.7 (22.3–29.1)	13.8 (11.2–16.5)	29.5 (26.2–32.7)	42.3 (37.9–46.7)
≥65	36.6 (32.0–41.2)	26.9 (21.0–32.7)	40.4 (34.4–46.3)	72.0 (66.7–77.3)
Age-specific groups (years)				
12–19	12.7 (8.9–16.6)	3.4 (1.4–5.5)	16.0 (10.9–21.0)	16.3 (11.3–21.2)
20–39	13.1 (10.3–15.9)	7.3 (4.6–10.0)	17.9 (14.1–21.8)	21.1 (17.1–25.0)
40–59	31.3 (24.3–38.3)	13.3 (9.2–17.5)	34.6 (28.2–41.0)	47.0 (39.7–54.3)
60–74	37.9 (31.8–43.9)	21.3 (15.4–27.3)	36.8 (30.2–43.4)	66.7 (59.8–73.6)
≥75	35.1 (30.5–39.7)	35.1 (26.3–43.9)	46.7 (38.7–54.6)	75.7 (68.7–82.8)
Sex by age (years)				
Men				
≥12	30.3 (25.5–35.0)	12.9 (9.8–16.0)	34.0 (29.3–38.7)	44.7 (38.9–50.4)
≥20	32.1 (26.9–37.3)	14.6 (11.3–18.0)	36.0 (30.8–41.2)	48.4 (42.2–54.5)
Women				
≥12	17.9 (15.6–20.3)	12.0 (9.2–14.7)	21.6 (18.8–24.4)	33.2 (29.5–36.8)
≥20	19.8 (17.3–22.2)	13.1 (10.0–16.1)	23.4 (20.6–26.3)	36.7 (33.1–40.3)
Race/ethnicity by age (years)				
Non-Hispanic white				
≥12	24.3 (20.3–28.2)	13.1 (9.7–16.6)	27.8 (23.9–31.8)	38.6 (33.1–44.1)
≥20	25.8 (21.6–29.9)	14.5 (10.8–18.1)	29.3 (25.1–33.6)	41.5 (35.8–47.3)
Non-Hispanic black				
≥12	18.7 (14.9–22.6)	8.4 (6.4–10.4)	22.5 (19.9–25.1)	36.5 (32.1–40.9)
≥20	20.5 (16.2–24.9)	10.0 (7.3–12.6)	25.1 (22.0–28.1)	42.1 (37.2–47.0)
Mexican American				
≥12	24.6 (18.1–31.1)	11.2 (6.9–15.4)	28.9 (23.2–34.6)	41.1 (33.7–48.4)
≥20	26.8 (18.9–34.7)	13.0 (7.8–18.1)	31.7 (24.7–38.7)	46.4 (37.2–55.7)
Standardized* prevalence				
Combined age-groups (years)				
≥12	23.5 (20.8–26.2)	12.2 (10.3–14.1)	27.2 (24.8–29.7)	38.1 (35.1–41.1)
≥20	25.2 (22.4–28.1)	13.6 (11.5–15.8)	29.0 (26.4–31.6)	41.6 (38.6–44.7)
≥65	36.9 (32.1–41.7)	27.1 (21.2–32.9)	40.8 (34.9–46.7)	72.2 (67.0–77.3)
Age-specific groups (years)				
12–19	12.4 (8.7–16.1)	3.5 (1.3–5.6)	15.6 (10.8–20.5)	15.9 (11.2–20.7)
20–39	12.9 (10.1–15.7)	7.4 (4.6–10.1)	17.8 (13.9–21.7)	20.9 (16.9–24.9)
40–59	31.2 (24.3–38.2)	13.3 (9.1–17.5)	34.5 (28.2–40.8)	46.9 (39.5–54.3)
60–74	38.2 (32.0–44.4)	21.8 (15.8–27.7)	37.4 (30.7–44.2)	67.4 (60.6–74.1)
≥75	35.6 (31.0–40.2)	34.7 (25.6–43.8)	46.8 (39.0–54.6)	75.6 (68.4–82.7)
Sex by age (years)				
Men				
≥12	30.1 (25.9–34.3)	13.0 (10.7–15.4)	33.9 (30.0–37.7)	44.7 (40.7–48.8)
≥20	31.9 (27.3–36.5)	14.7 (12.0–17.4)	35.7 (31.3–40.2)	48.3 (43.7–52.8)
Women				
≥12	17.2 (15.2–19.1)	11.6 (8.9–14.3)	21.0 (18.0–23.9)	31.8 (28.4–35.2)
≥20	19.0 (16.9–21.0)	12.8 (9.8–15.8)	22.8 (19.8–25.8)	35.4 (32.1–38.7)
Race/ethnicity by age (years)				
Non-Hispanic white				
≥12	22.5 (19.2–25.8)	12.2 (9.8–14.5)	26.2 (23.1–29.3)	35.7 (32.0–39.5)
≥20	24.0 (20.6–27.4)	13.5 (10.9–16.2)	27.7 (24.4–31.0)	38.7 (34.8–42.5)
Non-Hispanic black				
≥12	19.4 (16.2–22.6)	8.8 (6.3–11.4)	23.3 (20.7–25.9)	39.4 (36.8–42.0)
≥20	20.9 (17.3–24.5)	10.1 (7.1–13.1)	25.4 (22.5–28.2)	44.1 (41.2–46.9)
Mexican American				
≥12	26.0 (19.4–32.6)	12.8 (9.7–16.0)	29.9 (25.2–34.5)	47.3 (41.0–53.6)
≥20	27.8 (20.3–35.4)	14.4 (10.6–18.1)	32.0 (26.5–37.4)	52.0 (44.5–59.6)

Data are % (95% CI). Values by age alone and by sex in people aged ≥12 and ≥20 years include those of race/ethnic groups not listed separately. *Estimates for the total population aged ≥12 and ≥20 years and for race/ethnic groups were age and sex standardized, estimates for age-specific groups including those aged ≥65 years were sex standardized, and estimates for sex groups were age standardized (all using the 2000 U.S. Census population). IFG, FPG 5.6–7.0 mmol/l; IGT, 2-h plasma glucose 7.8–11.1 mmol/l. Total diabetes includes diagnosed diabetes (determined by self-report on interview) and undiagnosed diabetes (FPG ≥7.0 mmol/l or 2-h plasma glucose ≥11.1 mmol/l).

Table 3—*Distribution of FPG and 2-h (OGTT) plasma glucose diagnostic categories, and mean A1C, in U.S. adults aged ≥20 years, NHANES 2005–2006*

Diagnostic category based on FPG	Diagnostic category based on 2-h glucose	Distribution across 2-h glucose categories *by* FPG diagnostic category	Distribution across FPG *and* 2-h glucose diagnostic categories	A1C (%)
Undiagnosed diabetes	Undiagnosed diabetes	91.0 (74.0–97.3)	2.3 (1.3–4.0)	7.04 (6.37–7.70)
	IGT	1.4* (0.1–12.7)	0.0*†	‡
	Normal	7.6* (2.3–22.2)	0.2* (0.1–0.7)	‡
IFG	Undiagnosed diabetes	8.5 (5.9–12.2)	2.2 (1.5–3.3)	5.80 (5.71–5.88)
	IGT	31.3 (24.3–39.2)	8.1 (5.9–11.0)	5.66 (5.60–5.73)
	Normal	60.2 (52.6–67.3)	15.7 (13.7–17.9)	5.50 (5.46–5.55)
Normal	Undiagnosed diabetes	0.6* (0.3–1.5)	0.4* (0.2–0.9)	‡
	IGT	8.9 (6.4–12.2)	5.7 (4.1–7.8)	5.44 (5.39–5.50)
	Normal	90.5 (87.2–93.0)	57.7 (53.2–62.0)	5.28 (5.25–5.30)
Diagnosed diabetes			7.7 (6.7–8.8)	
Total			100.0	

Data are % (95% CI) except for A1C values, which are means (95% CI). *Relative standard error >30%: the confidence interval is wide, relative to the size of the estimate. †Rounds to zero. ‡$n < 30$. Undiagnosed diabetes determined by either FPG ≥7.0 mmol/l or 2-h plasma glucose ≥11.1 mmol/l. IFG, FPG 5.6–7.0 mmol/l; IGT, 2-h plasma glucose 7.8–11.1 mmol/l; diagnosed diabetes determined by self-report on interview.

lence of pre-diabetes in men. Whereas crude prevalence of any hyperglycemic condition was not significantly different by race/ethnicity, standardized prevalence was significantly higher in non-Hispanic blacks (aged ≥20 years 44.1%) compared with whites (38.7%; $P = 0.01$) and significantly higher in Mexican Americans (52.0%) compared with non-Hispanic whites ($P = 0.004$) but not compared with non-Hispanic blacks ($P = 0.06$).

Comparison of FPG and 2-h glucose values

Among those classified as diabetic or normal by FPG, >90% were classified likewise by 2-h glucose (Table 3). However, whereas the prevalence of undiagnosed diabetes by FPG was 2.5%, the prevalence by either definition was 5.1%; when combined with diagnosed diabetes, total diabetes was 10.2 and 12.9%, respectively. For people with IFG, there was much less agreement between the classifications. Only 31.3% of those with IFG also had IGT, comprising 8.1% of the population. Among those defined as having IFG, 8.5% were classified as having diabetes based on 2-h glucose. This largely explains the doubling of the prevalence of undiagnosed diabetes based on 2-h glucose compared with undiagnosed diabetes based on FPG, as described earlier; 2.2% of the population comprised this category. In contrast, 60% of those with IFG were classified by 2-h glucose as having normal glucose tolerance. This explains the approximate halving of prevalence of pre-diabetes based on the 2-h glucose, compared with the prevalence of IFG, as described earlier. Although 8.5% of those with IFG were classified by 2-h glucose as having diabetes, the mean A1C of this group (5.80%) was within the normal range.

Trends in prevalences from 1988–1994 to 2005–2006

The crude prevalence of diagnosed diabetes in individuals aged ≥20 years rose significantly from 5.1% in 1988–1994 to 7.7% in 2005–2006 ($P = 0.0001$) (online appendix Tables A1 and A2); this was significant after accounting for differences in age/sex distributions between the two surveys ($P = 0.0002$). The rise in prevalence occurred for all groups but was particularly dramatic for non-Hispanic blacks (crude 6.9 to 12.8%, $P < 0.0001$; standardized 8.4 to 13.9%, $P < 0.0001$). There were no significant changes between the surveys in prevalence of undiagnosed diabetes (FPG, 2-h glucose, or total undiagnosed); however, the small sample sizes in 2005–2006 may limit the ability to detect changes for subgroups. Total diabetes (diagnosed and undiagnosed) prevalence changed significantly only for non-Hispanic blacks (aged 40–74 years crude 20.3 to 26.1%, $P = 0.007$; standardized 20.2 to 27.1%, $P = 0.001$). Whereas the proportion of total diabetes that was undiagnosed appeared to decrease between the surveys for all groups, changes were only significant in Mexican Americans (aged 40–74 years crude 44.9 to 30.0%; $P = 0.02$).

There was no substantial change in prevalence of IFG or IGT between 1988–1994 and 2005–2006. Likewise, total pre-diabetes (IFG or IGT) did not change significantly except in Mexican Americans (aged 40–74 years standardized 41.7 to 33.1%; $P = 0.03$). The combined total prevalence of diabetes and pre-diabetes increased significantly between the surveys only in non-Hispanic blacks (aged 40–74 years standardized 53.3 to 61.4%; $P = 0.01$). The decrease in prevalence in Mexican Americans was not significant (aged 40–74 years standardized 67.1 to 59.8%; $P = 0.06$).

CONCLUSIONS — These recent data indicate that 12.9% of the adult U.S. population aged ≥20 years have diabetes (7.7% previously diagnosed and 5.1% undiagnosed), of which 39.8% is undiagnosed. Another 29.5% of the population is at risk of diabetes based on having pre-diabetes (IFG or IGT). Overall, approximately 40% of the U.S. population has some hyperglycemic condition. The el-

derly population is particularly susceptible, with about one-third having diagnosed or undiagnosed diabetes and three-quarters having diabetes or pre-diabetes. Minority groups continue to suffer disproportionately, as prevalence of diagnosed and undiagnosed diabetes combined is 70–80% higher in non-Hispanic blacks and Mexican Americans than in non-Hispanic white subjects. But whereas diagnosed diabetes has risen significantly over the last 10–15 years, particularly in non-Hispanic blacks, undiagnosed diabetes as a proportion of total diabetes has remained relatively stable and may be decreasing, particularly in Mexican Americans.

NHANES is unique because its results represent people in the U.S. noninstitutionalized population, and the survey, in contrast with other national surveys, includes a laboratory component that measures FPG. NHANES was particularly unique in 2005–2006 because of inclusion of an OGTT not previously performed since 1988–1994. The FPG is recommended for screening for diabetes and IFG because it is more reproducible and convenient and less costly. FPG and 2-h OGTT glucose, however, measure different physiological phenomena (4). Two-hour glucose is more sensitive than FPG to detecting glucose defects in the elderly (7). Whereas 91% of people having diabetes by FPG were likewise classified by 2-h glucose, the 2-h glucose added another 2.6% of diabetes prevalence. The corresponding figure among people aged 40–74 years in NHANES 1988–1994 was 2.0%, which is not significantly different (9). There was substantial disagreement among those having IFG, in whom 8.5% were diabetic and 60.2% normoglycemic based on 2-h glucose. This explains the doubling of the prevalence of undiagnosed diabetes based on 2-h glucose (aged ≥20 years crude 2.5% by FPG, 4.9% by 2-h glucose, and 5.1% having either) and halving of pre-diabetes (aged ≥20 years crude 25.7% by FPG,13.8% by 2-h glucose, and 29.5% having either).

We note that determination of undiagnosed diabetes and pre-diabetes by either FPG or 2-h glucose was based on a single plasma glucose reading from subjects who self-reported that they fasted appropriately, whereas retesting is suggested for diagnosis in a clinical setting. Consequently, some of the prevalence estimates may be overstated. In addition, the available sample size in 2005–2006 limited the ability to detect differences. Nevertheless, some important differences were detected between groups and over time.

As shown in previous reports (3), diagnosed diabetes remains more than twice as high in non-Hispanic blacks and Mexican Americans than in non-Hispanic whites, after accounting for differences in age and sex distributions. The racial/ethnic disparity is reflected in prevalence of total diabetes (diagnosed and undiagnosed) and total hyperglycemic conditions. Undiagnosed diabetes was not greater in these groups.

Diagnosed diabetes increased significantly between 1988–1994 and 2005–2006 in all age groups and in both men and women. The rise in prevalence of diagnosed diabetes was particularly prominent in non-Hispanic blacks and was reflected in a rise in total diabetes and total hyperglycemic conditions over time (most prominently in non-Hispanic blacks).

Based on both FPG and 2-h glucoses, almost 40% of total diabetes was undiagnosed. The proportion that was undiagnosed was significantly higher in non-Hispanic whites than in Mexican Americans. The proportion of total diabetes that was undiagnosed tended to decrease between the surveys, but this was statistically significant only among Mexican Americans.

Thus, whereas diagnosed and total diabetes and total hyperglycemic conditions remain disproportionately high in minority groups, it may be that diabetes is being diagnosed more frequently in these groups, both over time and relative to non-Hispanic whites. This was also found when comparing data from 1999–2002 with those from 1988–1994 (3). More focused screening may be occurring in these groups (19). Decreases over the past several decades in the proportion of diabetes that is undiagnosed have occurred only among the most obese (20). We also found that pre-diabetes decreased significantly over time in Mexican Americans.

Overall, almost 30% of the population had pre-diabetes (IFG or IGT), a condition that increases the risk for diabetes and is associated with other cardiovascular risk factors (4,8). In 2005–2006, IFG was 70% higher in men than in women, consistent with findings in 1999–2002 (3). This was reflected in their higher prevalences of total pre-diabetes and total hyperglycemic conditions. No differences by sex, however, were found in the prevalence of diagnosed or undiagnosed diabetes. These observations currently lack explanation. It is encouraging that prevalence of pre-diabetes did not appear to increase between the surveys; this is surprising given the increase in diagnosed diabetes and obesity (10) over time.

The sheer magnitude of prevalence of hyperglycemic conditions found in 2005–2006 portends all the consequences of diabetes including its myriad of complications and costs both to individuals and to society. The prevalence of diabetes continues to increase over time but appears to be recognized more commonly. Despite some evidence that overweight and obesity may be plateauing in adults (21) and adolescents (22), their prevalences remain high; and, even in adolescents, features of insulin resistance are found in the presence of IFG (23). Lifestyle modification including weight management and increased physical activity should be prescribed and practiced in those with diabetes (24) and pre-diabetes (25), particularly in minority groups.

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References

1. Engelgau MM, Geiss LS, Saaddine JB, Boyle JP, Benjamin SM, Gregg EW, Tierney EF, Rios-Burrows N, Mokdad AH, Ford ES, Imperatore G, Narayan KM: The evolving diabetes burden in the United States. *Ann Intern Med* 140:945–950, 2004
2. American Diabetes Association: Economic costs of diabetes in the U.S. in 2007. *Diabetes Care* 31:596–615, 2008
3. Cowie CC, Rust KF, Byrd-Holt DD, Eberhardt MS, Flegal KM, Engelgau MM, Saydah SH, Williams DE, Geiss LS, Gregg EW: Prevalence of diabetes and impaired fasting glucose in adults in the U.S. population: National Health And Nutrition Examination Survey 1999–2002. *Diabetes Care* 29:1263–1268, 2006
4. Unwin N, Shaw J, Zimmet P, Alberti KG: Impaired glucose tolerance and impaired fasting glycaemia: the current status on definition and intervention. *Diabet Med* 19:708–723, 2002
5. Harris MI, Eastman RC: Early detection of undiagnosed diabetes mellitus: a US perspective. *Diabetes Metab Res Rev* 16:230–236, 2000
6. Abdul-Ghani MA, Tripathy D, DeFronzo RA: Contributions of β-cell dysfunction and insulin resistance to the pathogenesis of impaired glucose tolerance and impaired fasting glucose. *Diabetes Care* 29:

1130–1139, 2006
7. Wahl PW, Savage PJ, Psaty BM, Orchard TJ, Robbins JA, Tracy RP: Diabetes in older adults: comparison of 1997 American Diabetes Association classification of diabetes mellitus with 1985 WHO classification. *Lancet* 352:1012–1015, 1998
8. Genuth S, Alberti KG, Bennett P, Buse J, Defronzo R, Kahn R, Kitzmiller J, Knowler WC, Lebovitz H, Lernmark A, Nathan D, Palmer J, Rizza R, Saudek C, Shaw J, Steffes M, Stern M, Tuomilehto J, Zimmet P; the Expert Committee on the Diagnosis and Classifciation of Diabetes Mellitus: Follow-up report on the diagnosis of diabetes mellitus. *Diabetes Care* 26:3160–3167, 2003
9. Harris MI, Eastman RC, Cowie CC, Flegal KM, Eberhardt MS: Comparison of diabetes diagnostic categories in the U.S. population according to the 1997 American Diabetes Association and 1980–1985 World Health Organization diagnostic criteria. *Diabetes Care* 20:1859–1862, 1997
10. Flegal KM, Carroll MD, Ogden CL, Johnson CL: Prevalence and trends in obesity among US adults, 1999–2000. *JAMA* 288:1723–1727, 2002
11. Centers for Disease Control and Prevention National Center for Health Statistics: National Health and Nutrition Examination Survey 2005–2006 [Internet], 2008. Available from http://www.cdc.gov/nchs/about/major/nhanes/nhanes2005-2006/nhanes05_06.htm. Accessed 28 May 2008
12. American Diabetes Association: Diagnosis and classification of diabetes mellitus. *Diabetes Care* 31 (Suppl. 1):S55–S60, 2008
13. Centers for Disease Control and Prevention National Center for Health Statistics: National Health and Nutrition Examination Survey III (1988–1994) [Internet], 2008. Available from http://www.cdc.gov/nchs/about/major/nhanes/nh3data.htm. Accessed 28 May 2008
14. Harris MI, Flegal KM, Cowie CC, Eberhardt MS, Goldstein DE, Little RR, Wiedmeyer HM, Byrd-Holt DD: Prevalence of diabetes, impaired fasting glucose, and impaired glucose tolerance in U.S. adults: the Third National Health and Nutrition Examination Survey, 1988–1994. *Diabetes Care* 21:518–524, 1998
15. Flegal KM, Ezzati TM, Harris MI, Haynes SG, Juarez RZ, Knowler WC, Perez-Stable EJ, Stern MP: Prevalence of diabetes in Mexican Americans, Cubans, and Puerto Ricans from the Hispanic Health and Nutrition Examination Survey, 1982–1984. *Diabetes Care* 14:628–638, 1991
16. Research Triangle Institute: *SUDAAN User's Manual, release 9.0.1*. Research Triangle Park, NC, Research Triangle Institute, 2005
17. LaVange LM, Stearns SC, Lafata JE, Koch GG, Shah BV: Innovative strategies using SUDAAN for analysis of health surveys with complex samples. *Stat Methods Med Res* 5:311–329, 1996
18. Rust KF, Rao JN: Variance estimation for complex surveys using replication techniques. *Stat Methods Med Res* 5:283–310, 1996
19. National Institutes of Health and the Centers for Disease Control and Prevention: National Diabetes Education Program: ten years of progress 1997–2007 [article online], 2007. Available from http://ndep.nih.gov/diabetes/pubs/NDEP_ProgressRpt07.pdf. Accessed 28 May 2008
20. Gregg EW, Cadwell BL, Cheng YJ, Cowie CC, Williams DE, Geiss L, Engelgau MM, Vinicor F: Trends in the prevalence and ratio of diagnosed to undiagnosed diabetes according to obesity levels in the U.S. *Diabetes Care* 27:2806–2812, 2004
21. Ogden CL CM, McDowell MA, Flegal KM: Obesity among adults in the United States: no statistically significant change since 2003–2004. *National Center for Health Statistics Data Brief* 1:1–6, 2007
22. Ogden CL, Carroll MD, Flegal KM: High body mass index for age among US children and adolescents, 2003–2006. *JAMA* 299:2401–2405, 2008
23. Williams DE, Cadwell BL, Cheng YJ, Cowie CC, Gregg EW, Geiss LS, Engelgau MM, Narayan KM, Imperatore G: Prevalence of impaired fasting glucose and its relationship with cardiovascular disease risk factors in US adolescents, 1999-2000. *Pediatrics* 116:1122–1126, 2005
24. Pi-Sunyer X, Blackburn G, Brancati FL, Bray GA, Bright R, Clark JM, Curtis JM, Espeland MA, Foreyt JP, Graves K, Haffner SM, Harrison B, Hill JO, Horton ES, Jakicic J, Jeffery RW, Johnson KC, Kahn S, Kelley DE, Kitabchi AE, Knowler WC, Lewis CE, Maschak-Carey BJ, Montgomery B, Nathan DM, Patricio J, Peters A, Redmon JB, Reeves RS, Ryan DH, Safford M, Van Dorsten B, Wadden TA, Wagenknecht L, Wesche-Thobaben J, Wing RR, Yanovski SZ; the Look AHEAD Research Group: Reduction in weight and cardiovascular disease risk factors in individuals with type 2 diabetes: one-year results of the look AHEAD trial. *Diabetes Care* 30:1374–1383, 2007
25. Knowler WC, Barrett-Connor E, Fowler SE, Hamman RF, Lachin JM, Walker EA, Nathan DM: Reduction in the incidence of type 2 diabetes with lifestyle intervention or metformin. *N Engl J Med* 346:393–403, 2002