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Trends in Prevalence and Control of Diabetes in the United States, 1988–1994 and 1999–2010

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Background: Trends in the prevalence and control of diabetes defined by hemoglobin A_{1c} (HbA_{1c}) levels are important for health care policy and planning.

Objective: To update trends in the prevalence of diabetes, prediabetes, and glycemic control.

Design: Cross-sectional.

Setting: NHANES (National Health and Nutrition Examination Survey) in 1988–1994 and 1999–2010.

Participants: Adults aged 20 years or older.

Measurements: We used calibrated HbA_{1c} levels to define undiagnosed diabetes (≥6.5%); prediabetes (5.7% to 6.4%); and, among persons with diagnosed diabetes, glycemic control (<7.0% or <8.0%). Trends in HbA_{1c} categories were compared with fasting glucose levels (≥7.0 mmol/L [≥126 mg/dL] and 5.6 to 6.9 mmol/L [100 to 125 mg/dL]).

Results: In 2010, approximately 21 million U.S. adults aged 20 years or older had total confirmed diabetes (self-reported diabetes or diagnostic levels for both fasting glucose and calibrated HbA_{1c}). During 2 decades, the prevalence of total confirmed diabetes increased, but the prevalence of undiagnosed diabetes remained fairly stable, reducing the proportion of total diabetes cases that are undiagnosed to 11% in 2005–2010. The prevalence of prediabetes was lower when defined by calibrated HbA_{1c} levels than when defined by fasting glucose levels but has increased from 5.8% in 1988–1994 to 12.4% in 2005–2010 when defined by HbA_{1c} levels. Glycemic control improved overall, but total diabetes prevalence was greater and diabetes was less controlled among non-Hispanic blacks and Mexican Americans compared with non-Hispanic whites.

Limitation: Cross-sectional design.

Conclusion: Over the past 2 decades, the prevalence of total diabetes has increased substantially. However, the proportion of undiagnosed diabetes cases decreased, suggesting improvements in screening and diagnosis. Among the growing number of persons with diagnosed diabetes, glycemic control improved but remains a challenge, particularly among non-Hispanic blacks and Mexican Americans.

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There has been a staggering increase in the prevalence of obesity over the past 30 years in the United States (1, 2). Diagnosed diabetes has increased concomitantly (3–6). In a major change to clinical guidelines in 2010, hemoglobin A_{1c} (HbA_{1c}) was recommended for use as a diagnostic test for diabetes (7). In addition to its central role in monitoring glycemic control, HbA_{1c} is now widely used as the first-line test for diagnosis of diabetes (8, 9). However, use of HbA_{1c} levels to characterize U.S. trends in prediabetes, undiagnosed diabetes, and glycemic control in NHANES (National Health and Nutrition Examination Survey) has been complicated by the challenges of ensuring a constant calibration of the assay over a long period of time, which included changes in laboratory method (10, 11). Uncalibrated mean HbA_{1c} levels have increased over successive NHANES surveys, even in normal-weight persons (12), but without parallel increases in fasting glucose levels. No specific cause for the shift in HbA_{1c} levels has been identified (10). The magnitudes of the changes in the distributions are small (approximately 4% to 5%), and such small shifts potentially would not be detectable in most laboratory quality-control analyses. Although such small changes are not important for individual (clinical) classification, they can have a substantial effect at the population level. They are particularly important when examining trends over time and looking at specific regions of the distribution. These shifts have significant ramifications for estimating the prevalence of diabetes and prediabetes in the population. We addressed these issues by calibrating the HbA_{1c} values to a stable standard distribution among young, healthy NHANES participants and then used the calibrated values to obtain national estimates.

Our objective was to update national trends in total diabetes (undiagnosed and diagnosed), prediabetes, and glycemic control in persons with diagnosed diabetes over the past 2 decades using data from the 1988–1994 (NHANES III) and 1999–2010 (continuous NHANES) survey periods based on calibrated HbA_{1c} and fasting glucose levels.

Methods

Setting and Participants

The NHANES surveys are cross-sectional, multistage, stratified, clustered probability samples of the U.S. civilian

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Context

Accurate information about the epidemiology of diabetes is important in identifying public health needs and areas on which to focus interventions. Changes in the methods used to measure hemoglobin A_{1c} (HbA_{1c}) may substantially affect population estimates of the burden of diabetes.

Contribution

This study calibrated HbA_{1c} levels from more than 20 years to allow comparison. Diabetes prevalence in the United States has increased, largely associated with increasing obesity. Although the proportion of undiagnosed diabetes has declined and glycemic control among diagnosed patients has improved overall, disparities in prevalence, undiagnosed disease, and glycemic control persist or have worsened among non-Hispanic blacks and Mexican Americans.

Implication

Despite improvements in glycemic control overall, the prevalence of diabetes is increasing and substantial disparities in diagnosis and care persist.

—The Editors

noninstitutionalized population conducted by the National Center for Health Statistics (NCHS), a branch of the Centers for Disease Control and Prevention. Data are available from the continuous NHANES (data released in 2-year cycles) and NHANES III. The protocols for the conduct of NHANES were approved by the NCHS institutional review board, and informed consent was obtained from all participants.

For this study, we limited our population to 43 439 total persons who attended the clinical examination, were aged 20 years or older, were not missing HbA_{1c} measurements, and were not pregnant: 15 578 participants in NHANES III, 12 726 in NHANES 1999–2004, and 15 135 in NHANES 2005–2010. For analyses incorporating fasting glucose measurements, we further limited the study population to participants who attended the morning fasting session and had fasting plasma glucose measurements: 7385 in NHANES III, 5680 in NHANES 1999–2004, and 6719 in NHANES 2005–2010. Our main analyses were based on NHANES III (1988–1994) and the two 6-year survey periods in the continuous NHANES (1999–2004 and 2005–2010). We also generated prevalence estimates for each 2-year survey period in the continuous NHANES (1999–2000, 2001–2002, 2003–2004, 2005–2006, 2007–2008, and 2009–2010).

Measurement of HbA_{1c} and Plasma Glucose Levels

Hemoglobin A_{1c} levels were measured in whole blood samples using high-performance liquid chromatography methods performed on instruments certified by the National Glycohemoglobin Standardization Program and standardized to the reference method used in the Diabetes Control and Complications Trial. There were several changes to the HbA_{1c} measurement methods across surveys. In NHANES III, HbA_{1c} levels were measured using the Diamat Analyzer (Bio-Rad Laboratories, Hercules, California) at the University of Missouri-Columbia (Columbia, Missouri). In NHANES 1999–2000, 2001–2002, and 2003–2004, HbA_{1c} levels were measured at the University of Missouri-Columbia using the Primus Automated HPLC System (models CLC330 [Primus I] or CLC385 [Primus IV]) (Primus, Kansas City, Missouri). In NHANES 2005–2006, 2007–2008, and 2009–2010, HbA_{1c} levels were measured at the University of Minnesota Medical Center, Fairview (Minneapolis, Minnesota), with several changes between 2005 and 2010. In 2005–2006, the Tosoh A_{1c} 2.2 Plus Analyzer (Tosoh Medics, San Francisco, California) was used. In 2007–2008, the Tosoh A_{1c} 2.2 Plus Analyzer was used in the first 6 months of 2007 and the Tosoh G7 Analyzer (Tosoh Medics) was used for the latter period. In 2009–2010, the Tosoh G7 Analyzer was used. We calibrated the HbA_{1c} values to account for changes in laboratory methods during this period (**Supplement 1**, available at www.annals.org).

Plasma glucose levels were measured in specimens collected from a subsample of participants who attended a morning fasting session using a hexokinase enzymatic method. In NHANES III and NHANES 1999–2004, plasma glucose levels were measured at the University of Missouri-Columbia using a Roche Cobas Mira instrument (Roche Diagnostics, Indianapolis, Indiana) (13). Plasma glucose levels were measured at the University of Minnesota using a Roche/Hitachi 911 instrument (Roche Diagnostics) in 2005–2006 and a Roche Modular P instrument (Roche Diagnostics) in 2007–2010. We applied regression equations recommended by the NCHS to account for changes in methods and align the plasma glucose level measurements across survey periods (14, 15). We confirmed the stability of the calibrated plasma glucose levels in a young, healthy, fasting subsample (see **Supplement 1**).

Definitions of Diabetes, Prediabetes, and Glycemic Control

Diagnosed diabetes was defined as a physician diagnosis of diabetes (other than during pregnancy) that was self-reported by the participant. Among persons with diagnosed diabetes, we evaluated trends in glycemic control defined by HbA_{1c} levels less than 7.0% or less than 8.0%. In persons without a diabetes diagnosis, we evaluated trends in undiagnosed diabetes and prediabetes defined using clinical cut points for HbA_{1c} levels (≥6.5% and 5.7% to 6.4%, respectively) (8). In the fasting subsample, we compared trends in undiagnosed diabetes and prediabetes defined using calibrated HbA_{1c} levels with those defined using fasting glucose level cut points (≥7.0 mmol/L [≥126 mg/dL] and 5.6 to 6.9 mmol/L [100 to 125 mg/dL], respectively). Also in the fasting subsample, we exam-

ined trends in total confirmed cases of diabetes, defined as diagnosed diabetes or both elevated fasting glucose levels (≥7.0 mmol/L [≥126 mg/dL]) and HbA_{1c} levels (≥6.5%), a definition that more closely approximates cases that would be classified as having diabetes in clinical practice (8). The term "total diabetes" is used here to refer to the combination of diagnosed and undiagnosed diabetes where undiagnosed cases were defined by either an elevation in fasting glucose levels, an elevation in HbA_{1c} levels, either, or both (confirmed cases).

Other Measures

Anthropometry measurements, including waist circumference, height, and weight, were measured using a standardized protocol. Body mass index (BMI) was calculated from measured height and weight. We used clinical categories of BMI to define normal weight (<25 kg/m^2), overweight (25 to <30 kg/m^2), and obese (≥30 kg/m^2). High-risk waist circumference was defined as 102 cm or greater in men and 88 cm or greater in women (16). Information on age and race or ethnicity was self-reported. Diabetes medication use and type (oral hypoglycemic agents or insulin) was self-reported among persons who reported a diagnosis of diabetes.

Statistical Analysis

We used an equipercentile equating approach to statistically correct for the nonequivalency of HbA_{1c} values across the NHANES surveys (17–19) (see **Supplement 2**, available at www.annals.org). Prevalence estimates and their SEs were obtained for each survey period. We examined 2-year survey cycles and also combined estimates across 6-year survey periods to provide more reliable estimates, according to NCHS guidelines. Analyses were done incorporating sampling weights to obtain unbiased estimates from the complex NHANES sampling design. We obtained SEs using the Taylor series (linearization) method following analytic procedures recommended by the NCHS levels (20, 21). Prevalence estimates from this study are nationally representative of the civilian, noninstitutionalized U.S. population of adults aged 20 years or older. Prevalence estimates for 2005–2010 were applied to the 2010 Census population to obtain estimates of the number of persons with diabetes in the United States in 2010. We used logistic regression to obtain predictive margins to examine trends in total diabetes (diagnosed diabetes or calibrated HbA_{1c} levels ≥6.5%) after adjustment for demographic characteristics, BMI, and waist circumference. *P* values for linear trend were calculated by regressing the continuous variable of interest (such as BMI) on the median year of the survey cycle. Statistical analyses were conducted using Stata, version 13.0 (StataCorp, College Station, Texas), and R, version 2.15.1 (R Foundation for Statistical Computing, Vienna, Austria). We used svy commands in Stata to account for the complex survey design of NHANES; the prop command to obtain prevalence estimates; and the logistic command in conjunction with the margins, nlcom, and test postestimation commands to obtain predictive margins and prevalence ratios with 95% CIs and *P* values. The equipercentile equating was conducted using the equate package in R.

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RESULTS

Demographic characteristics of the U.S. population aged 20 years or older without diagnosed diabetes remained relatively stable across the survey periods, with the exception of changes in the racial or ethnic makeup of the population (**Table 1**). Most notable, there was a substantial increase in the percentage of persons self-reporting race or ethnicity as Mexican American. The mean BMI of the U.S. adult population increased significantly over this period (*P* trend < 0.001), and the prevalence of obesity increased from 21.2% in 1988–1994 to 32.4% among persons without diagnosed diabetes in 2005–2010. Trends among persons with diagnosed diabetes were similar, although obesity prevalence was much greater in all periods. Among persons without diagnosed diabetes, mean calibrated HbA_{1c} levels were 5.25% in 1988–1994, 5.35% in 1999–2004, and 5.36% in 2005–2010 (*P* trend < 0.001). By contrast, mean calibrated HbA_{1c} and fasting glucose levels in a young, healthy subgroup (persons aged 20 to 39 years with normal BMI and no diagnosed diabetes, hypertension, or high cholesterol) were stable over this same period (5.1% and 5.0 mmol/L [90 mg/dL], respectively). Similar trends were seen when examining 2-year survey cycles within the continuous NHANES (**Table 1** of **Supplement 2**).

The prevalence of total diabetes (defined as diagnosed diabetes or calibrated HbA_{1c} levels ≥6.5%) increased over the 20-year period from 6.2% (95% CI, 5.6% to 6.8%) in 1988–1994, 8.8% (CI, 8.1% to 9.6%) in 1999–2004, and 9.9% (CI, 9.2% to 10.7%) in 2005–2010 (**Table 2**). A similar trend was seen when increased fasting glucose levels (≥7.0 mmol/L [≥126 mg/dL]) were combined with diagnosed diabetes cases: 7.3% (CI, 6.4% to 8.4%) in 1988–1994, 9.1% (CI, 8.0% to 10.2%) in 1999–2004, and 10.9% (CI, 9.8% to 12.0%) in 2005–2010. Across all survey periods, the prevalence of undiagnosed diabetes was substantially greater (60% to 180% greater) when defined by fasting glucose levels of 7.0 mmol/L or greater (≥126 mg/dL) obtained at a single visit compared with HbA_{1c} levels of 6.5% or greater. For example, in 2005–2010, the prevalence of undiagnosed diabetes defined by fasting glucose levels of 7.0 mmol/L or greater (≥126 mg/dL) was twice as high as undiagnosed diabetes defined by calibrated HbA_{1c} levels (2.6% vs. 1.3%, or 100% greater). When defined by calibrated HbA_{1c} levels (5.7% to 6.4%), the prevalence of prediabetes was 5.8% (CI, 5.2% to 6.5%) in

Table 1. **Characteristics of Adults With and Without Diagnosed Diabetes***

Variable	No Diagnosed Diabetes			Diagnosed Diabetes		
	NHANES 1988–1994 (*n* = 14 368)	NHANES 1999–2004 (*n* = 11 404)	NHANES 2005–2010 (*n* = 13 343)	NHANES 1988–1994 (*n* = 1210)	NHANES 1999–2004 (*n* = 1322)	NHANES 2005–2010 (*n* = 1792)
Mean age (±SE), *y*	44.3 ± 0.46	45.7 ± 0.28	46.2 ± 0.32	60.2 ± 0.68	59.4 ± 0.56	59.4 ± 0.50
Aged 65 y or older (±SE), %	15.8 ± 0.92	15.6 ± 0.42	15.5 ± 0.59	41.6 ± 1.91	39.6 ± 1.87	39.5 ± 1.46
Male (±SE), %	49.0 ± 0.43	49.0 ± 0.41	48.9 ± 0.37	45.5 ± 2.40	49.5 ± 1.36	48.4 ± 1.81
Race/ethnicity (±SE), %						
Non-Hispanic white	76.9 ± 1.27	72.7 ± 1.63	71.5 ± 1.84	74.3 ± 2.00	64.4 ± 2.90	62.5 ± 2.91
Mexican American	5.0 ± 0.41	7.1 ± 0.83	8.1 ± 0.92	5.5 ± 0.44	7.2 ± 1.32	8.5 ± 1.41
Non-Hispanic black	10.3 ± 0.59	10.0 ± 0.93	10.1 ± 0.86	14.2 ± 1.32	14.8 ± 1.85	16.7 ± 1.73
Other	7.9 ± 0.86	10.1 ± 1.21	10.2 ± 0.91	6.0 ± 1.21	13.7 ± 2.44	12.4 ± 1.43
Mean BMI (±SE), kg/m^2†	26.4 ± 0.10	27.8 ± 0.10	28.3 ± 0.10	30.2 ± 0.28	32.0 ± 0.36	32.8 ± 0.27
BMI category (±SE), %†						
Normal/underweight (<25 kg/m^2)	46.0 ± 0.83	35.4 ± 0.69	33.2 ± 0.73	20.3 ± 1.30	16.0 ± 1.71	12.9 ± 0.81
Overweight (25–30 kg/m^2)	32.7 ± 0.60	35.2 ± 0.70	34.3 ± 0.58	36.1 ± 2.21	29.4 ± 1.78	25.9 ± 1.40
Obese (≥30 kg/m^2)	21.2 ± 0.65	29.4 ± 0.70	32.4 ± 0.68	43.6 ± 2.32	54.6 ± 2.31	61.2 ± 1.68
Mean waist circumference (±SE), *cm*†	91.4 ± 0.23	95.5 ± 0.24	96.9 ± 0.29	103.8 ± 0.63	108.2 ± 0.85	110.0 ± 0.56
High-risk waist circumference (±SE), %†‡	35.8 ± 0.65	47.7 ± 0.86	51.1 ± 0.92	72.5 ± 2.42	76.1 ± 1.93	82.1 ± 1.25
Calibrated HbA_{1c} level (±SE), %§	5.25 ± 0.01	5.35 ± 0.01	5.36 ± 0.01	7.31 ± 0.09	7.42 ± 0.09	7.07 ± 0.05
Mean fasting plasma glucose level (±SE)‖						
mmol/L	5.40 ± 0.01	5.41 ± 0.02	5.43 ± 0.02	10.05 ± 0.24	8.54 ± 0.19	8.37 ± 0.17
mg/dL	97.3 ± 0.27	97.0 ± 0.38	97.8 ± 0.36	181.6 ± 4.27	153.9 ± 3.41	150.9 ± 3.08
Healthy subpopulation¶						
Calibrated HbA_{1c} level (±SE), %§	5.11 ± 0.01	5.11 ± 0.01	5.11 ± 0.01	–	–	–
Mean fasting plasma glucose level (±SE)‖						
mmol/L	4.97 ± 0.01	5.02 ± 0.02	4.98 ± 0.02			
mg/dL	89.6 ± 0.27	90.6 ± 0.39	89.8 ± 0.41	–	–	–

BMI = body mass index; HbA_{1c} = hemoglobin A_{1c}; NHANES = National Health and Nutrition Examination Survey.
* Data from U.S. adults aged ≥20 y.
† Among persons with no diagnosed diabetes, 461 were missing BMI data and 1483 were missing waist circumference data; among persons with diagnosed diabetes, 129 were missing BMI data and 319 were missing waist circumference data.
‡ Waist circumference cutoffs are sex-specific (≥102 cm for men and ≥88 cm for women).
§ Results use calibrated HbA_{1c} levels.
‖ Fasting plasma glucose level results were obtained from the subset of participants who attended the morning fasting session. Among persons with no diagnosed diabetes: 6830 participants in 1988–1994, 5225 participants in 1999–2004, and 5914 participants in 2005–2010. Among persons with diagnosed diabetes: 555 participants in 1988–1994, 455 participants in 1999–2004, and 805 participants in 2005–2010. Among the healthy subpopulation: 892 participants in 1988–1994, 453 participants in 1999–2004, and 521 participants in 2005–2010.
¶ The healthy subpopulation was limited to nonpregnant women and men aged 20–39 y without diagnosed diabetes, hypertension, or cholesterol-lowering medication use; BMIs of 18.5 to <25 kg/m^2 and total cholesterol levels <5.18 mmol/L (<200 mg/dL). Results for the healthy subpopulation are unweighted.

1988–1994, 11.9% (CI, 11.0% to 12.9%) in 1999–2004, and 12.4% (CI, 11.6% to 13.2%) in 2005–2010. Prediabetes prevalence was substantially greater when defined by single-visit fasting glucose levels of 5.6 to 6.9 mmol/L (100 to 125 mg/dL), with a prevalence of 25.2% (CI, 23.5% to 26.9%) in 1988–1994, 25.7% (CI, 23.6% to 28.0%) in 1999–2004, and 28.7% (CI, 26.9% to 30.5%) in 2005–2010.

Among persons with diagnosed diabetes, the prevalence of glycemic control improved during the study (**Table 2**). The prevalence of calibrated HbA_{1c} levels less than 7.0% increased from 50.9% (CI, 45.8% to 55.9%) in 1988–1994 to 58.8% (CI, 55.3% to 62.1%) in 2005–2010 among adults with diagnosed diabetes. Among persons who reported currently taking medications for diabetes, the prevalence of calibrated HbA_{1c} levels less than 7.0% increased from 39.7% (CI, 34.6% to 45.0%) in 1988–1994 to 55.1% (CI, 51.2% to 58.8%) in 2005–2010. Alongside the improvements in glycemic control, there were increases in the use of any type of diabetes medication and, in particular, increases in use of oral diabetes medications (alone or in combination with insulin) and decreases in treatment with insulin only (**Table 2**).

In general, trends in prevalence of total diabetes, undiagnosed diabetes, prediabetes, and glycemic control were similar when the continuous NHANES (1999–2010) was divided into 2-year cycles (**Table 2** of **Supplement 2**).

Despite considerable increases in total diabetes cases over the past 2 decades, trends in undiagnosed diabetes (whether defined by fasting glucose or calibrated HbA_{1c} levels) have remained fairly stable (**Table 2**). As a result of these trends, the proportion of total diabetes cases that are undiagnosed has decreased. Major differences in the prevalence of diagnosed and undiagnosed diabetes were seen by age and race or ethnic groups (**Figure 1**). There were also substantial differences in type of diabetes treatment and glycemic control by age group (**Table 3** of **Supplement 2**).

There was a substantially greater prevalence of diabetes, notably undiagnosed diabetes, in ethnic minorities compared with whites. This disparity has increased over the past 20 years (**Table 4** of **Supplement 2** and **Figure 1**). Indeed, the prevalence of total diabetes (diagnosed diabetes

or calibrated HbA_{1c} levels ≥6.5%) in non-Hispanic blacks was nearly double that in whites (15.4% vs. 8.6%). Mexican Americans also had a greater prevalence of diabetes than whites (11.6% vs. 8.6%). Both ethnic minority groups had a greater prevalence of undiagnosed diabetes. There were also race and ethnic differences in diabetes treatment type and glycemic control that have persisted over time (**Table 4** of **Supplement 2**). Indeed, among persons with diagnosed diabetes who reported currently taking medications, only 52% (CI, 46.2% to 56.7%) of non-Hispanic blacks and 43% (CI, 38.1% to 49.0%) of Mexican Americans had a calibrated HbA_{1c} level less than 7.0% compared with 57% (CI, 51.9% to 61.8%) of non-Hispanic whites (**Table 4** of **Supplement 2**).

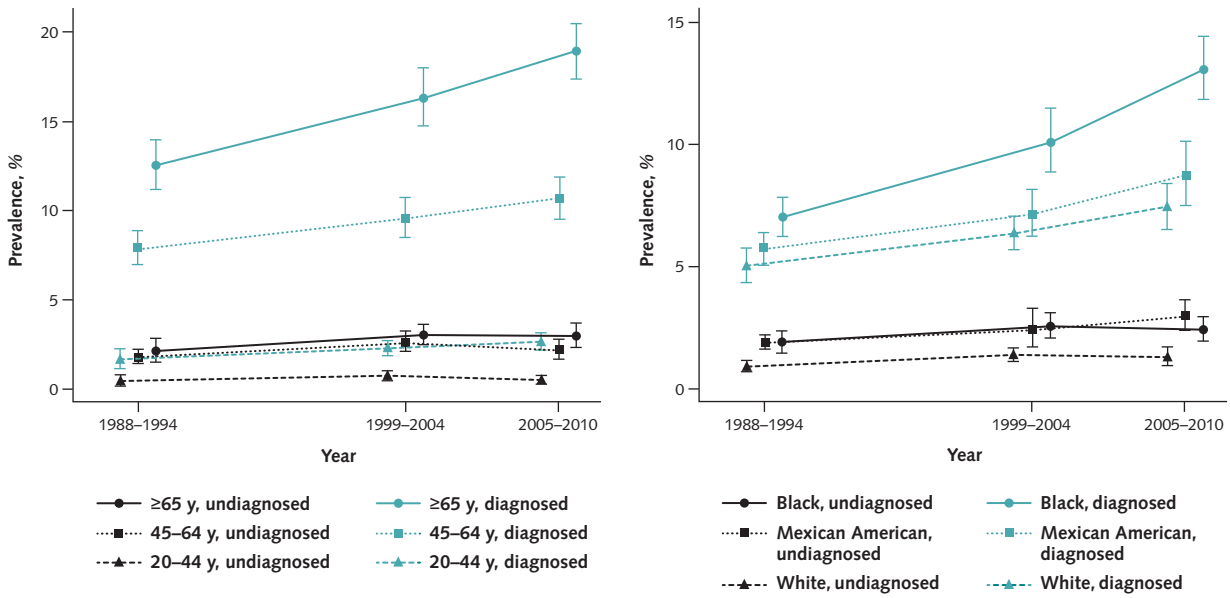
The use of a more restrictive definition of undiagnosed diabetes (both fasting glucose levels ≥7.0 mmol/L [≥126 mg/dL] and calibrated HbA_{1c} levels ≥6.5%), which more closely approximates clinical practice, still shows an increase in what could be called total confirmed diabetes cases during the study (**Table 2** and **Figure 2**). Overall estimates of diabetes cases were slightly lower with this more specific definition, but the trends remained similar to previous analyses. **Figure 2** shows the prevalence of total confirmed diabetes juxtaposed with trends in the preva-

Table 2. **Prevalence of Diagnosed Diabetes, Undiagnosed Diabetes, Prediabetes, and Glycemic Control***

Variable	Prevalence (±SE), %		
	NHANES 1988–1994 (*n* = 15 578)	NHANES 1999–2004 (*n* = 12 726)	NHANES 2005–2010 (*n* = 15 135)
Definitions of total diabetes			
Diagnosed diabetes or calibrated HbA_{1c} level ≥6.5%	6.2 ± 0.30	8.8 ± 0.36	9.9 ± 0.37
Diagnosed diabetes only	5.1 ± 0.27	7.1 ± 0.32	8.4 ± 0.34
Fasting subsample†			
Diagnosed diabetes or FPG level ≥7.0 mmol/L (≥126 mg/dL)	7.3 ± 0.50	9.4 ± 0.51	10.9 ± 0.55
Diagnosed diabetes or calibrated HbA_{1c} level ≥6.5%	5.6 ± 0.43	8.3 ± 0.53	9.6 ± 0.44
Diagnosed diabetes, calibrated HbA_{1c} level ≥6.5%, or FPG level ≥7.0 mmol/L (≥126 mg/dL)	7.5 ± 0.51	9.8 ± 0.52	11.2 ± 0.55
Diagnosed diabetes or both calibrated HbA_{1c} level ≥6.5% and FPG level ≥7.0 mmol/L (≥126 mg/dL) (total confirmed diabetes)‡	5.5 ± 0.41	8.0 ± 0.52	9.3 ± 0.45
Definitions of undiagnosed diabetes			
Calibrated HbA_{1c} level ≥6.5%	1.1 ± 0.10	1.7 ± 0.13	1.5 ± 0.14
Fasting subsample†			
FPG level ≥7.0 mmol/L (≥126 mg/dL)	2.8 ± 0.25	2.8 ± 0.22	2.6 ± 0.26
Calibrated HbA_{1c} level ≥6.5%	1.0 ± 0.12	1.7 ± 0.19	1.3 ± 0.16
Calibrated HbA_{1c} level ≥6.5% or FPG level ≥7.0 mmol/L (≥126 mg/dL)	2.9 ± 0.26	3.1 ± 0.24	2.9 ± 0.26
Calibrated HbA_{1c} level ≥6.5% and FPG level ≥7.0 mmol/L (≥126 mg/dL) (confirmed undiagnosed diabetes)‡	0.9 ± 0.12	1.3 ± 0.17	1.0 ± 0.15
Definitions of prediabetes			
Calibrated HbA_{1c} level of 5.7%–6.4%	5.8 ± 0.35	11.9 ± 0.47	12.4 ± 0.42
Fasting subsample†			
FPG level of 5.6–6.9 mmol/L (100–125 mg/dL)	25.2 ± 0.84	26.3 ± 1.14	28.7 ± 0.87
HbA_{1c} level of 5.7%–6.4%	6.0 ± 0.40	11.9 ± 0.56	12.4 ± 0.50
Definitions of glycemic control and diabetes treatment in persons with diagnosed diabetes			
Calibrated HbA_{1c} level <7%	50.9 ± 2.57	49.6 ± 2.15	58.8 ± 1.71
Calibrated HbA_{1c} level <8%	67.2 ± 2.21	70.8 ± 1.66	79.4 ± 1.33
Currently taking diabetes medication			
Calibrated HbA_{1c} level <7%	39.7 ± 2.64	43.2 ± 2.22	55.1 ± 1.93
Calibrated HbA_{1c} level <8%	58.9 ± 2.57	67.7 ± 1.71	77.6 ± 1.46
Currently not taking diabetes medication			
Calibrated HbA_{1c} level <7%	82.0 ± 4.97	78.3 ± 4.30	82.6 ± 2.96
Calibrated HbA_{1c} level <8%	89.5 ± 4.42	84.6 ± 3.88	91.6 ± 2.18
Diabetes treatment			
Insulin only	26.8 ± 2.15	15.0 ± 1.59	14.9 ± 1.14
Oral only	43.3 ± 2.53	56.7 ± 1.86	57.8 ± 1.84
Insulin and oral	3.5 ± 0.61	9.8 ± 1.30	13.9 ± 0.84
No medications	26.4 ± 2.02	18.5 ± 1.73	13.4 ± 1.36

FPG = fasting plasma glucose; HbA_{1c} = hemoglobin A_{1c}.
* Data from U.S. adults aged ≥20 y.
† Analyses incorporating FPG measurements were limited to the subsample of participants who attended the morning fasting session (7385 participants for 1988–1994, 5680 for 1999–2004, and 6719 for 2005–2010).
‡ Total confirmed diabetes was defined as diagnosed diabetes or undiagnosed diabetes with diagnostic levels of both HbA_{1c} (≥6.5%) and FPG (≥7.0 mmol/L [≥126 mg/dL]). Confirmed undiagnosed diabetes was defined as diagnostic levels of both HbA_{1c} (≥6.5%) and FPG (≥7.0 mmol/L [≥126 mg/dL]) among persons without diagnosed diabetes.

Figure 1. **Trends in the prevalence of diagnosed diabetes and undiagnosed diabetes (calibrated hemoglobin A_{1c} levels ≥6.5%), by age and race/ethnic group.**



Data from U.S. adults aged ≥20 y in NHANES 1988–1994, 1999–2004, and 2005–2010. NHANES = National Health and Nutrition Examination Survey.

lence of obesity (BMI ≥30 kg/m^2). The decrease in undiagnosed diabetes as a proportion of total diabetes cases is also evident from this figure; undiagnosed cases were 16% of total confirmed diabetes cases in 1988–1994 (0.9% of 5.5%) but only 11% in 2005–2010 (1.0% of 9.3%). When applied to the 2010 U.S. Census, the total number of adults aged 20 years or older with total confirmed diabetes was 20.6 million (**Table 5** of **Supplement 2**).

Compared with 1988–1994, the greater prevalence of total diabetes in 1999–2004 and 2005–2010 remained significant after adjustment for demographic characteristics (**Table 3**). However, after further adjustment for current BMI and waist circumference, the prevalence ratios were strongly attenuated (*P* values were 0.136 and 0.058, respectively), suggesting that changes in demographic characteristics and adiposity explained most of the increase in total diabetes prevalence in the United States.

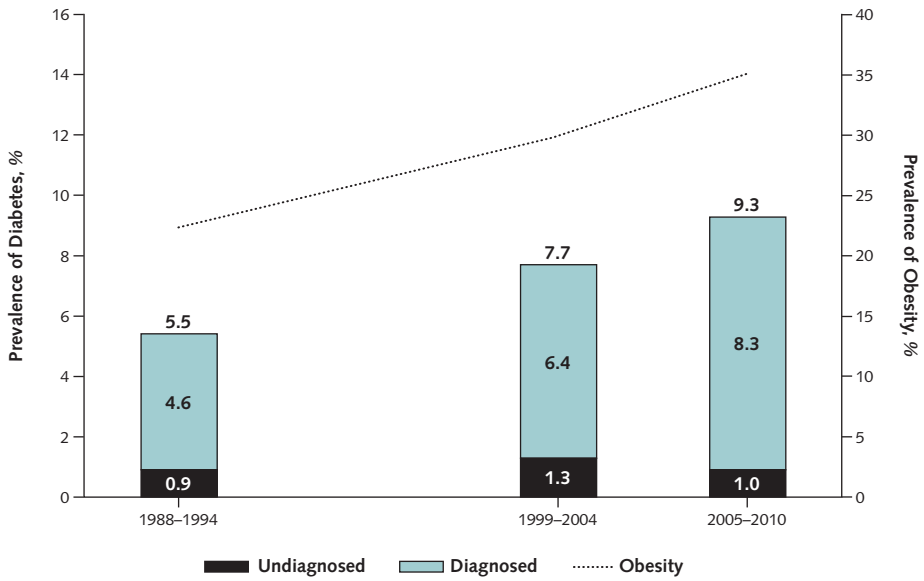
DISCUSSION

The prevalence of diabetes has increased substantially over the past 2 decades. The prevalence of total confirmed diabetes (diagnosed and undiagnosed) among noninstitutionalized adults aged 20 years or older in the United States was 9.3% in 2005–2010 compared with 7.6% in 1999–2004 and 5.5% in 1988–1994. This corresponds to approximately 21 million U.S. adults with total confirmed diabetes in 2010. Despite the increase in total diabetes cases, the prevalence of undiagnosed diabetes has remained fairly stable, which probably reflects improvements in screening and diagnosis. As a result of these trends, the proportion of diabetes cases that are undiagnosed has decreased over the past 20 years. At present, the proportion of persons with undiagnosed diabetes is only 11% of total confirmed diabetes cases. Our analyses used calibrated HbA_{1c} levels to account for population-wide shifts in the distribution of HbA_{1c} levels across NHANES cycles that could not be attributed to metabolic processes. However, it is important to note that the observed calibration differences were within the range of error of the HbA_{1c} assays (<5%) and would likely not be detected by standard laboratory quality control methods.

We found that the increases in diabetes cases over the past 2 decades were largely explained by increases in obesity. It should be noted that current levels of BMI and waist circumference are unlikely to fully capture the true cumulative effects of adiposity. Thus, the estimates from our regression model cannot fully eliminate residual confounding because of the cross-sectional design, mismeasurement of adiposity, and unmeasured factors that have also contributed to the increase in diabetes in the U.S. population.

We saw striking differences in the prevalence of diabetes by age and race or ethnicity. Recent studies have highlighted the important effect that diabetes can have on functional status and mobility (22–24), cognition (25–27), fracture risk (28), and life expectancy (29). The high burden of diabetes among older adults suggests the need for national efforts to address this growing population, partic-

Figure 2. **Prevalence of total confirmed diabetes and obesity.**



Data from U.S. adults aged ≥20 y in NHANES 1988–1994, 1999–2004, and 2005–2010. Total confirmed diabetes was defined as diagnosed diabetes or undiagnosed diabetes with diagnostic levels of both hemoglobin A_{1c} (≥6.5%) and fasting glucose (7.0 mmol/L [≥126 mg/dL]). Obesity was defined as body mass index ≥30 kg/m^2; 601 persons were missing body mass index data. Prevalence estimates for total confirmed diabetes and obesity were obtained using only the subsample of participants who attended the morning fasting session (7385 participants for 1988–1994, 5680 participants for 1999–2004, and 6719 participants for 2005–2010). The midpoint for obesity prevalence between 1988–1994 and 1999–2004 was calculated as the average of the prevalence of the 2 periods. NHANES = National Health and Nutrition Examination Survey.

ularly as the number of older adults is expected to increase dramatically over the next 2 decades (30). The substantially greater prevalence of diabetes and prediabetes and poor rates of glycemic control (even among persons with medication-treated diabetes) in ethnic minority populations compared with whites is particularly concerning because blacks and Mexican Americans are also at greater risk for complications of diabetes, particularly retinopathy and kidney disease (31–34).

The past 2 decades have seen increases in the use of oral diabetes medications and improvements in glycemic control among persons with diagnosed diabetes. In combination with evidence for better detection (smaller proportion of undiagnosed cases), these results are consistent with improvements in diabetes screening and care in the past 20 years. Nonetheless, despite these improvements, large portions of the population are not achieving optimal HbA_{1c} levels, suggesting that further efforts are needed.

Because fasting glucose and HbA_{1c} levels are often used in combination or would be repeated in clinical practice to confirm a diagnosis (8), we included a definition of diabetes where elevated fasting glucose levels were "confirmed" with elevated HbA_{1c} levels. This results in a more conservative estimate of the prevalence of diabetes in the population, especially compared with definitions that use a single fasting glucose level measurement, which has high within-person variability (35). Consistent with other studies, we found that the prevalence of prediabetes based on fasting glucose levels (5.6 to 6.9 mmol/L [100 to 125 mg/dL]) was more than double the prevalence defined by cal-

Table 3. **Trends in Total Diabetes* Before and After Adjustment for Demographic Characteristics and Measures of Adiposity**

Survey	Unadjusted†		Adjusted for Age, Sex, and Race/Ethnicity†		Additionally Adjusted for BMI and Waist Circumference†	
	Prevalence (95% CI), %	Prevalence Ratio (95% CI)	Prevalence (95% CI), %	Prevalence Ratio (95% CI)	Prevalence (95% CI), %	Prevalence Ratio (95% CI)
NHANES 1988–1994	6.0 (5.4–6.6)	1.00 (reference)	6.4 (5.8–7.0)	1.00 (reference)	7.5 (6.9–8.2)	1.00 (reference)
NHANES 1999–2004	8.4 (7.7–9.2)	1.40 (1.21–1.59)	8.4 (7.6–9.1)	1.31 (1.14–1.47)	8.3 (7.5–9.0)	1.10 (0.97–1.22)
NHANES 2005–2010	9.6 (8.9–10.2)	1.59 (1.39–1.78)	9.1 (8.5–9.8)	1.42 (1.27–1.58)	8.3 (7.8–8.9)	1.11 (1.00–1.22)

BMI = body mass index; NHANES = National Health and Nutrition Examination Survey.
* Diagnosed diabetes or calibrated hemoglobin A_{1c} level ≥6.5%. Data from U.S. adults aged ≥20 y.
† 1978 persons were missing BMI and/or waist circumference data; all models exclude persons missing these data.

ibrated HbA_{1c} levels (5.7% to 6.4%). This highlights the discordance of fasting glucose and HbA_{1c} categories to define prediabetes (11, 36). Although HbA_{1c} criteria classify far fewer persons in the population as having prediabetes, studies have demonstrated that this group is at greater risk for diabetes and its complications compared with persons identified by the fasting glucose criteria (37–40). Of importance, after calibration, the trends in undiagnosed diabetes and prediabetes based on HbA_{1c} levels were more closely aligned to those based on fasting glucose levels.

Several limitations of this study deserve mention. First, this analysis was based on cross-sectional data, and we cannot determine the causes for the underlying trends. Second, we relied on single measurements of fasting glucose and HbA_{1c} levels to identify undiagnosed cases of diabetes; in clinical practice, these measurements should be repeated to confirm the diagnosis. Third, we relied on self-report to identify diagnosed diabetes; self-reported diabetes is known to be highly specific (41, 42), but some misclassification may have occurred. Fourth, despite calibration, small drift in laboratory assays over time is difficult to eliminate. Fifth, fasting glucose measurements were available only in a subsample of each of the surveys, resulting in less precise estimates, particularly in the 2-year survey periods. The 6-year combined estimates are more reliable. Nonetheless, our conclusions about trends were similar across the fasting subsamples and 2-year survey cycles. In addition, the NHANES surveys sampled only noninstitutionalized adults, and therefore, certain segments of the population are not represented in these estimates. For example, diabetes prevalence in nursing homes is unknown, but it is probably high (43).

In conclusion, the past 2 decades have seen a major increase in the prevalence of diabetes in the U.S. population, from 5.5% to 9.3%, with greater estimates among older adults and minorities; this increase was associated with increases in the prevalence of obesity. In contrast, the prevalence of undiagnosed diabetes remained relatively stable over this period. At present, approximately 89% of all diabetes cases are diagnosed. Furthermore, glycemic control among persons with diagnosed diabetes improved, probably reflecting a combination of improvements in diagnosis, screening, and care. However, a substantial proportion of persons with diabetes still have HbA_{1c} levels greater than 7.0%, particularly among blacks and Mexican Americans.

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