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Trends in Prevalence and Control of Diabetes in the U.S., 1988-1994 and 1999-2010

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Abstract

Background—Trends in the prevalence and control of diabetes defined by hemoglobin A1c (HbA1c) are important for health care policy and planning.

Objective—To update trends in prevalence of diabetes, pre-diabetes, and glycemic control in persons with diagnosed diabetes over the past two decades in U.S. adults.

Design—Cross-sectional.

Setting—The National Health and Nutrition Examination Surveys 1988-1994 and 1999-2010.

Participants—Adults 20 years or older.

Measurements—We used calibrated HbA1c to define undiagnosed diabetes (≥6.5%), pre-diabetes (5.7-6.4%), and, among persons with diagnosed diabetes, glycemic control (<7.0% or <8.0%). Trends in HbA1c categories were compared to fasting glucose (≥7.0 and 5.6-6.9 mmol/l [≥126 and 100-125 mg/dL]).

Results—In 2010, there were ~21 million adults aged 20 years or older with total confirmed diabetes (self-reported diabetes or diagnostic values for both fasting glucose and calibrated HbA1c) in the U.S. The prevalence of total confirmed diabetes increased but the prevalence of undiagnosed diabetes has remained fairly stable, reducing the proportion of total diabetes cases that are undiagnosed to 11% in 2005-10. The prevalence of pre-diabetes was lower when defined by calibrated HbA1c compared to when defined by fasting glucose but has increased from 5.8% in

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1988-1994 to 12.4% in 2005-2010 when defined by HbA1c. Glycemic control has improved overall but total diabetes prevalence was higher and diabetes was less controlled among non-Hispanic blacks and Mexican Americans compared to non-Hispanic whites.

Limitations—Cross-sectional design.

Conclusions—Over the past two decades, the prevalence of total diabetes has increased substantially. However, the proportion of diabetes cases that are undiagnosed has 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.

INTRODUCTION

There has been a staggering increase in the prevalence of obesity over the past 30 years in the U.S. (1, 2). Diagnosed diabetes has increased concomitantly (3-6). In a major change to clinical guidelines in 2010, hemoglobin A1c (HbA1c) was recommended for use as a diagnostic test for diabetes (7). In addition to its central role in monitoring glycemic control, HbA1c is now widely used as the first-line test for diagnosis of diabetes (8, 9). However, use of HbA1c to characterize U.S. trends in pre-diabetes, undiagnosed diabetes and glycemic control in the National Health and Nutrition Examination Survey (NHANES) 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 methodology (10, 11). Uncalibrated mean HbA1c values have increased over successive NHANES surveys, even in normal weight persons (12), but without parallel increases in fasting glucose. No specific cause for the shift in HbA1c has been identified (10). The magnitudes of the changes in the distributions are small (approximately 4-5%) and such small shifts potentially would not be detectable in most laboratory quality control analyses. While such small changes are not important for individual (clinical) classification, they can have a substantial impact at the population level. They are particularly important when examining trends over time and when looking at specific regions of the distribution. These shifts have significant ramifications for estimating the prevalence of diabetes and pre-diabetes in the population. We addressed these issues by calibrating the HbA1c 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), pre-diabetes, and glycemic control in persons with diagnosed diabetes over the past two decades using data from the 1988-1994 (NHANES III) and the 1999-2010 (continuous NHANES) survey periods based on calibrated HbA1c and fasting glucose.

METHODS

Setting and Participants

The NHANES are cross-sectional multi-stage, stratified, clustered probability samples of the U.S. civilian non-institutionalized population conducted by the National Center for Health Statistics (NCHS), a branch of the Centers for Disease Control and Prevention. Data are

available from NHANES III (conducted from 1988 to 1994) and the continuous NHANES, conducted from 1999 to 2010 (data released in two year cycles). The protocols for the conduct of NHANES were approved by the NCHS institutional review board and informed consent was obtained from all participants.

For the present study we limited our study population to 43,439 total persons who attended the clinical examination and who were aged 20 years or older, who were not missing HbA1c measurements and who were not pregnant: 15,578 participants in NHANES III, 12,726 in NHANES 1999-2004, and 15,135 in 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: 7,385 in NHANES III, 5,680 in NHANES 1999-2004, and 6,719 in 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, 2001-02, 2003-04, 2005-06, 2007-08, 2009-10).

Measurement of HbA1c and Plasma Glucose

HbA1c was 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 HbA1c measurement methods across surveys. In NHANES III (1988-1994), HbA1c was measured using the Diamat Analyzer performed at the University of Missouri-Columbia. In NHANES 1999-2000, 2001-2002, and 2003-2004, HbA1c was measured using the Primus Automated HPLC System (models CLC330 (Primus I) or CLC385 (Primus IV)) at the University of Missouri-Columbia. In NHANES 2005-2006, 2007-2008, and 2009-2010, HbA1c was measured at the University of Minnesota Medical Center, Fairview, with several changes in methodology over the 2005 to 2010 time period. In 2005-2006, the Tosoh A1c 2.2 Plus Analyzer was used. In 2007-2008, the Tosoh A1c 2.2 Plus analyzer was used in the first 6 months of 2007 while the Tosoh G7 analyzer was used for the latter period. In NHANES 2009-10, the Tosoh G7 Analyzer was used. We calibrated the HbA1c values to account for changes in laboratory methodology during this time period (see **Online Supplement**).

Plasma glucose was measured in specimens collected from morning fasting subsample participants and performed using a hexokinase enzymatic method. In NHANES III (1998-1994) and 1999-2004, plasma glucose was measured at the University of Missouri-Columbia using a Roche Cobas Mira instrument (13). Plasma glucose was measured at the University of Minnesota using a Roche/Hitachi 911 instrument in 2005-06 and a Roche Modular P instrument in 2007-10. We applied regression equations recommended by the NCHS to account for changes in methods and align the plasma glucose measurements across survey periods (14, 15). We confirmed the stability of the calibrated plasma glucose values in a young, healthy fasting subsample (see **Online Supplement**).

Definitions of Diabetes, Pre-diabetes, 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 HbA1c <7.0% or <8.0%. In persons without a diagnosis of diabetes, we evaluated trends in undiagnosed diabetes and pre-diabetes defined using clinical cut-points for HbA1c (≥6.5% and 5.7-6.4%, respectively) (8). In the fasting subsample, we compared trends in undiagnosed diabetes and pre-diabetes defined using calibrated HbA1c values to those defined using fasting glucose cut-points (≥7.0 and 5.6-6.9 mmol/l [≥126 mg/dL and 100-125 mg/dL], respectively). Also in the fasting subsample, we examined trends in total confirmed cases of diabetes, defined as diagnosed diabetes or both elevated fasting glucose (≥7.0 mmol/l [≥126 mg/dL]) and elevated HbA1c (≥6.5%), a definition which 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, HbA1c, either, or both (confirmed cases).

Other Measures

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

Statistical Analyses

We used an equipercentile equating approach to statistically correct for the non-equivalency of HbA1c values across the different NHANES surveys (17-19) (see **Appendix**). Prevalence estimates and their standard errors 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, as per NCHS guidelines. Analyses were performed incorporating sampling weights to obtain unbiased estimates from the complex NHANES sampling design. Standard errors were obtained using the Taylor series (linearization) method following analytic procedures recommended by the NCHS (20, 21). Prevalence estimates from this study are nationally representative of the civilian, non-institutionalized 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 individuals with diabetes in the U.S in the year 2010. We used logistic regression to obtain predictive margins to examine trends in total diabetes (diagnosed diabetes or calibrated HbA1c ≥6.5%) after adjustment for demographics and body mass index and waist circumference. P-values for linear trend were calculated by regressing the continuous variable of interest (e.g. body mass index) 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 (The 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 post-estimation commands to obtain predictive margins and prevalence ratios with 95% confidence intervals 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/ethnic make-up of the population (**Table 1**). Most notably, there was a substantial increase in the percentage of people self-reporting race/ethnicity as Mexican American. The mean body mass index 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 higher in all time periods. Among persons without diagnosed diabetes, mean calibrated HbA1c was 5.25% in 1988-1994, 5.35% in 1999-2004, and 5.36% 2005-2010 (p-trend <0.001). By contrast, mean calibrated HbA1c and fasting glucose in a young healthy subgroup (persons aged 20-39 years with normal body mass index, no diagnosed diabetes, and without hypertension or high cholesterol) were stable over this same period (5.1% and 90 mg/dL, respectively). Similar trends were observed when examining 2-year survey cycles within the continuous NHANES (1999-2010) (**eTable 1**).

The prevalence of total diabetes (defined as diagnosed diabetes or calibrated HbA1c ≥6.5%) increased over the 20-year period from 6.2% (95% CI: 5.6-6.8%) in 1988-1994, 8.8% (95% CI: 8.1-9.6%) in 1999-2004, and 9.9% (95% CI: 9.2-10.7%) in 2005-2010 (**Table 2**). A similar trend was observed when elevated fasting glucose (≥7.0 mmol/l [≥126 mg/dL]) was combined with diagnosed diabetes cases: 7.3% (95% CI: 6.4-8.4%) in 1988-1994, 9.1% (95% CI: 8.0-10.2%) in 1999-2004, and 10.9% (95% CI: 9.8-12.0%) in 2005-10. Across all survey periods, the prevalence of undiagnosed diabetes was substantially higher (+60% to +180% higher) when defined by fasting glucose ≥7.0 mmol/l (≥126 mg/dL) obtained at a single visit compared to HbA1c ≥6.5%. For example, in 2005-2010, the prevalence of undiagnosed diabetes defined by fasting glucose ≥7.0 mmol/l (≥126 mg/dL) was twice as high as undiagnosed diabetes defined by calibrated HbA1c (2.6% vs 1.3% or +100% higher). When defined by calibrated HbA1c (5.7%-6.4%), the prevalence of pre-diabetes was 5.8% (95% CI: 5.2-6.5%) in 1988-1994, 11.9% (95% CI: 11.0-12.9%) in 1999-2004, and 12.4% (95% CI: 11.6-13.2%) in 2005-10. Pre-diabetes prevalence was substantially higher when defined by single-visit fasting glucose 5.6-6.9 mmol/l (100-125 mg/dL), with a

prevalence of 25.2% (95% CI: 23.5-26.9%) in 1988-1994, 25.7% (95% CI: 23.6-28.0%) in 1999-2004 and 28.7% (95% CI: 26.9-30.5%) in 2005-10.

Among persons with diagnosed diabetes, the prevalence of glycemic control improved over the study period (**Table 2**). The prevalence of calibrated HbA1c <7.0% increased from 50.9% (95% CI: 45.8-55.9%) in 1988-1994 to 58.8% (95% CI: 55.3-62.1%) in 2005-10 among adults with diagnosed diabetes. Among those persons who reported currently taking medications for diabetes, the prevalence of calibrated HbA1c <7.0% increased from 39.7% (95% CI: 34.6-45.0%) in 1988-1994 to 55.1% (95% CI: 51.2-58.8%) in 2005-10. 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, pre-diabetes and glycemic control were similar when the continuous NHANES (1999-2010) was divided into 2-year cycles (**eTable 2**).

Despite considerable increases in total diabetes over the past two decades, trends in undiagnosed diabetes (whether defined by fasting glucose or calibrated HbA1c) 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 observed by age (**Figure 1, Panel A**) and race/ethnic groups (**Figure 1, Panel B**). There were also substantial differences in type of diabetes treatment and glycemic control by age group (**eTable 3**).

There was a substantially higher prevalence of diabetes, notably undiagnosed diabetes, in ethnic minorities compared to whites. This disparity has increased over the past 20 years (**eTable 4 and Figure 1, Panel B**). Indeed, the prevalence of total diabetes (diagnosed diabetes or calibrated HbA1c ≥6.5%) in non-Hispanic blacks was almost double the prevalence in whites (15.4% vs 8.6%). Mexican Americans also had a higher prevalence of diabetes than whites (11.6% vs 8.6%). Both ethnic minority groups had a higher prevalence of undiagnosed diabetes. There were also race/ethnic differences in diabetes treatment type and glycemic control that have persisted over time (**eTable 4**). Indeed, among those persons with diagnosed diabetes who reported currently taking medications, only 52% (95% CI: 46.2-56.7%) of non-Hispanic blacks and 43% (95% CI: 38.1-49.0%) of Mexican Americans had a calibrated HbA1c <7.0% as compared to 57% (95% CI: 51.9-61.8%) of non-Hispanic whites (**eTable 4**).

Using a more restrictive definition of undiagnosed diabetes (both fasting glucose ≥7.0 mmol/l [≥126 mg/dL] and calibrated HbA1c≥6.5%), which more closely approximates clinical practice, still shows an increase in what could be called total confirmed diabetes over the study period (**Table 2** and **Figure 2**). Overall estimates of diabetes were slightly lower using 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 prevalence of obesity (body mass index ≥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 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 or older with total confirmed diabetes was 20.6 million (**eTable 5**).

Compared to 1988-1994, the higher prevalence of total diabetes in 1999-2004 and 2005-2010 remained significant after adjustment for demographics (**Table 3**). However, after further adjustment for current body mass index and waist circumference, the prevalence ratios were strongly attenuated (p-values were 0.136 and 0.058, respectively), suggesting that changes in demographics and adiposity explained most of the increase in total diabetes prevalence in the U.S.

DISCUSSION

The prevalence of diabetes has increased substantially over the past two decades. The prevalence of total confirmed diabetes (diagnosed and undiagnosed) among non-institutionalized adults aged 20 years or older in the U.S. was 9.3% in 2005-2010 compared to 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 rise in total diabetes, the prevalence of undiagnosed diabetes has remained fairly stable, likely reflecting improvements in screening and diagnosis. As a result of these trends, the proportion of diabetes cases that are undiagnosed has dropped over the past 20 years. Currently, the proportion of persons with undiagnosed diabetes is only 11% of total confirmed diabetes cases. Our analyses used calibrated HbA1c values to account for population-wide shifts in the distribution of HbA1c 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 HbA1c assays (<5%) and would likely not be detected by standard laboratory quality control methods.

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

We observed striking differences in the prevalence of diabetes by age and race/ethnicity group. Recent studies have highlighted the important impact 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, particularly as the number of older adults is expected to increase dramatically over the next two decades (30). The substantially higher prevalence of diabetes and pre-diabetes and poor rates of glycemic control (even among persons with medication-treated diabetes) in ethnic minority populations compared to whites is particularly concerning as blacks and Mexican Americans are also at higher risk for complications of diabetes, particularly retinopathy and kidney disease (31-34).

The past two 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 HbA1c levels, suggesting further efforts are needed.

Because fasting glucose and HbA1c are often used in combination or would be repeated in clinical practice to confirm a diagnosis (8), we included here a definition of diabetes where elevated fasting glucose was “confirmed” with elevated HbA1c. This results in a more conservative estimate of the prevalence of diabetes in the population, especially compared to definitions which employ a single fasting glucose measurement, which has high within-person variability (35). Consistent with other studies, we found that the prevalence of pre-diabetes based on fasting glucose (5.6-6.9 mmol/l [100-125 mg/dL]) was more than double the prevalence of pre-diabetes defined by calibrated HbA1c (5.7-6.4%). This highlights the discordance of fasting glucose and HbA1c categories to define pre-diabetes (11, 36). While the HbA1c criteria classify far fewer persons in the population as having pre-diabetes, previous studies have demonstrated that this group is at higher risk for the development of diabetes and its complications compared to persons identified by the fasting glucose criteria (37-40). Importantly, after calibration, the trends in undiagnosed diabetes and pre-diabetes based on HbA1c were more closely aligned to those based on fasting glucose.

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 HbA1c 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 only available 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 regarding trends were similar across the fasting subsamples and 2-year survey cycles. Finally, the NHANES surveys only sampled non-institutionalized 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 likely to be high (43).

In conclusion, the past two decades have seen a major increase in the prevalence of diabetes in the U.S. population, from 5.5% to 9.3%, with higher 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. Currently, approximately 89% of all diabetes cases are diagnosed. Furthermore, glycemic control among persons with diagnosed diabetes improved, likely reflecting a combination of improvements in diagnosis, screening, and care. However, a substantial proportion of persons with diabetes still have HbA1c values above 7.0%, particularly among blacks and Mexican Americans.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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REFERENCES

1. Flegal KM, Carroll MD, Ogden CL, Curtin LR. Prevalence and trends in obesity among US adults, 1999-2008. JAMA. 2010; 303(3):235–41. PMID: 20071471. [PubMed: 20071471]
2. Flegal KM, Carroll MD, Kuczmarski RJ, Johnson CL. Overweight and obesity in the United States: prevalence and trends, 1960-1994. Int J Obes Relat Metab Disord. 1998; 22(1):39–47. PMID: 9481598. [PubMed: 9481598]
3. Mokdad AH, Ford ES, Bowman BA, Nelson DE, Engelgau MM, Vinicor F, et al. Diabetes trends in the U.S.: 1990-1998. Diabetes Care. 2000; 23(9):1278–83. PMID: 10977060. [PubMed: 10977060]
4. Lee JW, Brancati FL, Yeh HC. Trends in the prevalence of type 2 diabetes in Asians versus whites: results from the United States National Health Interview Survey, 1997-2008. Diabetes Care. 2011; 34(2):353–7. PMCID: PMC3024348. PMID: 21216863. [PubMed: 21216863]
5. Trends in the Prevalence and Incidence of Self-Reported Diabetes Mellitus — United States, 1980–1994. Morbidity and Mortality Weekly Report. 1997; 46(43):1014–8. PMID: [PubMed: 9367135]
6. Centers for disease Control and Prevention. Maps of Trends in Diagnosed Diabetes. CDC's Division of Diabetes Translation, National Diabetes Surveillance System. 2011. http://www.cdc.gov/diabetes/statistics/slides/maps_diabetes_trends.pdf. PMID:
7. American Diabetes A. Standards of medical care in diabetes--2010. Diabetes Care. 2010; 33(Suppl 1):S11–61. PMCID: PMC2797382. PMID: 20042772. [PubMed: 20042772]
8. American Diabetes A. Standards of medical care in diabetes--2013. Diabetes Care. 2013; 36(Suppl 1):S11–66. PMCID: PMC3537269. PMID: 23264422. [PubMed: 23264422]
9. Organization, WH. Use of Glycated Hemoglobin (HbA1c) in the Diagnosis of Diabetes Mellitus. Abbreviated Report of a WHO Consultation. 2011. http://www.who.int/diabetes/publications/report-hba1c_2011.pdf. PMID:
10. National Center for Health Statistics. Updated Advisory for NHANES Hemoglobin A1c (Glycohemoglobin) Data. (revised March 2012) [internet]. Available from: http://wwwcdcgov/nchs/data/nhanes/A1c_webnotice.pdf. 2012;Last accessed 5 August 2013. PMID:
11. Abraham TM, Fox CS. Implications of rising prediabetes prevalence. Diabetes Care. 2013; 36(8): 2139–41. PMCID: PMC3714497. PMID: 23881964. [PubMed: 23881964]
12. Bullard KM, Saydah SH, Imperatore G, Cowie CC, Gregg EW, Geiss LS, et al. Secular changes in u.s. Prediabetes prevalence defined by hemoglobin a1c and fasting plasma glucose: national health and nutrition examination surveys, 1999-2010. Diabetes Care. 2013; 36(8):2286–93. PMID: 23603918. [PubMed: 23603918]
13. Laboratory Procedures Used for the Third National Health and Nutrition Examination Survey (NHANES III), 1988-1994. [internet]. Available from: http://wwwcdcgov/nchs/data/nhanes/nhanes3/cdrom/nchs/manuals/labman.pdf. 1996;Accessed 5 August 2013. PMID:
14. National Center for Health Statistics. National Health and Nutrition Examination Survey 2005–2006 data documentation, codebook, and frequencies: plasma fasting glucose and insulin (GLU_D). [Internet]. Available from http://wwwcdcgov/nchs/nhanes/nhanes2005-2006/GLU_D.htm. 2008:Accessed 5 August 2013. PMID:
15. National Center for Health Statistics. National Health and Nutrition Examination Survey 2007–2008 data documentation, codebook, and frequencies: plasma fasting glucose and insulin

(GLU_E). [Internet]. Available from http://wwwcdcgov/nchs/nhanes/nhanes2007-2008/GLU_E.htm. 2008;Accessed 5 August 2013. PMID:

16. World Health Organization. Waist Circumference and Waist–Hip Ratio: Report of a WHO Expert Consultation. http://whqlibdocwhoint/publications/2011/9789241501491_eng.pdf. 2008. PMID:
17. Albano, A. Statistical Equating Methods. http://cranr-projectorg/web/packages/equate/vignettes/equatevignette.pdf. 2011. PMID:
18. Gross AL, Inouye SK, Rebok GW, Brandt J, Crane PK, Parisi JM, et al. Parallel but not equivalent: challenges and solutions for repeated assessment of cognition over time. J Clin Exp Neuropsychol. 2012; 34(7):758–72. PMCID: PMC3574868. PMID: 22540849. [PubMed: 22540849]
19. Albano, A. R package 'equate'. http://cranr-projectorg/web/packages/equate/equate.pdf Last accessed: 15 August 2013. PMID:
20. National Center for Health Statistics. National Health and Nutrition Examination Survey (NHANES) Analytic Guidelines. http://www.cdc.gov/nchs/about/major/nhanes/nhanes2003-2004/analytical_guidelines.htm,. 2007:Last Accessed: 19 August 2013. PMID:
21. National Center for Health Statistics. Analytic and Reporting Guidelines: National Health and Nutrition Examination Survey, NHANES III (1988-94). http://wwwcdcgov/nchs/data/nhanes/nhanes3/nh3gui.pdf. October 1996:Last accessed: 19 August 2013. PMID:
22. Kalyani RR, Saudek CD, Brancati FL, Selvin E. The Association of Diabetes, Comorbidities, and Hemoglobin A1c with Functional Disability in Older Adults: Results from the National Health and Nutrition Examination Survey (NHANES), 1999-2006. Diabetes Care. 2010 PMID: 20185736.
23. Ryerson B, Tierney EF, Thompson TJ, Engelgau MM, Wang J, Gregg EW, et al. Excess physical limitations among adults with diabetes in the U.S. population, 1997-1999. Diabetes Care. 2003; 26(1):206–10. PMID: 12502682. [PubMed: 12502682]
24. Rejeski WJ, Ip EH, Bertoni AG, Bray GA, Evans G, Gregg EW, et al. Lifestyle change and mobility in obese adults with type 2 diabetes. N Engl J Med. 2012; 366(13):1209–17. PMCID: PMC3339039. PMID: 22455415. [PubMed: 22455415]
25. Christman AL, Matsushita K, Gottesman RF, Mosley T, Alonso A, Coresh J, et al. Glycated haemoglobin and cognitive decline: the Atherosclerosis Risk in Communities (ARIC) study. Diabetologia. 2011; 54(7):1645–52. PMID: 21360189. [PubMed: 21360189]
26. Biessels GJ, Staekenborg S, Brunner E, Brayne C, Scheltens P. Risk of dementia in diabetes mellitus: a systematic review. The Lancet Neurology. 2006; 5(1):64–74. PMID: [PubMed: 16361024]
27. Crane PK, Walker R, Hubbard RA, Li G, Nathan DM, Zheng H, et al. Glucose levels and risk of dementia. N Engl J Med. 2013; 369(6):540–8. PMID: 23924004. [PubMed: 23924004]
28. Schneider AL, Williams EK, Brancati FL, Blecker S, Coresh J, Selvin E. Diabetes and Risk of Fracture-Related Hospitalization: The Atherosclerosis Risk in Communities Study. Diabetes Care. 2012 PMID: 23248194.
29. Emerging Risk Factors C. Seshasai SR, Kaptoge S, Thompson A, Di Angelantonio E, Gao P, et al. Diabetes mellitus, fasting glucose, and risk of cause-specific death. N Engl J Med. 2011; 364(9): 829–41. PMID: 21366474. [PubMed: 21366474]
30. U.S. Census Bureau. The Next Four Decades: The Older Population in the United States: 2010 to 2050. Current Population Reports. 2010. http://www.census.gov/prod/2010pubs/p25-1138.pdf. PMID:
31. Tarver-Carr ME, Powe NR, Eberhardt MS, LaVeist TA, Kington RS, Coresh J, et al. Excess risk of chronic kidney disease among African-American versus white subjects in the United States: a population-based study of potential explanatory factors. J Am Soc Nephrol. 2002; 13(9):2363–70. PMID: 12191981. [PubMed: 12191981]
32. Perneger TV, Brancati FL, Whelton PK, Klag MJ. End-stage renal disease attributable to diabetes mellitus. Ann Intern Med. 1994; 121(12):912–8. PMID: 7978716. [PubMed: 7978716]
33. Bower JK, Brancati FL, Selvin E. No Ethnic Differences in the Association of Glycated Hemoglobin With Retinopathy: The National Health and Nutrition Examination Survey 2005-2008. Diabetes Care. 2012 PMID: 23069841.

34. Debnath S, Thameem F, Alves T, Nolen J, Al-Shahrouri H, Bansal S, et al. Diabetic nephropathy among Mexican Americans. Clin Nephrol. 2012; 77(4):332–44. PMID: 22445478. [PubMed: 22445478]

35. Selvin E, Crainiceanu CM, Brancati FL, Coresh J. Short-term Variability in Measures of Glycemia and Implications for the Classification of Diabetes. Archives of Internal Medicine. 2007; 167(14): 1545–51. PMID: 17646610. [PubMed: 17646610]

36. Mann DM, Carson AP, Shimbo D, Fonseca V, Fox CS, Muntner P. Impact of A1C screening criterion on the diagnosis of pre-diabetes among U.S. adults. Diabetes Care. 2010; 33(10):2190–5. PMID: [PubMed: 20628087]

37. Selvin E, Steffes MW, Gregg E, Brancati FL, Coresh J. Performance of A1C for the classification and prediction of diabetes. Diabetes Care. 2011; 34(1):84–9. PMCID: PMC3005486. PMID: 20855549. [PubMed: 20855549]

38. Selvin E, Steffes MW, Zhu H, Matsushita K, Wagenknecht L, Pankow J, et al. Glycated hemoglobin, diabetes, and cardiovascular risk in nondiabetic adults. N Engl J Med. 2010; 362(9): 800–11. PMID: 20200384. [PubMed: 20200384]

39. Pankow JS, Kwan DK, Duncan BB, Schmidt MI, Couper DJ, Golden S, et al. Cardiometabolic risk in impaired fasting glucose and impaired glucose tolerance: the Atherosclerosis Risk in Communities Study. Diabetes Care. 2007; 30(2):325–31. PMID: 17259502. [PubMed: 17259502]

40. Heianza Y, Hara S, Arase Y, Saito K, Fujiwara K, Tsuji H, et al. HbA1c 5.7-6.4% and impaired fasting plasma glucose for diagnosis of prediabetes and risk of progression to diabetes in Japan (TOPICS 3): a longitudinal cohort study. Lancet. 2011; 378(9786):147–55. PMID: 21705064. [PubMed: 21705064]

41. Schneider AL, Pankow JS, Heiss G, Selvin E. Validity and reliability of self-reported diabetes in the atherosclerosis risk in communities study. Am J Epidemiol. 2012; 176(8):738–43. PMID: 23013620. [PubMed: 23013620]

42. Saydah SH, Geiss LS, Tierney E, Benjamin SM, Engelgau M, Brancati F. Review of the performance of methods to identify diabetes cases among vital statistics, administrative, and survey data. Annals of Epidemiology. 2004; 14(7):507–16. PMID: [PubMed: 15301787]

43. Zhang X, Decker FH, Luo H, Geiss LS, Pearson WS, Saaddine JB, et al. Trends in the prevalence and comorbidities of diabetes mellitus in nursing home residents in the United States: 1995-2004. J Am Geriatr Soc. 2010; 58(4):724–30. PMID: 20398154. [PubMed: 20398154]

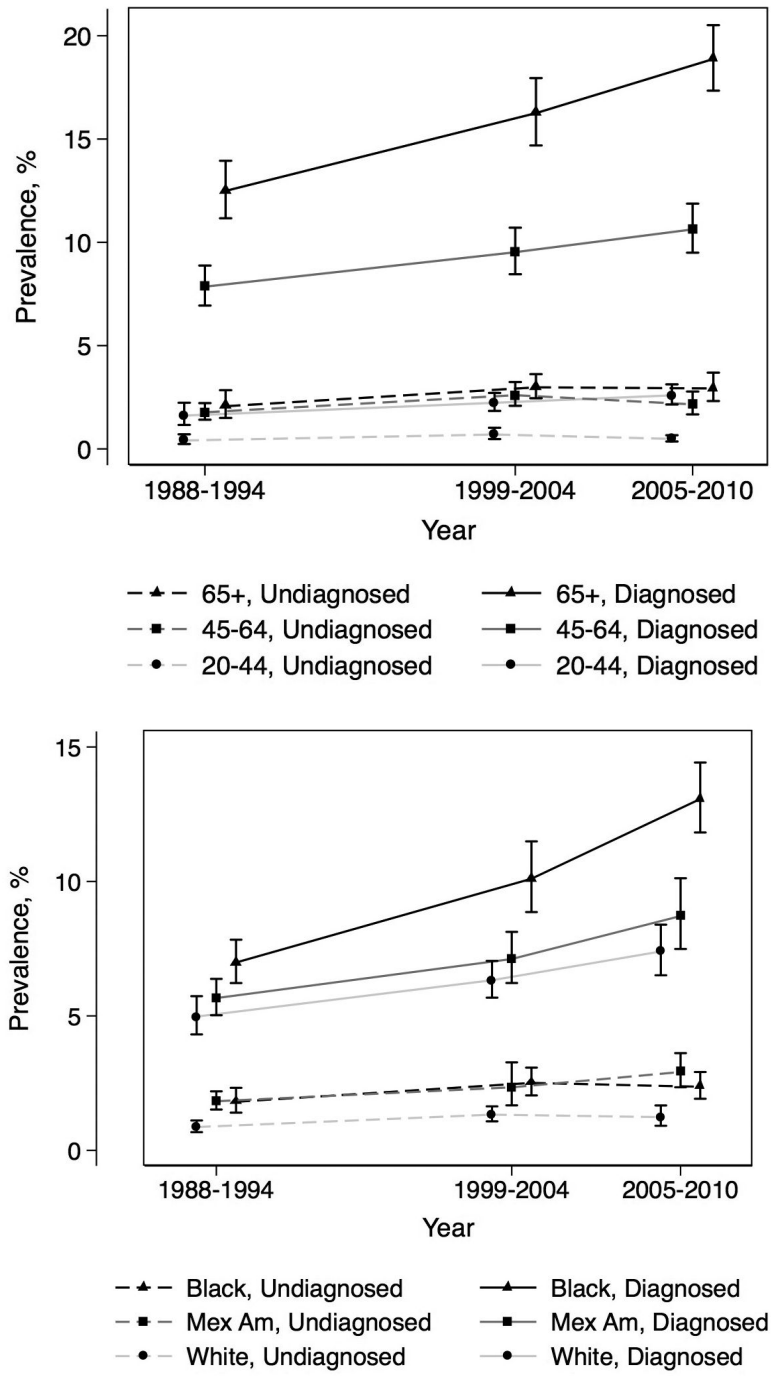

Figure 1. Trends in the prevalence of diagnosed diabetes and undiagnosed diabetes (calibrated hemoglobin A1c ≥6.5%) by age (Panel A) and race/ethnic group (Panel B), U.S. adults aged 20 years or older, NHANES 1988-1994, 1999-2004, and 2005-2010

Legend:

Abbreviations: White, Non-Hispanic White; Mex Am, Mexican-American; Black, Non-Hispanic Black

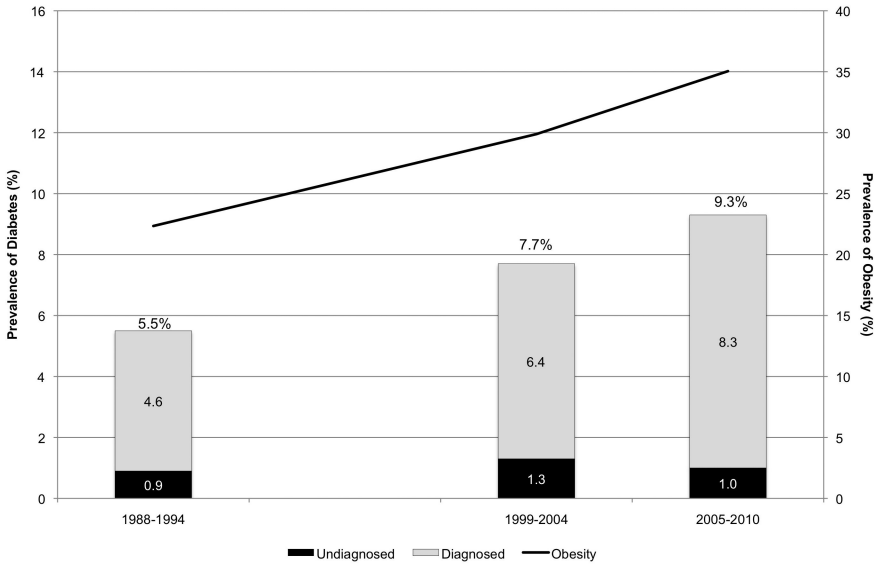

Figure 2. Prevalence of total confirmed diabetes* and obesity†, U.S. adults aged 20 years or older, NHANES 1988-1994, 1999-2004, and 2005-2010

Legend:

* "Total confirmed diabetes" was defined as diagnosed diabetes or undiagnosed diabetes with diagnostic levels of both HbA1c (≥6.5%) and fasting glucose (≥126 mg/dL).

†Obesity defined as body mass index≥30 kg/m^2; there were 601 people missing body mass index.

Prevalence estimates for total confirmed diabetes and obesity were obtained using only the subsample of participants who attended the morning fasting session (N=7,385 for 1988-94; 5,680 for 1999-2004; 6,719 for 2005-10).

The midpoint for obesity prevalence between 1988-94 and 1999-2004 was calculated as the average of the prevalence of the two time periods.

Table 1

Characteristics of adults with and without diagnosed diabetes, U.S. adults 20 or older, NHANES 1988-1994, 1999-2004, and 2005-2010

	No Diagnosed Diabetes			Diagnosed Diabetes		
	1988-94 N=14,368 Mean or % (SE)	1999-2004 N=11,404 Mean or % (SE)	2005-10 N=13,343 Mean or % (SE)	1988-94 N=1,210 Mean or % (SE)	1999-2004 N=1,322 Mean or % (SE)	2005-10 N=1,792 Mean or % (SE)
Age, years	44.3 (0.46)	45.7 (0.28)	46.2 (0.32)	60.2 (0.68)	59.4 (0.56)	59.4 (0.50)
Age 65 years or older, %	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	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						
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)
Body mass index, 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)
Body mass index category, %*						
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)
Waist Circumference, 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, %*†	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 HbA1c, %‡	5.25 (0.01)	5.35 (0.01)	5.36 (0.01)	7.31 (0.09)	7.42 (0.09)	7.07 (0.05)
Fasting plasma glucose, mg/dL§	97.3 (0.27)	97.5 (0.38)	97.8 (0.36)	181.6 (4.27)	153.9 (3.41)	150.9 (3.08)
Healthy subpopulation//						
Calibrated HbA1c, %‡	5.11 (0.01)	5.11 (0.01)	5.11 (0.01)	--	--	--
Fasting plasma glucose, mg/dL§	89.6 (0.27)	90.6 (0.39)	89.8 (0.41)	--	--	--

Abbreviations: HbA1c, hemoglobin A1c; SE, standard error

To convert glucose to mmol/L, multiply by 0.0555.

*Among persons with no diagnosed diabetes, there were 461 people missing body mass index and 1,483 missing waist circumference; among persons with diagnosed diabetes, there were 129 people missing body mass index and 319 missing waist circumference.

†Waist circumference cut-offs are gender-specific (>=102 cm for males and >=88 cm for females).

‡Results presented use calibrated HbA1c values.

§Fasting plasma glucose results were obtained from the subset of participants who attended the morning fasting session (Among persons with no diagnosed diabetes: N=6,830 in 1988-94; N=5,225 in 1999-2004; and N=5,914 in 2005-10. Among persons with diagnosed diabetes: N=555 in 1988-94; N=455 in 1999-2004; N=805 in 2005-10. Among the healthy subpopulation: N=892 in 1988-94; N=453 in 1999-2004; and N=521 in 2005-10.)

//The healthy subpopulation was limited to non-pregnant women and men aged 20-39 years without diagnosed diabetes, hypertension or cholesterol-lowering medication use, body mass index 18.5 to <25 kg/m^2, and total cholesterol<200 mg/dL. Results for the healthy subpopulation are unweighted.

Table 2

Prevalence of diagnosed diabetes, undiagnosed diabetes, pre-diabetes, and glycemic control, U.S. adults aged 20 years or older, NHANES 1988-1994, 1999-2004, and 2005-2010

	1988-94 N=15,578 % (SE)	1999-2004 N=12,726 % (SE)	2005-10 N=15,135 % (SE)
Definitions of Total Diabetes			
Diagnosed diabetes or calibrated HbA1c ≥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 fasting glucose≥126 mg/dL	7.3 (0.50)	9.4 (0.51)	10.9 (0.55)
Diagnosed diabetes or calibrated HbA1c≥6.5%	5.6 (0.43)	8.3 (0.53)	9.6 (0.44)
Diagnosed diabetes or calibrated HbA1c≥6.5% or FPG≥126 mg/dL	7.5 (0.51)	9.8 (0.52)	11.2 (0.55)
Diagnosed diabetes or both calibrated HbA1c≥6.5% and FPG≥126 mg/dL (total confirmed diabetes)[†]	5.5 (0.41)	8.0 (0.52)	9.3 (0.45)
Definitions of Undiagnosed Diabetes			
Calibrated HbA1c≥6.5%	1.1 (0.10)	1.7 (0.13)	1.5 (0.14)
Fasting Subsample[*]			
FPG≥126 mg/dL	2.8 (0.25)	2.8 (0.22)	2.6 (0.26)
Calibrated HbA1c≥6.5%	1.0 (0.12)	1.7 (0.19)	1.3 (0.16)
Calibrated HbA1c≥6.5% or fasting glucose≥126 mg/dL	2.9 (0.26)	3.1 (0.24)	2.9 (0.26)
Calibrated HbA1c≥6.5% and FPG≥126 mg/dL (confirmed undiagnosed diabetes)[†]	0.9 (0.12)	1.3 (0.17)	1.0 (0.15)
Definitions of Pre-Diabetes			
Calibrated HbA1c 5.7-6.4%	5.8 (0.35)	11.9 (0.47)	12.4 (0.42)
Fasting Subsample[*]			
FPG 100-126 mg/dL	25.2 (0.84)	26.3 (1.14)	28.7 (0.87)
HbA1c 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 HbA1c<7%	50.9 (2.57)	49.6 (2.15)	58.8 (1.71)
Calibrated HbA1c<8%	67.2 (2.21)	70.8 (1.66)	79.4 (1.33)
Currently taking diabetes medication			
Calibrated HbA1c<7%	39.7 (2.64)	43.2 (2.22)	55.1 (1.93)
Calibrated HbA1c<8%	58.9 (2.57)	67.7 (1.71)	77.6 (1.46)
Currently not taking diabetes medication			
Calibrated HbA1c<7%	82.0 (4.97)	78.3 (4.30)	82.6 (2.96)
Calibrated HbA1c<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)

	1988-94 N=15,578 % (SE)	1999-2004 N=12,726 % (SE)	2005-10 N=15,135 % (SE)
No medications	26.4 (2.02)	18.5 (1.73)	13.4 (1.36)

Abbreviations: FPG, fasting plasma glucose; HbA1c, hemoglobin A1c; SE, standard error

To convert glucose to mmol/L, multiply by 0.0555.

*Analyses incorporating fasting plasma glucose measurements were limited to the subsample of participants who attended the morning fasting session (N=7,385 for 1988-94; 5,680 for 1999-2004; 6,719 for 2005-10).

†"Total Confirmed diabetes" was defined as diagnosed diabetes or undiagnosed diabetes with diagnostic levels of both HbA1c (≥6.5%) and fasting glucose (≥126 mg/dL). "Confirmed undiagnosed diabetes" was defined as diagnostic levels of both HbA1c (≥6.5%) and fasting glucose (≥126 mg/dL) among persons without diagnosed diabetes.

Table 3

Trends in total diabetes* before and after adjustment for demographics and measures of adiposity, U.S. adults aged 20 or older

	Unadjusted†		Adjusted for age, gender and race/ethnicity†		Additionally adjusted for body mass index 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 1988-94	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 2005-10	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)

Abbreviations: OR, odds ratio; CI, confidence interval

*Diagnosed diabetes or calibrated HbA1c≥6.5%

†There were 1,978 people missing body mass index and/or waist circumference; all models above exclude persons missing these data