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Original Contribution

Prevalence of Diagnosed and Undiagnosed Type 2 Diabetes Mellitus Among US Adolescents: Results From the Continuous NHANES, 1999–2010

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Although prevalence and incidence of type 2 diabetes mellitus (T2DM) are reportedly increasing among adolescents, national data are lacking, particularly in regard to undiagnosed T2DM. To estimate the prevalence of diagnosed and undiagnosed T2DM among US adolescents, we analyzed a nationally representative cross-section of 11,888 adolescents aged 12–19 years who received a diabetes interview in the Continuous National Health and Nutrition Examination Survey during 1999–2010. Among them, a random subsample of 4,661 adolescents also had fasting blood samples collected. Persons who reported a previous diabetes diagnosis and were either taking no medication or taking an oral hypoglycemic agent (with or without insulin) were classified as having T2DM; persons who reported using insulin alone were classified as having type 1 diabetes. Undiagnosed diabetes was defined as a fasting plasma glucose concentration of ≥126 mg/dL and was assumed to be type 2. In the fasting subsample, 31 diabetes cases (types 1 and 2) were identified, representing a prevalence of 0.84% (weighted 95% confidence interval (CI): 0.51, 1.40) (276,638 cases; 95% CI: 134,255, 419,020). Estimates of the prevalences of type 1 and type 2 diabetes were 0.48% (95% CI: 0.23, 1.02) and 0.36% (95% CI: 0.20, 0.67), respectively, indicating that T2DM accounted for 43% of all cases. Further, undiagnosed T2DM prevalence was 0.12% (95% CI: 0.05, 0.31), representing 34% of T2DM cases (40,611 cases; 95% CI: 2,850, 78,373). T2DM accounts for approximately half of adolescent diabetes in the United States, and one-third of these cases are undiagnosed.

adolescents; diabetes mellitus; etiology; prevalence; undiagnosed diabetes

Abbreviations: CDC, Centers for Disease Control and Prevention; CI, confidence interval; MODY, maturity-onset diabetes of the young; NHANES, National Health and Nutrition Examination Survey; SEARCH, SEARCH for Diabetes in Youth Study; T1DM, type 1 diabetes mellitus; T2DM, type 2 diabetes mellitus.

Diabetes mellitus is a serious disease which is linked to substantial morbidity and mortality in the United States and globally (1). Type 2 diabetes mellitus (T2DM) among adolescents is particularly concerning, since recent reports suggest that early-onset T2DM is challenging to control and represents a more aggressive disease phenotype than the later-onset form (i.e., more rapid decline in β-cell function and accrual of comorbid conditions) (2–4). Therefore, increased prevalence and incidence of early-onset T2DM would portend increased health-care costs, morbidity, and premature mortality (5, 6).

Although evidence suggests that the prevalence of T2DM has been increasing among US adolescents (7–16) as a result of the overweight/obesity epidemic (17–19), there are very few reports from population-based studies that can provide reliable estimates, because the overall prevalence of adolescent diabetes remains very low (<1%) (7, 8). In the largest nationally representative sample examining T2DM prevalence in US adolescents to date, Fagot-Campagna et al. (7) reported a total of only 4 cases, 2 of which were undiagnosed, making it difficult to generate precise upper and lower prevalence bounds or to consider variation by sex or race/ethnicity. Alternatively, the SEARCH for Diabetes in Youth Study (SEARCH) has identified more than 6,000 (9) cases of diabetes in youth through an innovative study design, which has attempted to identify all cases of diabetes in defined geographic areas (20). However, the SEARCH sample was recruited

from 6 distinct geographic areas (9) that are not completely representative of the US adolescent population, and estimates of undiagnosed diabetes cannot be obtained from SEARCH.

Obtaining nationally representative, reliable prevalence estimates for undiagnosed T2DM is important because it is possible that some of the reported increase in T2DM prevalence might be due to changing diagnostic standards across time and region (diagnostic bias), as well as increased awareness resulting in surveillance bias (16). The literature on autism incidence provides a recent and compelling example of how diagnostic and surveillance bias can misrepresent secular trends in pediatric conditions (21, 22). An accurate prevalence estimate of adolescent diabetes is necessary for informing public health prevention efforts and screening policy.

The purpose of this study was to determine the prevalence of diagnosed and undiagnosed T2DM among adolescents. These results arise from 6 nationally representative serial cross-sections of US adolescents enrolled in the Continuous National Health and Nutrition Examination Survey (NHANES) during a 12-year time period from 1999 to 2010.

MATERIALS AND METHODS

The Continuous NHANES is a complex, multistage probability sample of US noninstitutionalized civilians that began in 1999. It consists of 6 unique data sets that have been generated in 2-year cycles (i.e., 1999–2000, 2001–2002, 2003–2004, 2005–5006, 2007–2008, and 2009–2010) (23). Each 2-year survey cycle examines a nationally representative sample of approximately 10,000 persons and collects a variety of health-related data via questionnaire, physical examination, and laboratory assessments. Participation rates for the 6 survey cycles have ranged from 78% to 84%.

The current analysis included 11,888 adolescents aged 12–19 years who responded to a diabetes questionnaire (the interview sample). Among these 11,888 adolescents, a randomly selected subgroup of 4,661 also provided a fasting blood sample (the fasting subsample). Therefore, all 11,888 participants responded to interviewer-administered questionnaires, while only 4,661 participants also provided a fasting blood sample. Responses to interviewer-administered questionnaires were provided by a proxy for participants under 16 years of age; all other participants provided self-report responses.

The NHANES protocol was approved by the National Center for Health Statistics institutional review board, and written informed consent was obtained from all participants.

Fasting glucose assessments

Fasting status was verified via interview prior to blood collection. During the years 1999–2004, glucose measurements for NHANES were performed by the Diabetes Diagnostic Laboratory at the University of Missouri-Columbia using the Cobas Mira Chemistry System (Roche Diagnostic Systems, Inc., Montclair, New Jersey). In 2005–2006, measurements were performed by the Fairview Medical Center Laboratory at the University of Minnesota using a Roche/Hitachi 911 Analyzer (Roche Diagnostics, Indianapolis, Indiana). In the NHANES 2007–2010 survey cycle, glucose measurements were still performed at the University of Minnesota, but the Roche Modular P Chemistry Analyzer (Roche Diagnostics) was used. In all survey cycles and laboratories, fasting glucose was measured according to a hexokinase enzymatic method (24). All glucose values measured from 2005 to 2010 were standardized to the 1999–2004 values using regression equations provided in the analytical notes of the NHANES data documentation for glucose measurement (25, 26).

Diabetes classification

Diagnosed diabetes was defined on the basis of a participant self-report of a previous diabetes diagnosis by a physician or health professional, as has been done in previous studies (7, 8). Two respondents who reported "no" or "borderline" for diabetes but reported that they were taking "diabetic pills to lower blood sugar" were conservatively classified as diabetes-free. Participants who reported either no medication use or use of any blood glucose-lowering medication (with or without insulin) were defined as having T2DM, while participants who reported only insulin use were defined as having type 1 diabetes mellitus (T1DM). This approach differs from previously used epidemiologic case definitions of diabetes (7, 8) in that participants receiving both insulin and oral hypoglycemic agents were classified as having T2DM, whereas in previous studies all subjects receiving any insulin therapy had been classified as having T1DM. Approximately 25%–30% of persons with T2DM are treated with insulin (usually along with oral hypoglycemic agents) (27, 28), while very few persons with T1DM are treated with oral hypoglycemic agents (29, 30). Therefore, our current approach, while not perfect, was less likely to underestimate the prevalence of T2DM while having little impact on the underestimation of T1DM, as previously discussed (14).

In the fasting subsample, diagnosed diabetes was defined as above (irrespective of fasting glucose values) and undiagnosed diabetes was defined by a fasting blood glucose concentration of $\geq$126 mg/dL among participants who did not report a previous diabetes diagnosis during the interview (31). All undiagnosed diabetes cases were classified as T2DM (7).

Estimates of the prevalence of diagnosed diabetes were derived from both the interview sample (diagnosed) and the fasting subsample (undiagnosed) for comparative purposes, but we based all final inferences regarding the prevalence of undiagnosed diabetes on the results obtained from the interview sample because the sample size was approximately 3 times larger, resulting in more precise estimates.

Statistical analysis

Survey procedures in SAS, version 9.3 (SAS Institute, Inc., Cary, North Carolina), were used for all analyses to obtain the correct variance estimates and corresponding 95% confidence intervals. Publicly available survey weights were generated for all 6 continuous NHANES survey cycles by the Centers for Disease Control and Prevention (CDC). These survey weights were used to create a final analysis survey weight, per the CDC protocol (32), enabling the generation of prevalence estimates and absolute counts representative of US adolescents aged 12–19 years at the midpoint of the combined 12-year survey period. Survey weights are necessary

to account for nonresponse and oversampling. For example, because NHANES oversamples participants on the basis of characteristics such as race/ethnicity, unweighted prevalence estimates for all US adolescents aged 12–19 years would be biased as a result of the overrepresentation of population subgroups. Statistical hypothesis tests were based on 2-sample *t* tests for continuous variables and on χ^2 tests for proportions. The Wilson method was used to estimate 95% confidence intervals, as the prevalence estimates were close to zero. Prevalence estimates were also provided for subgroups based on sex and race/ethnicity. Race/ethnicity was categorized as non-Hispanic white, non-Hispanic black, Mexican-American, other Hispanic, and other (including Asian/Pacific Islander, American Indian, and multiracial). Because Hispanics other than Mexican Americans were not oversampled until 2007–2008, the sample size in this group was not sufficient to provide reliable prevalence estimates; therefore, any estimates presented here should be interpreted cautiously. We opted to present estimates for this subgroup because no data on this demographic group exist to date. The prediction of undiagnosed diabetes by sex and race/ethnicity was explored using logistic regression analyses.

RESULTS

The interview sample included 11,888 adolescents aged 12–19 years who provided self-report information on diabetes status, representing 32,676,471 US adolescents. Weighted for the US population, the participants analyzed were 49% female, 61% white, 12% Mexican-American, 6% other Hispanic, 14% non-Hispanic black, and 7% other race/ethnicity and had a mean age of 15.4 years (standard error, 0.04). Among the subgroup of 4,661 adolescents (representing 32,746,826 US adolescents) who also provided fasting blood samples (the fasting sample), the mean fasting glucose concentration was 92.6 mg/dL (standard error, 0.5). The sex and race/ethnicity distributions in the fasting subsample were similar to those in the full sample (data not shown).

Diagnosed diabetes in the interview sample

The total number of diagnosed diabetes cases detected in the 6 serial cross-sections of the Continuous NHANES (1999–2010) was 58, representing 182,960 (weighted 95% confidence interval (CI): 119,963, 245,956) diagnosed cases of diabetes. The prevalence was 0.56% (95% CI: 0.4, 0.8) or 5.6 diagnosed diabetes cases per 1,000 US adolescents as of the decade's midpoint. Estimates of diabetes prevalence among males and females were 0.69% versus 0.42% ($P = 0.22$), and prevalence varied according to race/ethnicity (Table 1), although this finding was not statistically significant ($P = 0.44$).

The absolute numbers of diagnosed T1DM and T2DM cases detected were 30 and 28 (for the unweighted frequency distribution according to sex and race/ethnicity, see Web Table 1, available at http://aje.oxfordjournals.org/), representing weighted prevalence estimates of 0.38% (95% CI: 0.25, 0.58) and 0.18% (95% CI: 0.10, 0.30), respectively, and indicating that T1DM and T2DM account for 69% and 31% of diagnosed adolescent diabetes.

Only 4 persons reported using both insulin and oral medication, and they would have been defined as having T1DM according to previous methods (7, 8), but they were defined as having T2DM here. As is shown in Web Table 2, the influence of these 4 participants on the overall estimates of self-reported T1DM and T2DM was marginal; when defining the 4 participants using insulin and oral medications as having T1DM, 72% of all diabetes cases were T1DM, while 28% were T2DM. Among these 4 participants, 50% were male, 75% reported their race/ethnicity as non-Hispanic black, and 25% reported their race/ethnicity as Mexican-American. The mean age was 15.25 years (range, 13–17 years), and all 4 participants were obese (i.e., above the 95th percentile of body mass index for age according to CDC clinical growth charts).

Total (diagnosed and undiagnosed) diabetes in the fasting subsample

Prevalence estimates were higher in the fasting subsample because of undiagnosed diabetes. The overall number of diabetes cases detected was 31, representing a prevalence of 0.84% (95% CI: 0.51, 1.40) or 8.4 adolescents with diabetes per 1,000 US adolescents (for the unweighted frequency distribution by sex and race/ethnicity, see Web Table 3). The weighted prevalence estimates of T1DM and T2DM were 0.48% (95% CI: 0.23, 1.02) and 0.36% (95% CI: 0.2, 0.67), respectively. T1DM and T2DM accounted for 57% and 43% of adolescent diabetes cases, respectively. The seemingly paradoxical finding that the unweighted number of T2DM cases was larger than the unweighted number of T1DM cases, while the reverse was true of the weighted frequencies (Table 2), was due to the higher prevalence of T2DM among participants who were oversampled in various NHANES survey cycles (e.g., among Mexican Americans—an oversampled population subgroup in NHANES—the weighted estimated prevalences of T2DM and T1DM were 0.73% and 0%, respectively). Prevalence estimates by sex and race/ethnicity were similar to those in the interview sample, although there was a notable increase in the diabetes prevalence among participants reporting "other" race/ethnicity (Table 2). Among adolescents with T2DM, 34% were estimated to be undiagnosed, which represents 40,611 (95% CI: 2,850, 78,373) cases in the general US adolescent population (Table 3). Sex and racial/ethnic variations in the proportion of T2DM that was undiagnosed (Web Figure 1) were not statistically significant. In comparison with persons with T2DM, those with T1DM had lower body mass indices and were much more likely to have normal weight (Table 4).

DISCUSSION

We examined 12 years of data from the Continuous NHANES (1999–2010) to provide the first nationally representative estimates of T2DM, including undiagnosed diabetes, among adolescents in the United States. We found the total prevalence of diabetes (types 1 and 2, diagnosed and undiagnosed) to be 0.84%. The prevalence of T2DM was 0.36%, representing an estimated 119,224 cases of adolescent T2DM in the United States, 34% (>40,000 cases) of which were undiagnosed. T2DM accounted for 43% of total diabetes cases.

The current NHANES data suggest a higher prevalence of total diabetes (i.e., 0.84%) in comparison with the estimated

Table 1. Prevalence of Self-Reported Diabetes Mellitus[a] Among 11,888 US Adolescents Aged 12–19 Years, National Health and Nutrition Examination Survey, 1999–2010

	Total No. of Persons[b]	All Diabetes			Type 1 Diabetes[c]			Type 2 Diabetes[c]		
		No. of Persons[b]	%[d]	95% CI[d]	No. of Persons[b]	%[d]	95% CI[d]	No. of Persons[b]	%[d]	95% CI[d]
Total population	32,676,471	182,960	0.56	0.40, 0.79	125,422	0.38	0.25, 0.58	57,538	0.18	0.10, 0.30
Sex										
Male	16,776,646	115,851	0.69	0.44, 1.09	81,460	0.49	0.29, 0.82	34,391	0.21	0.10, 0.43
Female	15,899,824	67,109	0.42	0.23, 0.76	43,962	0.28	0.12, 0.63	23,147	0.15	0.08, 0.28
Race/ethnicity										
Non-Hispanic white	19,904,320	113,784	0.57	0.35, 0.93	86,342	0.43	0.26, 0.73	27,442	0.14	0.05, 0.35
Non-Hispanic black	4,758,796	33,470	0.70	0.44, 1.12	13,343	0.28	0.14, 0.57	20,127	0.42	0.23, 0.78
Mexican-American	3,757,873	13,807	0.37	0.20, 0.67	5,075	0.14	0.04, 0.44	8,732	0.23	0.12, 0.44
Other Hispanic	2,040,119	18,707	0.92	0.22, 3.61	18,707	0.92	0.23, 3.61	0		
Other[e]	2,215,363	3,192	0.14	0.02, 0.98	1,955	0.08	0.009, 0.88	1,237	0.06	0.004, 0.82

Abbreviation: CI, confidence interval.

[a] Respondents (adolescents aged 12–19 years) were asked, "Have you ever been told by a doctor or health professional that you have diabetes or sugar diabetes?" Adolescents who responded "yes" and reported using only insulin were defined as having type 1 diabetes; adolescents who responded "yes" and reported either no medication use or use of oral diabetic pills (with or without insulin) to lower blood sugar were defined as having type 2 diabetes.

[b] Number of noninstitutionalized US adolescents weighted for the US population. Differences from totals are due to rounding.

[c] Unweighted frequencies of observed diabetes cases by etiology in the sample were as follows: type 1 diabetes, $n = 30$; type 2 diabetes, $n = 28$.

[d] Percentage of noninstitutionalized US adolescents (and 95% confidence interval) weighted for the US population.

[e] Including Asian/Pacific Islander, American Indian, and multiracial.

prevalence of 0.41% in the Third National Health and Nutrition Examination Survey (NHANES III; 1988–1994) (7), and the proportion of total diabetes that is type 2 also appears to be higher (31% in NHANES III vs. 43% presently). However, comparisons with NHANES III estimates should be interpreted very cautiously, because the NHANES III findings were based on a total of only 13 diabetes cases, which resulted in low precision for the total diabetes prevalence estimate (reflected by a 95% confidence interval that included 0) (7). Moreover, the total number of T2DM cases detected in NHANES III was only 4 (2 undiagnosed), precluding the investigators' ability to provide a precise prevalence estimate of diagnosed or undiagnosed T2DM or to explore variation by sex or race/ethnicity (7). Therefore, it was not possible for us to compare the current NHANES data with data from NHANES III and determine whether the increased prevalence was driven by chance versus an actual increase in T2DM, T1DM, or both.

When only diagnosed diabetes was considered, we found the prevalences of total diagnosed diabetes (type 1 or type 2) and diagnosed T2DM to be 0.56% and 0.18%, respectively. These estimates were based on the interview sample as opposed to the fasting subsample, because the sample size was nearly 3-fold greater in the interview sample, which enhanced the precision of prevalence estimates. In comparison with a previous single NHANES cross-section from 1999–2002, Duncan (8) estimated the prevalence of total diagnosed diabetes (type 1 or type 2) to be 0.5% and the prevalence of diagnosed T2DM to be 0.15%—figures which are very comparable with, yet still lower than, our current estimates. The current estimates are also higher than those previously published by the SEARCH investigators (approximately 0.3%) in a similar age group (9). The increased prevalence of T2DM currently reported in NHANES 1999–2010 (12 years) in comparison with NHANES 1999–2002 or SEARCH might reflect a true increase in prevalence, which would be consistent with trends of increasing obesity and body mass index, albeit very modest ones, occurring from 1999–2000 through 2009–2010 (18). It is also possible that the higher prevalence of diagnosed T2DM observed presently reflects increased awareness and screening among clinicians, which has in turn decreased the proportion of T2DM that goes undiagnosed. Unfortunately, the very low number of undiagnosed T2DM cases observed in any specific NHANES cross-section precludes reliable estimation of secular trends in these data. A comparison of undiagnosed diabetes prevalence between NHANES 1999–2010 and SEARCH cannot be made, because SEARCH does not identify undiagnosed disease. Alternatively, while the SEARCH study is remarkable in its scope, it is not representative of all US geographic areas (9), since it would be untenable to identify all diagnosed diabetes cases in the United States. Therefore, the lower prevalence observed in SEARCH might reflect a truly lower

Table 2. Total Prevalence of All Diabetes Mellitus (Diagnosed and Undiagnosed) Among 4,661 US Adolescents Aged 12–19 Years, National Health and Nutrition Examination Survey, 1999–2010

	Total No. of Persons[a]	All Diabetes			Type 1 Diabetes[b]			Type 2 Diabetes[b]		
		No. of Persons[a]	%[c]	95% CI[c]	No. of Persons[a]	%[c]	95% CI[c]	No. of Persons[a]	%[c]	95% CI[c]
Total population	32,746,826	276,638	0.84	0.51, 1.40	157,413	0.48	0.23, 1.02	119,224	0.36	0.20, 0.67
Sex										
Male	16,790,805	160,599	0.96	0.51, 1.77	86,076	0.51	0.21, 1.22	74,523	0.44	0.19, 1.02
Female	15,956,021	116,039	0.73	0.30, 1.73	71,337	0.45	0.12, 1.60	44,701	0.28	0.13, 0.60
Race/ethnicity										
Non-Hispanic white	20,201,342	145,421	0.72	0.36, 1.42	89,249	0.44	0.18, 1.06	56,170	0.28	0.10, 0.78
Non-Hispanic black	4,760,434	35,241	0.74	0.34, 1.61	16,338	0.34	0.11, 1.05	18,904	0.40	0.14, 1.14
Mexican-American	3,732,743	27,386	0.73	0.39, 1.38	0			27,386	0.73	0.39, 1.38
Other Hispanic	1,880,888	51,826	2.75	0.60, 11.67	51,826	2.80	0.60, 11.67	0		
Other[d]	2,171,419	16,764	0.77	0.17, 3.40	0			16,764	0.77	0.17, 3.60

Abbreviation: CI, confidence interval.

[a] Number of noninstitutionalized US adolescents weighted for the US population. Differences from totals are due to rounding.

[b] Unweighted frequencies of observed diabetes cases by etiology in the sample were as follows: type 1 diabetes, $n = 10$; type 2 diabetes, $n = 21$.

[c] Percentage of noninstitutionalized US adolescents (and 95% confidence interval) weighted for the US population.

[d] Including Asian/Pacific Islander, American Indian, and multiracial.

prevalence in the geographical regions covered by the study. It is also possible that the self-reported nature of diagnosed diabetes in NHANES leads to overreporting by adolescents (or their proxies). For example, youths who were told by a health-care provider that they either had prediabetes or were at risk of developing future diabetes might have misunderstood that they actually had diabetes.

In regard to our estimate of undiagnosed T2DM, some important limitations should be noted. It is possible that our estimates were biased because we had only 1 fasting glucose

Table 3. Proportions of Diagnosed and Undiagnosed Type 2 Diabetes Mellitus Among US Adolescents Aged 12–19 Years, by Sex and Race/Ethnicity, National Health and Nutrition Examination Survey, 1999–2010

	All T2DM[a]			Diagnosed T2DM[a]			Undiagnosed T2DM[a]		
	No. of Persons[b]	%[c]	95% CI[c]	No. of Persons[b]	%[c]	95% CI[c]	No. of Persons[b]	%[c]	95% CI[c]
Total population	119,224	0.36	0.20, 0.67	78,613	0.24	0.11, 0.51	40,611	0.12	0.05, 0.31
Sex									
Male	74,523	0.44	0.19, 1.02	44,087	0.26	0.08, 0.82	30,436	0.18	0.06, 0.55
Female	44,701	0.28	0.13, 0.60	34,526	0.22	0.09, 0.53	10,175	0.06	0.01, 0.29
Race/ethnicity									
Non-Hispanic white	56,171	0.28	0.10, 0.80	44,783	0.22	0.07, 0.72	11,388	0.06	0.01, 0.40
Non-Hispanic black	18,904	0.40	0.14, 1.14	12,819	0.27	0.07, 1.07	6,084	0.13	0.03, 0.50
Mexican-American	27,386	0.73	0.40, 1.40	17,737	0.48	0.22, 1.04	9,649	0.26	0.09, 0.75
Other Hispanic	0			0			0		
Other[d]	16,764	0.77	0.17, 3.40	3,274	0.15	0.01, 2.04	13,490	0.62	0.11, 3.45

Abbreviations: CI, confidence interval; T2DM, type 2 diabetes mellitus.

[a] Unweighted frequencies of observed type 2 diabetes cases in the sample were as follows: total diabetes, $n = 21$; diagnosed type 2 diabetes, $n = 13$; undiagnosed type 2 diabetes, $n = 8$.

[b] Number of noninstitutionalized US adolescents weighted for the US population. Differences from totals are due to rounding.

[c] Percentage of noninstitutionalized US adolescents (and 95% confidence interval) weighted for the US population.

[d] Including Asian/Pacific Islander, American Indian, and multiracial.

Table 4. Characteristics[a] of 4,661 Fasting US Adolescents Aged 12–19 Years According to Diabetes Mellitus Status and Type, National Health and Nutrition Examination Survey, 1999–2010

	No Diabetes[b]			T1DM[b]			Diagnosed T2DM[b]			Undiagnosed T2DM[b]		
	Mean (SE)	Range	%	Mean (SE)	Range	%	Mean (SE)	Range	%	Mean (SE)	Range	%
Age, years	15.5 (0.05)	12–19		16.8 (0.7)	12–19		16.0 (0.6)	13–19		15.8 (0.8)	14–19	
BMI[c]	23.4 (0.1)	13–57		22.7 (1.0)	18–26		29.1 (3.3)	21–46		35.7 (3.9)	20–47	
BMI *z* score	0.6 (0.03)	−3.9 to 3.3		0.5 (0.2)	−1.4 to 1.2		1.3 (0.5)	−0.1 to 2.9		2.1 (0.4)	−0.7 to 3.0	
BMI category												
Overweight[d]			16			19			25			0
Obese[e]			18			0			36			79
Fasting plasma glucose, mg/dL	91 (0.2)	58–123		314 (46)	65–517		155 (27)	81–362		182 (14)	128–249	

Abbreviations: BMI, body mass index; SE, standard error; T1DM, type 1 diabetes mellitus; T2DM, type 2 diabetes mellitus.

[a] Weights from the National Health and Nutrition Examination Survey were used to obtain results representative of US adolescents.

[b] Unweighted frequencies of observed diabetes cases in the sample, overall and by etiology, were as follows: no diabetes, $n = 4{,}630$; type 1 diabetes, $n = 10$; diagnosed type 2 diabetes, $n = 13$; undiagnosed type 2 diabetes, $n = 8$.

[c] Weight (kg)/height (m)^2.

[d] Overweight (≥85th–94th percentile of BMI for age) was defined according to Centers for Disease Control and Prevention clinical growth charts.

[e] Obesity (≥95th percentile of BMI for age) was defined according to Centers for Disease Control and Prevention clinical growth charts.

value and no glucose challenge data, which have enhanced sensitivity for diagnosing T2DM in children (33). While our approach is commonly used in epidemiologic studies, it does not meet the specific American Diabetes Association criteria, which require repeat testing in the absence of unequivocal hyperglycemia (31). Utilization of the NHANES hemoglobin A_{1c} data might have modestly improved our sensitivity, but unfortunately there was an unexplained shift of hemoglobin A_{1c} distributions in 2007–2010 versus 1999–2006 reported in the online NHANES documentation (34), which raised as many problems as solutions for our current aims. Nevertheless, recent studies have demonstrated that fasting glucose measurement has enhanced T2DM diagnostic accuracy among youth when compared with hemoglobin A_{1c} level (33). Overestimation of undiagnosed disease is also possible if some participants did not fast, although fasting status was verified via questionnaire for all participants prior to blood collection, which minimized the potential for this bias.

There appear to be possible disparities in the prevalences of both diagnosed and undiagnosed diabetes by sex, with males having a higher prevalence of diabetes overall as well as a higher prevalence of diagnosed and undiagnosed T2DM. The results also suggested possible racial/ethnic disparities that would be consistent with diabetes trends among adults (35). However, neither the sex difference nor the racial/ethnic differences were statistically significant, which makes it possible that these variations were due to chance. Studies with higher numbers of diabetes cases will be required to definitively examine these trends.

Presently, self-reported medication use was incorporated into our definition of diabetes type. In situations where participants report use of both insulin and oral hypoglycemic agents, the best method for defining T1DM versus T2DM is unclear. We chose to define persons who reported insulin use combined with oral medication use as having type 2, whereas previous reports defined them as type 1. We believe our approach is less likely to misclassify T2DM cases as T1DM (28), with minimal risk of misclassifying T1DM cases as T2DM. Therefore, our definition probably enhances sensitivity without sacrificing specificity, and our supplemental analyses alternatively defining anyone using both medications as type 1 did not meaningfully change the results in the full sample. However, there was evidence to suggest that the method for defining diabetes type could be important among certain racial/ethnic groups, as well as among obese adolescents. Among the 4 participants who self-reported using both insulin and oral medication, 3 were non-Hispanic black, one was Mexican-American, and all 4 were obese. Future research that can inform the prevalence of combined insulin and oral medication use among persons whose diabetes type has been rigorously validated will be important to help ensure optimal and standardized definitions over time and across research settings.

While most T2DM among adolescents is related to overweight/obesity, we opted not to utilize this information in defining etiological type, because 33% of SEARCH participants with T1DM also have body mass index values at the 85th percentile or above (36). Therefore, using adiposity as an etiological criterion in an epidemiologic setting where overweight/obesity is highly prevalent would probably misclassify many cases of T1DM as T2DM and would therefore overestimate T2DM prevalence.

The lack of detailed information on diabetes etiology in NHANES also precluded the identification of maturity-onset diabetes of the young (MODY) in these data, although the influence of misclassified MODY on the current prevalence estimates is likely to have been minimal, since MODY accounts for less than 5%–10% of youth-onset diabetes (37).

Despite limitations regarding our diabetes case definition and etiology classification in addition to the inability to present reliable secular trends, we believe these data are of

high value given the fact that no other study can provide nationally representative benchmark estimates of total (diagnosed and undiagnosed) T2DM among adolescents.

We found the prevalence of T2DM during the period 1999–2010 to be 0.36% in a nationally representative sample of US adolescents, and 34% of T2DM appeared to be undiagnosed. The overall prevalence of adolescent diabetes was 0.84%, which suggests an increase in comparison with the prevalence observed in the late 1980s/early 1990s. The degree to which the apparent increase in both diagnosed and overall diabetes prevalence is attributable to diagnostic bias, surveillance bias, and/or true increases in adolescent T2DM incidence remains to be determined in future studies. Nevertheless, the data reported presently from NHANES 1999–2010 serve as an important benchmark against which future studies can be compared to better inform the burden of diabetes among adolescents, particularly as the joint pandemics of obesity and diabetes continue to evolve in the United States and globally.

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