Prevalence of Diabetes and Impaired Fasting Glucose Levels Among US Adolescents

National Health and Nutrition Examination Survey, 1999-2002

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**Objective:** To determine the current prevalence of self-reported diabetes and impaired fasting glucose levels among US adolescents.

**Design and Setting:** Cross-sectional, National Health and Nutrition Examination Survey (1999-2002).

**Participants:** A sample of 4370 adolescents (aged 12-19 years) with self-reported diabetes and a subsample of 1496 adolescents without self-reported diabetes who had fasted for at least 8 hours. Subjects who reported having diabetes and using insulin were further categorized as having type 1 diabetes, those reporting having diabetes and not using insulin as having type 2 diabetes, and those with a fasting plasma glucose level greater than or equal to 5.6 mmol/L (100 mg/dL) as having impaired fasting glucose levels.

**Main Outcome Measures:** Prevalence of self-reported diabetes, type 1 and type 2 diabetes, and impaired fasting glucose levels among US adolescents.

**Results:** In the full sample, 0.5% (95% confidence interval [CI], 0.24%-0.76%) of adolescents reported having diabetes. Of those reporting diabetes, roughly 71% (95% CI, 56%-86%) were categorized as having type 1 and 29% (95% CI, 14%-44%) as having type 2 diabetes. In the subsample, roughly 11% (95% CI, 8%-14%) had impaired fasting glucose levels. Using population-based sample weights, these proportions were equivalent to 39,005 US adolescents with type 2 diabetes and 2,769,736 with impaired fasting glucose levels.

**Conclusions:** The prevalence of type 2 diabetes and impaired fasting glucose levels is substantial among US adolescents. These estimates have important implications for public health because of the high rate of conversion from impaired fasting glucose level to type 2 diabetes in adults and the increased risk of cardiovascular disease in individuals with type 2 diabetes.

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The current estimate of the number of people in the United States with diabetes is 18.2 million, or 6.3% of the population.1 This figure includes 13 million people with diagnosed diabetes and 5.2 million with undiagnosed diabetes. About 210,000 people younger than 20 years have diabetes, and approximately 1 in every 400 to 500 children and adolescents has type 1 diabetes.1 Although type 2 diabetes is an emerging problem among youth,2-5 nationally representative data to monitor diabetes trends in this age group are not available.

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In the only population-based study of diabetes among US adolescents (aged 12-19 years) to date,6 the prevalence of diabetes was estimated at 0.41% between 1988 and 1994. Although the presence of type 2 diabetes was reported, the survey sample size was not large enough to obtain precise prevalence estimates because of the relatively low prevalence at the time of the survey. More recent reports indicate that impaired glucose tolerance is highly prevalent among overweight youth,7 and that prediabetes in youth is associated with altered fat partitioning in muscle and intraabdominal regions and the development of severe peripheral insulin resistance.8 Similarly, the metabolic syndrome is common among US adolescents9-11 and has increased significantly over the past decade.10

Because the prevalence of being overweight has continued to increase substantially over the past several decades among US children and adolescents,12,13 it is also likely that the prevalence of diabetes has increased among these youths. Further
supporting this contention, a recent report indicates that the lifetime probability of being diagnosed with diabetes is substantial for individuals born in the United States in the year 2000. The objective of this article is to present the most recent national estimates for the prevalence of diabetes and impaired fasting glucose levels among US adolescents, based on data from the 1999-2000 and 2001-2002 National Health and Nutrition Examination Surveys (NHANES).

METHODS

The NHANES design is a stratified, multistage probability sample of the civilian noninstitutionalized US population. Approximately 9965 persons aged 2 months to 85 years were studied in the NHANES 1999-2000 survey period, and 11 039 in the 2001-2002 survey period. A subsample of more than 3000 individuals from each survey was invited to attend a morning examination after fasting overnight. Fully informed consent and assent were obtained from all participants and these documents were approved by the National Center for Health Statistics’s Institutional Review Board.

Details of the NHANES protocol are available elsewhere. Briefly, blood specimens were stored frozen until they were shipped to a central laboratory for analysis. Plasma glucose levels were measured with an enzymatic technique using the hexokinase/glucose-6-phosphate dehydrogenase reaction. Whole-blood hemoglobin A1c levels were measured using fully automated glycohemoglobin analyzers (CLC330 and CLC385; Primus Corp, Kansas City, Mo) and boromate affinity high-performance liquid chromatography, serum insulin levels were measured using a double-antibody radioimmunoassay technique, and serum C-peptide levels were measured using a polyethylene glycol–accelerated double-antibody technique. Height was measured in an upright position with a stadiometer and weight was also measured in a standing position on a self-zeroing scale. The poverty-to-income ratio, a ratio of family income to poverty thresholds established by the US Census Bureau, was used as a measure of socioeconomic status.

Data from each survey were linked using a unique survey participant identifier. The full sample consisted of 4370 adolescents (aged 12-19 years) who were given a personal interview on diabetes, including use of medications and symptoms associated with diabetes. All subjects were asked the lead-in question pertaining to history of diabetes: “Have you ever been told by a doctor or health professional that you have diabetes or sugar diabetes?” Subjects with a missing response (n=1) or those who responded “borderline” (n=1) were excluded from the analyses. Thus, the only possible responses were “yes” or “no.” Pregnant women (n=101) and subjects categorized as “other Hispanics” (n=231) and “other races, including multiracial” (n=202) were also excluded from the analyses, the latter because of inadequate sample sizes for these groups. The subsample consisted of 1496 adolescents with a fasting (≥ 8 hours) glucose value recorded and who responded “no” to the lead-in question on diabetes history. Only subjects who had complete data were included in the subsample analyses.

DEFINITIONS

In the full sample, subjects who responded “yes” to the lead-in question were further categorized by specific diabetes type. Those who reported using insulin were categorized as having type 1 diabetes, and those who reported not using insulin as having type 2 diabetes. Subjects in the subsample with a fasting glucose level of less than 5.6 mmol/L (100 mg/dL) were categorized as having normal fasting glucose levels, and those with a value greater than or equal to 5.6 mmol/L (100 mg/dL) as having impaired fasting glucose levels. Using the Centers for Disease Control and Prevention growth charts for the United States in the year 2000, being overweight among adolescents was defined as having a body mass index (BMI) (calculated as weight in kilograms divided by the square of height in meters) of greater than or equal to the 85th percentile for age and sex; at risk for being overweight was defined as having a BMI value greater than or equal to the 85th percentile but less than the 95th percentile for age and sex; and normal weight was defined as having a BMI of less than the 85th percentile for age and sex.

STATISTICAL ANALYSIS

Data were analyzed using SAS statistical software (version 9.1; SAS Institute Inc, Cary, NC). The full sample was analyzed using the 4-year full sample interview weights to estimate means and 95% confidence intervals (CIs), and the masked variance units (psuedoprimary and pseudostratum sampling units) to estimate the standard error of those means. The subsample was analyzed using the 4-year fasting weights and the masked variance units. Continuous variables were presented as mean±SE. Categorical variables are presented as frequency, weighted frequency (based on sampling weights), and proportion with 95% CI. All proportions are based on a percentage of the weighted frequencies. Differences in continuous variables were tested univariately using t tests for independent samples, and prevalence values for categorical variables were compared using χ² tests for proportions. Statistical significance was established at α = .05 a priori.

The full sample included 4370 subjects, equivalent to a weighted sample of 26 649 401 adolescents, with mean age of 15.4±0.1 years. The sex distribution was roughly 48% female and 52% male, and the race distribution was 12.8% Mexican American, 16.6% non-Hispanic black, and 70.6% non-Hispanic white. The percentage of self-reported diabetes in the total sample and self-reported diabetes by sex and race are presented in Table 1. There was no difference (P=.94) in age among subjects reporting “yes” for having diabetes (15.4±0.6 years) or “no” to the lead-in question on diabetes history (15.4±0.1 years). There was a significant association between self-reported diabetes and sex, and between self-reported diabetes and race (P<.001).

The percentage of diabetes type in the overall sample and the percentage of diabetes by sex and race are presented in Table 2. There was no difference (P = .34) in age among subjects categorized as having type 1 (15.8±0.6 years) or type 2 (15.4±0.0 years) diabetes. Among subjects categorized as having type 1 diabetes (n=10; estimate =95.066), 5.9% also reported taking oral agents (n=2; estimate =56.35). Among subjects categorized as having type 2 diabetes (n=8; estimate =39.005), 31.3% reported taking oral agents (n=1; estimate =12.265). There was a significant association between diabetes type and sex, and between diabetes type and race (P<.001).

The subsample included 1496 subjects, equivalent to a weighted sample of 24 883 638 adolescents, with a mean age of 15.4±0.1 years. The sex distribution was roughly 49% female and 51% male and the race distribution was 11.6% Mexican American, 15.3% non-Hispanic black, and
73.1% non-Hispanic white. The proportion of subjects in the subsample (by fasting glucose level group and by sex and race) is presented in Table 3. Age was not different \( (P = .83) \) among subjects having normal \( (15.4 \pm 0.1 \) years) and impaired \( (15.4 \pm 0.3 \) years) fasting glucose levels. There was a significant association between fasting glucose group and sex, and between fasting glucose group and race \( (P < .001) \).
Demographic and clinical measures for the subjects in the subsample are presented in Table 4. Fasting glucose, hemoglobin A1c, insulin, and C-peptide levels were significantly different (P<.01) between groups, whereas BMI and the poverty-to-income ratio were not different between groups (P>.05). There was a significant association (P<.001) between the fasting glucose group and BMI status, expressed as a percentile for age and sex.

This study provides the most recent national estimates of the prevalence of diabetes and impaired fasting glucose levels among US adolescents. Eighteen subjects in the full sample had self-reported diabetes. Using population-based sample weights, this was equivalent to 134,071 US adolescents aged 12 to 19 years with self-reported diabetes, or 0.5% of all people in this age group. This estimate is reasonable and consistent with the estimate that 206,000 (0.25%) people younger than 20 years have diabetes, as reported elsewhere.1

The absolute percentage of self-reported diabetes was higher among boys than girls (eg, 54% vs 46%, respectively), and among non-Hispanic white youth than non-Hispanic black and Mexican American youth. This pattern was consistent when self-reported diabetes was expressed as a function of the number of individuals in a given sex or race with diabetes by the total number of individuals of that sex or race in the population. For example, about 0.53% of all adolescent boys in the population had self-reported diabetes (73,011 cases of self-reported diabetes among boys divided by 13,894,184 boys in the population), compared with about 0.48% of all adolescent girls in the population. Similarly, about 0.56% of all non-Hispanic white youth in the population had self-reported diabetes (104,907 cases of self-reported diabetes among non-Hispanic white youth divided by 18,805,881 non-Hispanic white youth in the population) compared with 0.42% of all non-Hispanic black and 0.31% of all Mexican American adolescents in the population. These percentages are different among adults (≥20 years), where the total prevalence of diabetes by race/ethnicity is highest among non-Hispanic black adults (11.4%), followed by non-Hispanic white (8.4%) and Hispanic/Latino adults (8.2%).1

By examining information on self-reported diabetes and medication use, subjects were further categorized as having type 1 or type 2 diabetes. In this analysis, 10 subjects with self-reported diabetes were categorized as having type 1 diabetes, whereas 8 subjects were categorized as having type 2 diabetes. Using population-based sample weights, this was equivalent to 95,066 adolescents with type 1 diabetes and 39,005 adolescents with type 2 diabetes. Thus, among the US adolescents in the population who have diabetes, 71% have type 1 diabetes and 29% have type 2 diabetes. Type 2 diabetes was once a condition only seen in adults, but this study provides evidence to support recent clinic-based reports and regional studies2-5,18 that point to an emerging problem of type 2 diabetes among US youth.

The absolute percentage of type 1 diabetes was higher among boys than girls, while the absolute percentage of type 2 diabetes was higher among girls than boys. About 78% of all adolescent boys in the population with self-reported diabetes had type 1 diabetes (36,743 cases of type 1 diabetes among boys divided by 47,311 boys in the population with self-reported diabetes), and 22% of all adolescent boys in the population with self-reported diabetes had type 2 diabetes. On the other hand, 63% of all

| Table 4. Clinical Measures for 1496 US Adolescents by Fasting Glucose Level Status* |
|----------------------------------------|----------------------------------------|----------------------------------------|
|                                      | Total (N = 1496)                       | NFG (n = 1318)                         | IFG (n = 178)                         |
| Weighted frequency                    | 24,885,638                            | 22,115,903                             | 2,769,736                             |
| Age ± SE, y                           | 15.4 ± 0.1                            | 15.4 ± 0.1                            | 15.4 ± 0.3                            |
| Glucose ± SE, mmol/L (mg/dL)          | 5.1 ± 0.02 (91.5 ± 0.3)               | 5.0 ± 0.02 (89.9 ± 0.3)†              | 5.8 ± 0.03 (104.7 ± 0.6)             |
| Percent hemoglobin A1c ± SE           | 5.10 ± 0.02                           | 5.09 ± 0.02†                          | 5.24 ± 0.03†                          |
| Insulin ± SE, U/mL                    | 12.4 ± 0.3                            | 11.8 ± 0.3†                           | 17.6 ± 1.5†                           |
| C-peptide ± SE, nmol/L               | 0.68 ± 0.01                           | 0.66 ± 0.01†                          | 0.83 ± 0.05†                          |
| PIR ± SE                              | 2.7 ± 0.1                             | 2.7 ± 0.1                             | 2.7 ± 0.1                             |
| BMI ± SE, kg/m²                       | 23.0 ± 0.2                            | 22.8 ± 0.2                            | 23.9 ± 0.6                            |
| Weighted Frequency (Percentage [95% CI]) |                                      |                                       |                                       |
| BMI status‡                          |                                       |                                       |                                       |
| Normal (<85th percentile)            | 16,937,629                            | 15,337,016 (69.35 [66.37-72.33])      | 1,600,614 (57.79 [45.76-69.82])      |
| Overweight (≥95th percentile)        | 4,342,742                             | 3,680,851 (16.64 [14.39-18.90])       | 661,891 (23.90 [15.88-31.91])        |

Abbreviations: BMI, body mass index (calculated as weight in kilograms divided by the square of height in meters); CI, confidence interval; IFG, impaired fasting glucose; NFG, normal fasting glucose; PIR, poverty-to-income ratio.

*Respondents were aged 12 to 19 years. Data are from the 1999-2000 and 2001-2002 National Health and Nutrition Examination Surveys. Values are expressed as mean ± SE, except for Centers for Disease Control–defined BMI percentiles which are expressed as frequency, weighted frequency (based on sample weights), and percentage with 95% CIs.

†Indicates significant difference between groups at P<.01.

‡Indicates significant association between row and column variables by χ² test (P<.001).
adolescent girls in the population with self-reported diabetes had type 1 diabetes and 37% had type 2 diabetes. The absolute percentage of type 1 and type 2 diabetes was higher among non-Hispanic white than non-Hispanic black and Mexican American youth. About 76% of all non-Hispanic white youth in the population with self-reported diabetes had type 1 diabetes (79,477 cases of type 1 diabetes among non-Hispanic white youth divided by 104,907 non-Hispanic youth in the population with self-reported diabetes), and 24% of all non-Hispanic white adolescents in the population with self-reported diabetes had type 2 diabetes. This is in contrast to 62% of all non-Hispanic black youth in the population with self-reported diabetes having type 1 diabetes and 38% having type 2 diabetes, and 37% of all Mexican American youth in the population with self-reported diabetes having type 1 diabetes and 63% having type 2 diabetes. Thus, the relative percentage of type 2 diabetes is highest among Mexican American adolescents, followed by non-Hispanic black and non-Hispanic white adolescents.

There were 178 subjects in the subsample who had impaired fasting glucose levels. Using population-based sample weights, this was equivalent to 2,769,736 US adolescents with impaired fasting glucose levels, or about 11% of all people in this age group. The number of adolescents with impaired fasting glucose levels in this study is about 9 percentage points higher than previously reported (1.76%).

However, at the time of that report the cut-point value for defining impaired fasting glucose levels was 6.1 mmol/L (110 mg/dL). The much higher prevalence of impaired fasting glucose levels in this study was entirely a result of the lowered cut-point value. There were only 24 subjects in the subsample who had impaired fasting glucose levels when using a value of 0.61 mmol/L (110 mg/dL). This was equivalent to 379,729 US adolescents with impaired fasting glucose levels, or about 1.5% (95% CI, 0.82-2.23) of all people in this age group. Sinha et al found that 21% of overweight adolescents aged 11 to 18 years had impaired glucose tolerance. However, it is important to note that their subjects were at high risk for diabetes, impaired fasting glucose levels, and/or impaired glucose tolerance as the entire sample had a BMI at or above the 95th percentile for age and sex. Although BMI was not different between the normal and impaired fasting glucose level groups in the present study when expressed on an absolute basis (ie, 22.8 vs 23.9, respectively), more than 15% of all adolescents with impaired fasting glucose levels were overweight (661,891 cases of impaired fasting glucose levels among overweight adolescents divided by 4,342,742 overweight adolescents in the population) compared with 14.1% who were at risk for being overweight and 9.5% who were normal weight. This was also the case when a cut-point value of 6.1 mmol/L (110 mg/dL) was used; roughly 2.4% of overweight or at risk for being overweight adolescents had impaired fasting glucose levels compared with 1.1% of normal-weight youth. Thus, impaired fasting glucose levels were more common among overweight youth on a relative basis in the present study, regardless of the cut-point value used. The distribution of impaired fasting glucose levels as a function of BMI percentile is shown in the Figure.

Impaired fasting glucose levels were more common in boys than girls (14.8% of all boys in the population vs 7.3% of all girls in the population). In contrast, Fagot-Campagna et al reported that slightly more girls than boys had impaired fasting glucose levels. Impaired fasting glucose levels were more common among Mexican American adolescents at 15.3% (439,035 cases of impaired fasting glucose levels among Mexican American adolescents divided by 2,877,893 Mexican American adolescents in the population) compared with 11.3% of all non-Hispanic white and 7.4% of all non-Hispanic black adolescents. These data are consistent with a previous report demonstrating large differences in the prevalence of impaired fasting glucose levels among the major race groups.

As expected, there were differences in several physiologic measures of glucose metabolism between adolescents categorized as having normal or impaired fasting glucose levels. By definition (as previously mentioned in the “Methods” section), fasting plasma glucose would have to be different between groups; levels were about 5.0 mmol/L (90 mg/dL) in those with normal fasting glucose levels and 5.8 mmol/L (105 mg/dL) in those with impaired fasting glucose levels. Fasting plasma insulin levels were also higher in subjects with impaired vs normal fasting glucose levels. This is consistent with the findings of Weiss et al who found significantly higher fasting insulin levels in young subjects with impaired glucose tolerance compared with matched youth with normal glucose tolerance. The impaired glucose tolerance group in that study also exhibited marked insulin resistance (measured by the glucose clamp technique) and higher fasting C-peptide levels. Similarly in this study, C-peptide levels were higher in the impaired vs normal fasting glucose group. Together these findings suggest that abnormalities in glucose metabolism (that manifest as impaired fasting glucose levels and/or impaired glucose tolerance) in adolescents are primarily owing to insulin resistance and not an absolute reduction in β-cell function.

A few limitations of this study are worth noting. First, the population estimate of diabetes prevalence among US adolescents aged 12 to 19 years was based on a self-
reported history of diabetes in a small number of subjects (n=18). The sample weights used to calculate population totals in the current NHANES are based on population estimates that incorporate the US Census Bureau counts from the year 2000. The population estimate for US adolescents aged 12 to 19 years in the full sample was 26,649,401 based on sample weights applied to 4370 subjects. Although this population estimate is lower than the actual population of US adolescents (aged 12-19 years), which is about 32,012,573 based on the monthly postcensal civilian noninstitutional population (April 1, 2000, to June 1, 2000), the population in this study was estimated after applying several exclusion criteria. Using all subjects (aged 12-19 years) in the current NHANES without applying the exclusion criteria gives a sample of 4902 adolescents, equivalent to a population of 32,113,578. Thus, the population of US adolescents in this study is quite reasonable and consistent with US Census data. Likewise, the population estimate of diabetes prevalence among US adolescents provided in this study (134,071 or 0.5% of all people in this age group) also appears quite reasonable, as evidenced by the report discussed previously where it was estimated that 206,000 (0.25%) people younger than 20 years have diagnosed diabetes.

Similar to this limitation, the classification of subjects into a specific type of diabetes was also based on self-reported use (or nonuse) of insulin, which was not optimal. However, this was the best method of doing so based on the available data in the current NHANES. It has been proposed that approximately 1 in every 400 to 500 children and adolescents younger than 20 years has type 1 diabetes. Based on the results of the present study, approximately 1 in every 338 adolescents aged 12 to 19 years has type 1 diabetes and 1 in every 823 has type 2 diabetes. Thus, type 1 diabetes remains the major contributor to the diagnosis of diabetes in a pediatric population. Finally, the classification of and prevalence estimate for impaired fasting glucose levels were determined from one measurement. Although only subjects who had fasted for at least 8 hours were included in this analysis, confirmation of these findings may require an additional fasting blood draw and/or an oral glucose tolerance test. Despite these limitations, this study does provide evidence that the prevalence of type 2 diabetes and impaired fasting glucose level is substantial among US adolescents. These findings have important implications for public health because of the high rate of conversion from impaired fasting glucose level to type 2 diabetes in adults, and the increased risk of cardiovascular disease among adults with type 2 diabetes. These data provide a compelling rationale for prevention of diabetes and impaired fasting glucose levels among adolescents in the US population.

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