BASIC SCIENCE RESEARCH

Relationship Between Obesity and Diabetes in a US Adult Population: Findings from the National Health and Nutrition Examination Survey, 1999–2006

Ninh T. Nguyen · Xuan-Mai T. Nguyen · John Lane · Ping Wang

Abstract

Background Obesity is one of the most important modifiable risk factors for the prevention of type 2 diabetes. The aim of this study was to examine the prevalence of diabetes with increasing severity of obesity and the distribution of HbA1c levels in diabetics participating in the latest National Health and Nutrition Examination Survey (NHANES).

Methods Data from a representative sample of adults with diabetes participating in the NHANES between 1999 and 2006 were reviewed. The prevalence of diabetes and levels of fasting glucose, insulin, c-peptide, and HbA1c were examined across different weight classes with normal weight, overweight, and obesity classes 1, 2, and 3 were defined as body mass index (BMI) of <25.0, 25.0–29.9, 30.0–34.9, 35.0–39.9, and equal to 40.0, respectively. The distribution of HbA1c levels among adults with diabetes was also examined.

Results There were 2,894 adults with diabetes (13.6%) among the 21,205 surveyed participants. Among the adults with diabetes, the mean age was 59 years, the mean fasting glucose was 155±2 mg/dl, and the mean HbA1c was 7.2%; 80.3% of diabetics were considered overweight (BMI≥25) and 49.1% of diabetics were considered obese (BMI≥30).

The prevalence of adults with diabetes increased with increasing weight classes, from 8% for normal weight individuals to 43% for individuals with obesity class 3; the distribution of HbA1c levels were considered as good (<7.0%) in 60%, fair (7.0–8.0%) in 17%, and poor (>8.0%) in 23%. The mean fasting glucose and HbA1c levels were highest for diabetics with BMI <25.0, suggesting a state of higher severity of disease. Mean insulin and c-peptide levels were highest for diabetics with BMI=35.0, suggesting a state of insulin resistance.

Conclusions In a nationally representative sample of US adults, the prevalence of diabetes increases with increasing weight classes. Nearly one fourth of adults with diabetes have poor glycemic control and nearly half of adult diabetics are considered obese suggesting that weight loss is an important intervention in an effort to reduce the impact of diabetes on the health care system.

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Introduction

The crude prevalence of total diabetes in adult's age equal to 20 years is 9.6% or 20.4 million in the US and many diabetic individuals are obese [1]. Obesity is one of the most important modifiable risk factors for the prevention of type 2 diabetes; however, obesity is an epidemic in the US. Recent data from the National Health and Nutrition Examination Survey (NHANES) in 2003–2004 indicate that among adults aged 20 to 39 years, 28.5% are obese while 36.8% of adults aged 40 to 59 years and 31.0% of those aged 60 years or older are obese, defined as a body mass index (BMI) of 30.0 or higher [2]. Similarly, during a

20-year period (1976–2006), the mean BMI among adults with type 2 diabetes increased from 29.2 to 34.2 kg/m [2] [3]. Excess weight has been shown to be associated with an increased prevalence of type II diabetes, gastroesophageal reflux, hypertension, dyslipidemia, and certain cancers and both obesity and diabetes are associated with an increased risk for mortality, particularly from cardiovascular disease [4–6]. The aim of this study was to (1) determine the prevalence of obesity and the state of glycemic control among diabetics and (2) examine the association between obesity and diabetes in a large cohort of US individuals participating in the 1999 to 2006 NHANES.

Subjects and Methods

Study Population

The NHANES survey is conducted by the National Center for Health Statistics, which is part of the Centers for Disease Control and Prevention. The NHANES provides cross-sectional data on the health and nutrition of the US population. The survey examines a nationally representative complex, multistage probability sample of about 5,000 US civilians each year, located within 15 counties across the country. The NHANES survey consists of an extensive health information interview, a complete physical examination, and extensive laboratory testing. The physical examinations are performed in a mobile examination center. Data from the four latest NHANES surveys were merged for analysis (1999–2000, 2001–2002, 2003–2004, and 2005–2006).

Data files extracted for this study included demographic information, systolic blood pressure measurements, medical disease history, smoking history, and laboratory measures (lipid profile and fasting glucose, insulin, c-peptide, and hemoglobin A1C levels). Height and weight were measured using standardized protocols. Participants were considered to have diabetes mellitus if they were told by their doctor they have diabetes, had a fasting plasma glucose concentration of 125 mg/dL, had a hemoglobin A1C level of 6.0%, or use anti-diabetic medication(s) such as insulin or oral hypoglycemic agents.

Definition of Obesity

BMI was calculated as weight in kilograms divided by the square of height in meters. The National Heart, Lung, and Blood Institute's definition for overweight and obesity were used to categorize the degree of obesity. A BMI <18.5 was categorized as *underweight*; a BMI between 18.5 and 24.9 was categorized as *normal weight* class; a BMI between 25.0 and 29.9 was categorized as *overweight*; a BMI between 30.0 and 34.9 was categorized as *obesity class 1*; a

BMI between 35.0 and 39.9 was categorized as *obesity class 2*; and a BMI ≥40.0 was categorized as *obesity class 3*. In this study, we did not differentiate between *normal weight* and *underweight* classes.

Endpoints

We categorized adults with diabetes according to increasing weight classes and also analyzed the levels of fasting glucose, insulin, c-peptide, and hemoglobin A1C across the classes of obesity. Among individuals with diabetes, the levels of HbA1c was categorized as good (<7.0%), fair (7.0–8.0%), and poor control (>8.0%) [7].

Statistical Analysis

All statistical analyses were conducted in SAS 9.1 (SAS Institute Inc., Cary, NC). Due to the NHANES' complex probability sampling of the US population, sample weights, stratification, and clustering of the sampling design were incorporated into all SAS survey procedures to ensure the correct estimation of standard errors, confidence intervals, and *P* values. An 8-year sample weight was created according to the NHANES analytic guidelines for the combined 1999–2006 data by assigning one half of the 4-year weight for 1999–2002 if a participant was sampled in 1999–2002 and assigning one fourth of the 2-year weight for those sampled in 2003–2006. The stratification and clustering variables were used in all analyses. Statistical significance was set at *P* values <0.05.

Results

Table 1 lists the demographics of the study population from 1999 to 2006 according to BMI. There were 2,894 adults with diabetes (13.6%) among 21,205 surveyed participants. Among adults with diabetes, there were 596 individuals with a BMI <25.0; 902 individuals with a BMI of 25.0–29.9; 710 individuals with a BMI of 30.0–34.9; 399 individuals with a BMI of 35.0–39.9; and 314 individuals with a BMI equal to 40.0. The prevalence of diabetes was lowest for the group with BMI <25.0 (8%). The prevalence of diabetes almost doubled between normal weight vs. overweight class (8% vs. 15%). The prevalence of diabetes continues to increase with the increasing class of obesity and was highest for class 3 obesity (43%).

Among adults with diabetes, the prevalence of individuals considered as overweight or higher (BMI≥25) was 80.3%; and the prevalence of obesity or higher (BMI=30) was 49.1%. For the entire cohort of adults with diabetes, the mean hemoglobin A1C level was 7.2±0.0 and the levels were highest for individuals with BMI <25.0. Table 2 lists

Table 1 Characteristics among adults with diabetes according to weight classes, NHANES 1999–2006

Weight Classes

	Normal weight	Overweight	Obesity class 1	Obesity class 2	Obesity class 3	Overall diabetic	Non-diabetic
No. of adults with diabetes	569	902	710	399	314	N=2,894	N=18,311
Prevalence of diabetes (%)	8	15	23	33	43	13.6	
Age (years)	62±0.9	62±0.6	59±0.7	56±0.7	51±1.0	59±0.5	44±0.3
Gender							
Male	311	526	342	176	108	1,463	8,662
Female	258	376	368	223	206	1,431	9,649
Diabetic medication (%)	61	69	71	72	71	68	–

the changes in levels of hemoglobin A1C, glucose, insulin, and c-peptide according to weight classes: the mean fasting glucose level was 155±2 mg/dl and the levels were highest for individuals with BMI <30.0; the mean insulin level was 22±1.0 µU/ml and the levels were highest for individuals with BMI equal to 40.0; the mean c-peptide level was 1.2±0.0 nmol/l and the levels were highest for individuals with BMI equal to 40.0.

Categories of levels of hemoglobin A1C among diabetic individuals are depicted in Table 3. Of the adults with diabetes, good glycemic control (hemoglobin A1C less than 7.0%) was observed in 60%; adequate control (hemoglobin A1C between 7.0% and 8.0%) was observed in 17%; and poor control (hemoglobin A1C >8.0%) was observed in 23%.

Discussion

The major finding of this study is the clear association between obesity and diabetes in a large, representative sample of the US population. In this cross-sectional survey of adults with diabetes, the lowest prevalence for diabetes was found in individuals with normal weight (BMI <25.0). The prevalence of diabetes increased throughout the range of obesity classes. Nearly a quarter of adults with diabetes

have poor glycemic control and nearly half of the individuals with diabetes are considered obese.

The prevalence of diabetes from our study is similar to the findings from Cowie and colleagues who reported the crude prevalence of total diabetes in adults age=20 years was 9.6% with another 3.5% of adults at high risk for diabetes with hemoglobin A1C between 6.0% and 6.5% [1]. The prevalence of obesity among diabetic in our study is much higher than the reported prevalence of obesity in the general US adult population. In our study, the prevalence of obesity among adults with diabetes was 49.1% while Flegal and colleagues reported the prevalence of obesity was 32.2% among US adult men and 35.5% among adult women [8]. The glycemic control for individuals with diabetes is improving during the past decade. Saaddine et al. reported that the hemoglobin A1C level between 6% and 8% increased from 34.2% in 1998–1994 to 47.0% in 1999–2002 [9]. In our study, the proportion of individuals with hemoglobin A1C level between 6% and 8% was 77%. Similarly, the mean hemoglobin A1C level among individuals with diabetes was reported by Hoerger and colleagues to decrease from 7.82% in 1999–2000 to 7.18% in 2003–2004. The mean hemoglobin A1C level in our study was 7.2% [10].

In this study, we also found the mean fasting glucose and HbA1c levels were highest for diabetics with BMI <25.0,

Table 2 Changes in hemoglobin A1C, glucose, insulin, and c-peptide levels among adults with diabetes according to weight classes, NHANES 1999–2006

Weight classes

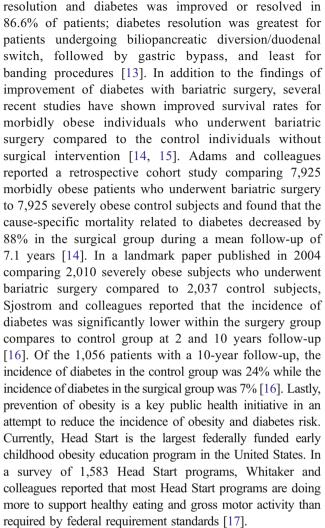|	Normal weight	Overweight	Obesity class 1	Obesity class 2	Obesity class 3	Overall diabetic	Non-diabetic
Hemoglobin A1C (%)	7.4±0.1	7.2±0.1	7.2±0.1	7.0±0.1	7.1±0.1	7.2±0.0	5.2±0.0
Fasting Glucose (mg/dl)	157±5.9	164±5.2	156±4.4	143±4.1	148±4.2	155±2.3	95±0.3
Insulin (µU/ml)	16±1.4	21±2.5	23±1.2	24±2.0	29±2.4	22±1.0	11±0.2
C-peptide[a] (nmol/l)	1.0±0.1	1.1±0.1	1.2±0.1	1.4±0.1	1.6±0.1	1.2±0.0	0.8±0.0

[a] Only 1999–2004

Table 3 Categories of hemoglobin A1C levels among adults with diabetes, NHANES 1999–2006

Hemoglobin A1C levels	Frequency of adults with diabetes $N=2,894$
<6%	461 (16%)
6–6.5%	819 (28%)
6.5–7%	448 (15%)
7–7.5%	290 (10%)
7.5–8%	208 (7%)
>8%	668 (23%)

suggesting a state of higher severity of disease. Mean insulin and c-peptide levels were highest for diabetics with BMI equal to 35.0, suggesting a state of insulin resistance. These results may suggest that more diabetics within normal weight range have type 1 classification and diabetes in the obese are mostly type 2 with associated insulin resistance. Type 2 diabetes account for 90–95% of those with diabetes and encompasses individuals who have insulin resistance and usually have relative insulin deficiency.

The finding of a high prevalence of obesity in adults with diabetes from this study suggests that more effort should be taken to combat obesity since obesity is a modifiable risk factor for the development of diabetes. These efforts should include prevention of obesity in combination with medical and surgical treatments of obesity. The look AHEAD trial is one of the largest trials of intentional weight loss in diabetics. This is a multi-centered, randomized, controlled trial of 5,145 individuals with type 2 diabetes with BMI >25 who were randomized to undergo intensive lifestyle intervention compared with diabetes support and education (control group). Participants randomized to lifestyle intervention lost an average of 8.6% of their initial weight compared to 0.7% in the control group [11]. A greater proportion of the individuals in the lifestyle intervention group had reduction in diabetes, hypertension, and lipid-lowering medications. The mean hemoglobin A1C level improved significantly more in the lifestyle intervention than control participants [11]. Bariatric surgery has also been shown to improve and even induce remission of diabetes in the morbidly obese. In a large study on 240 patients with diabetes or have impaired fasting glucose levels, Schauer et al. [12] reported that resolution of diabetes was achieved in 83% of patients and patients with a short duration of the disease (<5 years), mildest form of diabetes, and the greatest weight loss were more likely to achieve complete remission of diabetes. In a meta-analysis of 19 studies and 11,175 patients on the effect of bariatric surgery on diabetes, Buchwald et al. reported that 78.1% of diabetic patients had complete

resolution and diabetes was improved or resolved in 86.6% of patients; diabetes resolution was greatest for patients undergoing biliopancreatic diversion/duodenal switch, followed by gastric bypass, and least for banding procedures [13]. In addition to the findings of improvement of diabetes with bariatric surgery, several recent studies have shown improved survival rates for morbidly obese individuals who underwent bariatric surgery compared to the control individuals without surgical intervention [14, 15]. Adams and colleagues reported a retrospective cohort study comparing 7,925 morbidly obese patients who underwent bariatric surgery to 7,925 severely obese control subjects and found that the cause-specific mortality related to diabetes decreased by 88% in the surgical group during a mean follow-up of 7.1 years [14]. In a landmark paper published in 2004 comparing 2,010 severely obese subjects who underwent bariatric surgery compared to 2,037 control subjects, Sjostrom and colleagues reported that the incidence of diabetes was significantly lower within the surgery group compares to control group at 2 and 10 years follow-up [16]. Of the 1,056 patients with a 10-year follow-up, the incidence of diabetes in the control group was 24% while the incidence of diabetes in the surgical group was 7% [16]. Lastly, prevention of obesity is a key public health initiative in an attempt to reduce the incidence of obesity and diabetes risk. Currently, Head Start is the largest federally funded early childhood obesity education program in the United States. In a survey of 1,583 Head Start programs, Whitaker and colleagues reported that most Head Start programs are doing more to support healthy eating and gross motor activity than required by federal requirement standards [17].

Our study shows a clear association between obesity and diabetes, using a large nationwide database. However, there are notable limitations in the use and interpretation of this observational data. The NHANES survey is a series of cross-sectional analyses of the US population. Therefore, longitudinal data across study years is not provided, and no temporal analyses can be conducted. As with all survey data, there are inherent limitations in the collection methods, which can lead to sampling error, measurement error, and reporting bias.

Conclusions

In summary, our findings demonstrate an association between increasing obesity classes and increasing preva-lence of diabetes. Nearly one fourth of adults with diabetes have poor glycemic control and nearly half of adult diabetics are considered obese based on an 8-year period (1999–2006) data from a cross-sectional representative of the US adult population. An important implication from

this study is that medical or surgical weight loss and obesity prevention are important interventions in an effort to reduce the impact of diabetes on the health care system.

Conflict of interest   The authors declared that there are no conflicts of interest.

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