Diabetes Care In Press, published online March 19, 2007

EFFECT OF BODY MASS INDEX ON LIFETIME RISK FOR DIABETES MELLITUS IN THE UNITED STATES

K.M. Venkat Narayan, M.D., James P. Boyle, Ph.D., Theodore J. Thompson, M.S., Edward W. Gregg, Ph.D., David F. Williamson, Ph.D.

Received for publication 19 December 2006 and accepted in revised form 8 March 2007.

Affiliation of All Authors:
Centers for Disease Control and Prevention
National Center for Chronic Disease Prevention and Health Promotion
Division of Diabetes Translation

Corresponding Author:
K.M. Venkat Narayan, Hubert Professor of Global Health & Epidemiology
Emory University
Atlanta, GA 30322
email: kmvnarayan@sph.emory.edu

Additional information for this article can be found in an online appendix at http://care.diabetesjournals.org.

ABSTRACT

OBJECTIVE At birth, the lifetime risk of developing diabetes is 1 in 3, but lifetime risks across body mass index (BMI) categories are unknown. We estimated BMI-specific lifetime diabetes risk for the U.S. and age-, sex-, ethnicity-specific subgroups.

RESEARCH DESIGN & METHODS National Health Interview Survey data (n=780,694, 1997-2004) were used to estimate age-, race-, sex-,and BMI-specific prevalence and incidence of diabetes in 2004. U.S. Census Bureau age-, race-, and sex-specific population and mortality rate estimates for 2004 were combined with two previous studies of mortality to estimate Diabetes-BMI-specific mortality rates. These estimates were used in a Markov model to project lifetime risk of diagnosed diabetes by baseline age, race, sex, and BMI.

RESULTS Lifetime diabetes risks (percent) at age 18 increased from 7.6, to 70.3 between underweight and very obese men, and from 12.2, to 74.4 for women. The lifetime risk difference was lower at older ages. At age 65, compared with normal-weight males, lifetime risk differences (percent) increased from +3.7 to +23.9 percentage points, between overweight and very obese men, and from +8.7 to 26.7 percentage points for women. BMI's impact on diabetes duration also decreased with age.

CONCLUSIONS Overweight, and especially obesity, particularly at younger ages, substantially increases lifetime risk of diagnosed diabetes, while their impact on diabetes risk, life expectancy, and diabetes duration diminishes with age.

The prevalence of diagnosed diabetes among U.S. adults has risen twofold in the past 40 years and 75 percent during the past 25 years.[1,2] The lifetime risk of diabetes in the United States in 2000 was 33 percent for males and 39 percent for females, and was even higher among U.S. minority groups.[3] Body mass index (BMI, kg/m^2) is a powerful and modifiable risk factor for diabetes.[4,5] However, the impact of BMI on the lifetime risk of diabetes has not been evaluated, and no data are available on the comparative lifetime risks of diabetes across categories of BMI. Since lifetime risk estimates are easily understood measures of the impact of disease in individuals,[6-7] they have been used in public education campaigns for disease prevention.[10-14] Lifetime risk estimates for diabetes according to BMI would be valuable for (a) communicating an individual's risk of diabetes given his/her BMI and (b) identifying groups of individuals who would benefit most from primary prevention.

In this paper, we estimate the lifetime risk of diabetes (risk from age 18 until death or age 85 years) by baseline age, race, sex, and BMI for the U.S. population, and present the results in a form suitable for communication with individuals at risk and with policy-makers.

METHODS

We calculated prevalence and incidence rates for year 2004 from the nationally representative U.S. NHIS data.[8-11] Multi-year data (1997-2004) were modeled to improve precision of estimates for 2004. The NHIS is an ongoing, continuous, nationwide, cross-sectional survey of the U.S. non-institutionalized population. The NHIS uses a multistage, probability sampling strategy to select households and individuals each year; between 1997 and 2004, 301,840 households and 780,694 individuals participated, and in 2004 alone, 36,579 households and 94,460 individuals participated. The overall response rate varies annually, but is approximately 90 percent.

Prevalence was assessed from the answer to the question, "Have you EVER been told by a doctor or health professional (other than during pregnancy, if female) that you have diabetes or sugar diabetes?" Incidence was assessed from age at the time of survey and answer to the question, "How old were you when a doctor FIRST told you that you had diabetes or sugar diabetes?" We calculated the number of years each person had been diagnosed with diabetes by subtracting the age at which they were diagnosed from their current age. Adults who had a value of zero were identified as having been diagnosed with diabetes within the last year; half of the adults who had a value of one were classified as having been diagnosed with diabetes within the last year. Self-reported weight and height were used to calculate BMI.

There were 15,843 prevalent cases of diagnosed diabetes among the 242,957 respondents and 1514 incident cases among the 228,628 non-diabetic respondents, aged 18-84 years, in the NHIS for 1997-2004. We used Bayesian hierarchical logistic regression[12] with random intercepts by calendar year to estimate diabetes prevalence and incidence as a function of age (18 through 84 years in 1-year intervals), race/ethnicity (non-Hispanic white, non-Hispanic black, Hispanic, other), sex, and BMI (underweight: <18.5; normal weight: 18.5-<25; overweight: 25-<30; obese: 30-<35; very obese: ≥ 35). To derive 2004 age-, race/ethnicity-, sex-, BMI category-, and diabetes-specific mortality rates, we used the following additional sources: 1) U.S. Census Bureau 2004 population and mortality rates by age, race/ethnicity, and sex[13]; 2) NHIS estimates of BMI prevalence by age group, race/ethnicity, and sex; 3) age group- and sex-specific relative risk estimates of death attributable to diabetes[14]; and 4) age group- and BMI-specific relative risk estimates of death.[15]

Markov Chain Model

Markov chain models simulate the progression of individuals through mutually exclusive disease states. Transitions between states take place at discrete intervals, and the number of individuals who move from one state to another during each cycle is determined by transition probabilities. (Detail of model and methods available from authors and found in the online appendix at http://dx.doi.org/10.2337/dc06-2544). For each race/ethnicity-sex-BMI combination, we estimated three age-specific 1-year transition probabilities for non-diabetic individuals up through age 84: 1) the probability of remaining non-diabetic, 2) the probability of becoming diabetic, and 3) the probability of dying without diabetes. We estimated two probabilities for individuals who have developed diabetes: 1) the probability of remaining diabetic (for this analysis we assumed that once diagnosed, diabetes was not reversible), and 2) the probability of dying with diabetes.

Using these probabilities in a Markov chain model,[16] we estimated the following for each race/ethnicity, sex, and BMI category: 1) the remaining lifetime risk for diabetes among people not diabetic at a specific "baseline" age, 2) the average remaining lifetime, and 3) the average duration of diabetes. The Markov chain model presented here can be considered an extension of the life-table technique. It begins with age-specific transition rates for a given time period and then assumes that this schedule of rates is in operation for the lifetime of a hypothetical birth cohort. This cohort is "aged" year by year to produce remaining lifetime risks for diabetes at each age, assuming that the age-specific transition rates do not change. We estimated 40 sets of parameters and the associated Markov chains corresponding to the race/ethnicity-sex-BMI combinations. We calculated all races/ethnicities estimates (Table) by weighting the race/ethnicity-specific values by the proportions of non-diabetic individuals in the 2004 U.S. population.

RESULTS

Remaining Lifetime Risk by BMI

Lifetime diabetes risk increases with baseline BMI in both genders and at every baseline age (Figure 1). At age 18, for males, the remaining lifetime diabetes risk (percent) ranged from 7.6 for those with BMI <18.5 to 70.3 for those BMI >35; and for females, the remaining lifetime risk ranged from 12.2 to 74.4 for baseline BMIs of <18.5 and >35, respectively. The increase in remaining lifetime diabetes risk by BMI, however, is less steep at older baseline ages. At age 65, the remaining lifetime risk (percent) ranged from 2.2 to 34.7 for males with BMIs of <18.5 and >35, respectively, and from 3.7 to 36.0 for females with BMIs of <18.5 and >35, respectively.

At age 18, compared with normal weight, the absolute increase in lifetime risk for males were 9.9, 37.2, and 50.5 percentage points, for overweight, obese, and very obese, respectively; and for females were 18.3, 37.5, and 57.3 percentage points, respectively. By comparison, at age 65, compared with normal weight, lifetime risk increased for males by only 3.7, 18.8, and 23.9 percentage points, for overweight, obese, and very obese, respectively, and for females by only 8.7, 18.0, and 26.7 percentage points. The remaining lifetime risk for diabetes was generally higher among minority groups in both genders and at all ages and baseline BMI strata (Tables 1-2).

Expected years with and without diabetes

The average number of years of life remaining with and without diabetes by gender, baseline age, and BMI are shown in Figure 2. Women, on average, have both longer life expectancies and spend more years with diabetes. There is a U-shaped association between BMI and life expectancy in men and women at all baseline ages, with lowest life expectancy among people with BMI <18.5 and those with BMI ≥35. For example, remaining life expectancy at age 18 is 53.5 years and 47.9 years for males with BMI <18 and ≥35, respectively, and 57.9 and 53.5 years, respectively, for females. The impact of BMI on life expectancy and years spent with diabetes decreases with age. Because of earlier onset of disease, the number of expected years with diabetes is longer with increasing BMI at all baseline ages and in both genders. The impact of BMI on expected years with diabetes, however, decreases with increasing age.

COMMENT

Taken as a whole, our data suggest that adult lifetime risk of diabetes is most strongly affected by BMI of 30 and above, and that the impact of BMI, expressed in terms of absolute risk of diabetes, diminishes with increasing age at risk. Our data also underscore the strong impact of obesity on diabetes-associated morbidity and mortality, but the impact of BMI on expected years with diabetes and on life expectancy also decreases with age.

Although the lifetime risk of diabetes is directly related to BMI, the incremental increase in absolute risk is larger between overweight and obese people than between normal-weight and overweight people. These results are consistent with the findings that people with BMI of 30 and above have a clearly elevated risk of death.[15, 17] Furthermore, recent analyses of national diabetes trends also indicate that the substantial majority of the secular increase in diabetes has occurred in people with BMI of 30 and above.[18]

These estimates of lifetime risk for diabetes must be carefully interpreted. The lifetime risk estimates are for an "average person" in the U.S. population in 2004. The level of diabetes risk factors, especially obesity, genetic background, diet, physical activity, and socioeconomic factors, may raise or lower the lifetime risks away from the average for an individual.

Our data on diagnosed diabetes and BMI were based on self-report. The accuracy of self-reporting for diabetes is reasonably high in population surveys; self reported diabetes has high specificity and positive predictive value but low sensitivity.[19,20] When comparing self-reported to measured weight and height, heavier persons tend to under-report their weight more than leaner persons, and shorter persons tend to over-report their height.[21] The magnitude of reporting error depends on the mode of assessment, however. For example, when prevalence estimates for obesity were compared it was found that bias in self-reported weight was larger in telephone interviews than in-person interviews.[22] In the setting of rigorous in-person interviews, as in NHIS, it has been shown that relationships with serum glucose and other physiologic measures are equally strong for self-reported and measured weight and height.[23]

We assumed that diabetes incidence rates would be constant over the remaining lifetime of the cohort, even though obesity is increasing rapidly in the United States.[24] The incidence of diabetes may also consequently increase in the future[25-26]. An additional factor that may limit the accuracy of our projections is the projected increase in life expectancy, particularly for US ethnic minority groups,[27] which will also increase the average lifetime risk for diabetes in the total U.S. population. Our estimates, however, are based on age-, sex-, race/ethnicity-, and BMI-specific diabetes incidence and mortality rates. Another limitation is that we did not have BMI-specific data on life expectancy for people with diabetes and we had to use the relative risks of BMI on mortality for the general population in our estimations. Finally, we have computed remaining lifetime risk based on the BMI at one point in time. BMI, however, generally increases with age until the fifth and sixth decades of life and decreases thereafter.[28] Although it is difficult to predict the magnitude and direction of bias attributable to use of a single BMI value, we may have under-estimated risk attributable to BMI in our study. In younger adults, a single BMI value may lead to an under-estimation of their risk of future diabetes because they will likely continue to gain weight for several decades. For older adults, a single BMI value may also lead to an under-estimation of their remaining lifetime risk because it will not reflect the preceding decades of exposure to BMI levels that were likely elevated prior to experiencing age-related weight loss.

The data used for our estimates did not differentiate between type 1 and type 2 diabetes. However, type 2 diabetes accounts for up to 95 percent of cases.[29] Among children, however, type 1 diabetes poses a greater risk, but we have defined lifetime risk as the risk of diabetes from age 18 years to death or age 85 years. Although the accuracy of our estimates depends on the accuracy of the relative risks for death from diabetes and of BMI that we used, we believe that the age-specific relative risk estimates we used closely reflect those of people with diabetes in the United States, and the age- and sex-specific estimates of relative risk we used are consistent with recent estimates from a National Health and Nutrition Examination Survey (NHANES II) mortality study and with those from previous studies.[30,31] If the true age-specific relative risks of death from diabetes are higher than the values we used, then the duration with diabetes will be less, but the precise impact on lifetime risk of diabetes is not clear.

Unlike estimates of lifetime risks reported for other diseases and conditions—based on local or regional epidemiological cohort studies of disease incidence—our estimates are based on nationally representative data. Cohort studies are subject to several biases, including volunteer bias for healthy participants and temporal trends within a cohort may also confound the estimation of lifetime risks. Our method of estimation of lifetime risk allows more accurate inference to the general population than methods based on the experience of subjects followed in cohort studies.

Major clinical trials have shown that diabetes can be delayed or prevented among people at high risk.[5] Our findings on the lifetime risk by BMI point to people with BMI of 30 and above as an important sub-group for targeted diabetes prevention efforts. This is particularly true among people 65 or older, who are at increased risk of diabetes primarily because of age. Our analyses also confirm the large marginal increase in expected years with diabetes and on life years lost from diabetes among people with BMI 30 and above and the rather smaller impact among people with BMI 25-30, compared with normal-weight people. Although obesity appears to have a much more pronounced impact on risk of diagnosed diabetes than overweight, there is concern about young persons who begin adulthood in the overweight category. This is because young adults who are already overweight are substantially more likely to become obese earlier in adulthood than their normal weight peers.

People with BMI of 30 and above are at substantially heightened lifetime risk of diabetes, excess years with diabetes, and excess life years lost to diabetes. If this heightened risk can be communicated in a way people can readily understand, they may get motivated. Estimates of lifetime risks may help this process.

REFERENCES

1. Gregg EW, Cadwell BL, Cheng YJ, Cowie CC, Williams DE, Geiss L et al. Trends in the prevalence and ratio of diagnosed to undiagnosed diabetes according to obesity levels in the U.S. Diabetes Care. 2004;27:2806-12.
2. http://www.cdc.gov/diabetes/statistics/index.htm
3. Narayan KM, Boyle JP, Thompson TJ, Sorensen SE, Williamson DF. Lifetime risk of diabetes mellitus in the United States. JAMA 2003;290:1884-90.
4. Ford ES, Williamson DF, Liu S. Weight change and diabetes incidence: findings from a national cohort of US adults. Am J Epidemiol 1997;146:214-22.
5. Diabetes Prevention Program Research Group. Reduction in the incidence of type 2 diabetes with lifestyle intervention or metformin. N Engl J Med 2002;346:393-403.
6. Phillips K, Glendon G, Knight JA. Putting the risk of breast cancer in perspective. N Engl J Med 1999;340:141-44.
7. Sasieni PD, Adams J. Standardized lifetime risk. Am J Epidemiol 1999;149:869-75.
8. National Center for Health Statistics. 1990 National Health Interview Survey [database on CDROM]. CD-ROM Series 10, No. 4. SETS Version 1.21. Washington, DC: U.S. Government Printing Office; 1993.
9. Botman SL, Moore TF, Moriarity CL, Parsons VL. Design and estimation for the National Health Interview Survey, 1995-2004. Vital Health Stat 2000;2(130).
10. U.S. Department of Health and Human Services. Summary Health Statistics for U.S. Children: National Health Interview Survey, 1998. Atlanta: Centers for Disease Control and Prevention; 2002. Available at www.cdc.gov/nchs/data/series/sr_10/sr10_208.pdf.
11. www.cdc.gov/pub/Health_Statistics/NCHS/Dataset_Documentation/NHIS/2000/srvydesc.pdf
12. Gelman A, Carlin JB, Stern HS, Rubin DB. Bayesian Data Analysis. 2nd ed. Boca Raton, FL: Chapman & Hall/CRC;2004.
13. Bureau of the Census. Component assumptions of the resident population by age, sex, race/ethnicity, and Hispanic origin: lowest, middle, and highest series, 1999 to 2100. Washington DC: U.S. Census Bureau; 2000.
14. Tierney EF, Geiss LS, Engelgau MM., et al. Population-based estimates of mortality associated with diabetes: use of a death certificate check box in North Dakota. Am J Public Health 2001;91:84-92.
15. Flegal KM, Graubard BI, Williamson DF, Gail MH. Excess deaths associated with underweight, overweight, and obesity. JAMA 2005;293:1861-67.
16. Hoel PG, Port SC, Stone CJ. Introduction to stochastic processes. Boston: Houghten Mifflin Company; 1972.
17. Gu D, He J, Duan X, Reynolds K, Wu X, Chen J, Huang G, Chen C, Whelton PK. Body weight and mortality among men and women in China. JAMA 2006;295:776-783.
18. Gregg EW, Cheng YJ, Thompson TJ, Narayan KM, Williamson DF. The contributions of changes in prevalence of overweight, obesity, and severe obesity to the increase in diabetes prevalence in the U.S.: 1976-2004. (Submitted)
19. O'Connor PJ, Rush WA, Pronk NP, Cherney LM. Am J Man Care 1998;4:335-42.
20. Saydah SH, Geiss, 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. Ann Epidemiol 2004; 14:507-16.

21. Rowland ML. Self-reported Weight and Height. Am J Clin Nutr 1990;52:1125-33.
22. Majid Ezzati M, Martin H, Skjold S, Vander Hoorn S, Murray CJL. Trends in national and state-level obesity in the USA after correction for self-report bias: analysis of health surveys. J R Soc Med 2006;99:250–257.
23. McAdams MA, Van Dam RM, and Hu FB. Comparison of Self-reported and Measured BMI as Correlates of Disease Markers in U.S. Adults. Obesity. 2007;15:188 –196
24. Flegal KM, Carroll MD, Ogden CL, Johnson CL. Prevalence and trends in obesity among US adults, 1999-2000. JAMA 2002;288:1723-27.
25. Leibson CL, O'Brien PC, Atkinsin E, Palumbo PJ, Melton III LJ. Relative contributions of incidence and survival to increasing prevalence of adult-onset diabetes mellitus: a population-based study. Am J Epidemiol 1997;146:12-22.
26. Burke JP, Williams K, Gaskill SP, Hazuda HP, Haffner SM, Stern MP. Rapid rise in the incidence of type 2 diabetes from 1987 to 1997: results from the San Antonio Heart Study. Arch Intern Med 1999;159:1450-6.
27. National Center for Health Statistics. Health, United States, 2002. Available at www.cdc.gov/nchs/hus.htm
28. Williamson DF, Kahn HS, Remington PL, Anda RF. The 10-year incidence of overweight and major weight gain in United States adults. Arch Int Med 1990;150:665-672.
29. Harris MI. Summary. In: Diabetes in America. 2nd ed. Washington, DC: Government Printing Office; 1995:1-14. NIH Publication No. 95-1468.
30. Gu K, Cowie CC, Harris MI. Mortality in adults with and without diabetes in a national cohort of the U.S. population, 1971-1993. Diabetes Care 1998;21:1138-45.
31. Jagger C, Goyder E, Clarke M, Brouard N, Arthur A. Active life expectancy in people with and without diabetes. J Public Health Med 2003;25:42-46.

Figure 1. Remaining Average Lifetime Risk of Diabetes by Age and BMI among Women (Panel A) and Men (Panel B).

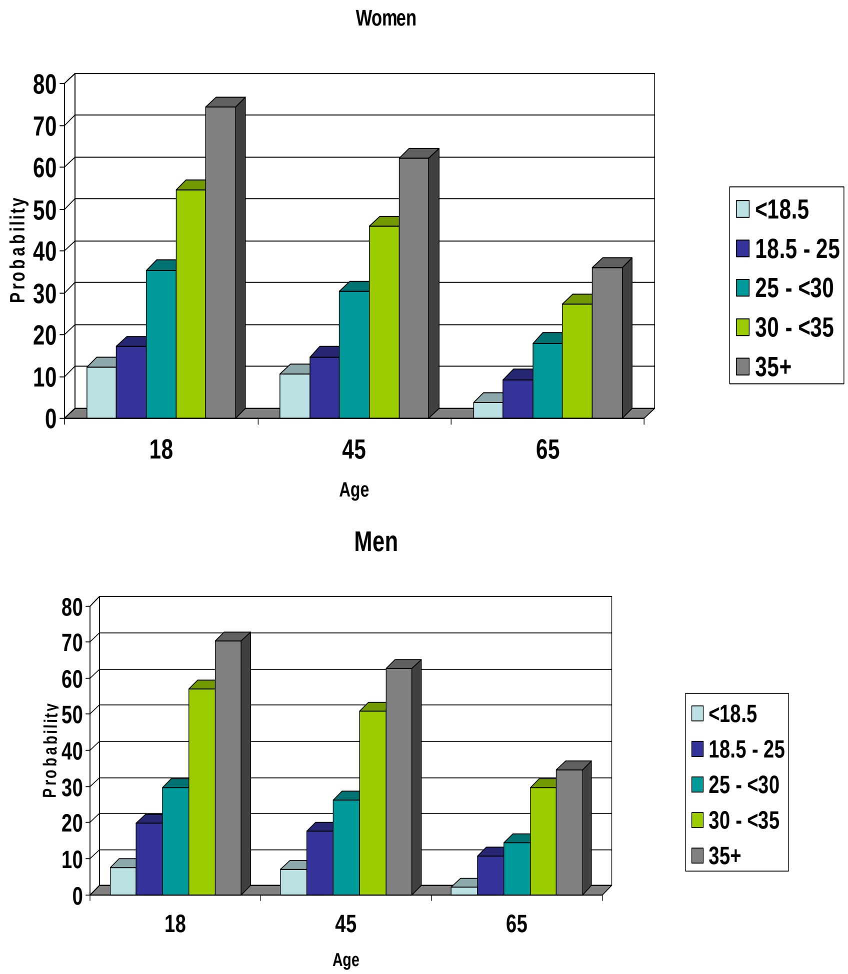
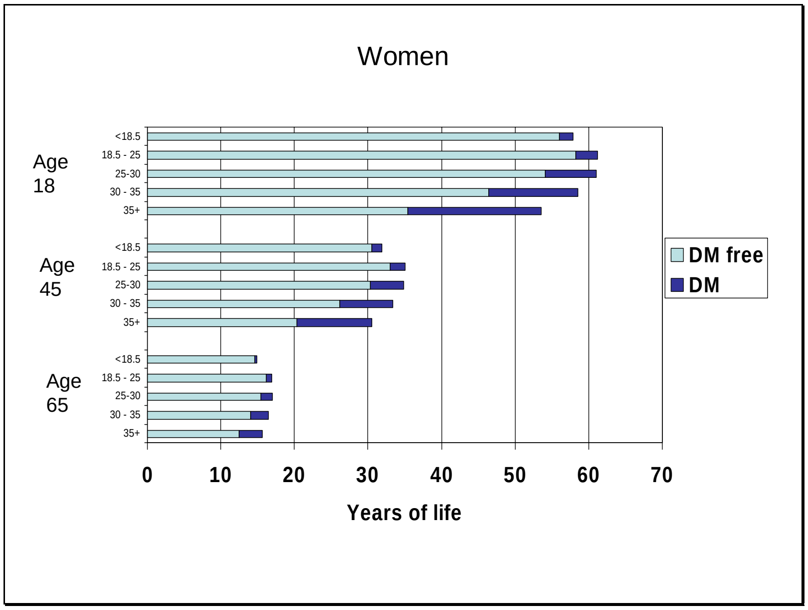


Figure 2. Average Number of Years of Life Remaining with and without Diabetes, According to Baseline Age and BMI among Women (Panel A) and Men (Panel B)



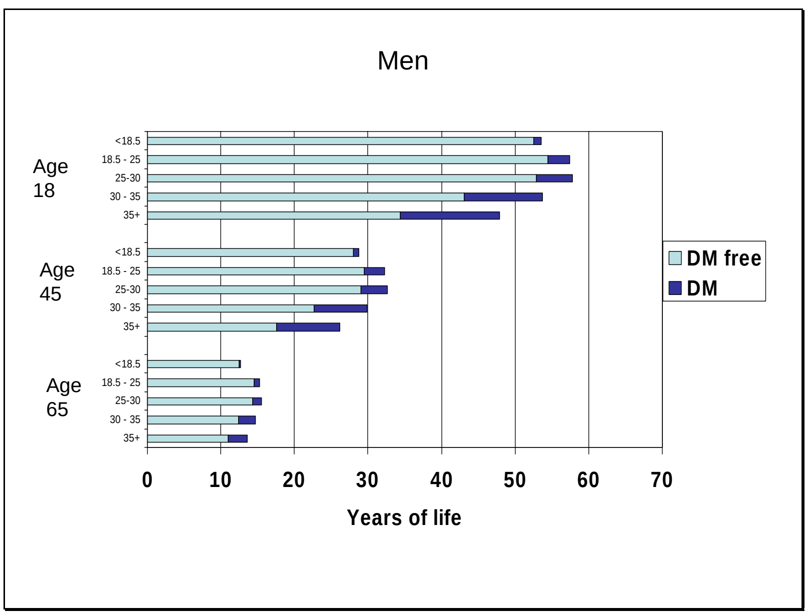


Table: Remaining Lifetime Risk of Developing Diabetes By Baseline BMI and Age

Baseline Age (Years)	BMI Group Kg/m^2	Remaining Lifetime Risk (95% Bayesian CI) %							
		Non-Hispanic							
		White		Black		Hispanic		Total	
		Male	Female	Male	Female	Male	Female	Male	Female
18	<18.5	6.2	9.8	9.0	14.9	9.7	15.5	7.6 (.2, 25.9)	12.2 (4.0, 24.4)
	18.5-<25	16.9	14.5	21.4	18.4	25.0	21.5	19.8 (16.1, 23.8)	17.1 (14.2, 20.4)
	25-<30	25.5	30.7	33.1	39.3	36.9	43.4	29.7 (25.9, 33.7)	35.4 (31.3, 20.4)
	30-<35	51.8	48.8	61.3	60.1	68.1	66.0	57.0 (51.4, 62.6)	54.6 (49.2, 60.3)
	35+	66.1	69.3	72.9	79.8	81.1	86.0	70.3 (63.9, 76.5)	74.4 (69.1, 79.3)
45	<18.5	6.0	9.1	9.2	14.1	9.3	14.0	6.9 (.1, 23.8)	10.6 (3.1, 22.2)
	18.5-<25	15.9	13.2	20.7	16.7	23.3	18.9	17.7 (14.2, 21.5)	14.7 (12.1, 17.7)
	25-<30	23.7	27.5	31.7	35.6	33.8	38.0	26.2 (22.7, 30.0)	30.4 (26.5, 34.7)
	30-<35	47.5	42.2	59.2	53.4	62.9	56.4	50.9 (45.1, 56.9)	45.8 (40.3, 51.7)
	35+	59.4	58.4	71.0	71.2	75.6	74.5	62.7 (55.2, 69.8)	62.2 (55.9, 68.4)
65	<18.5	2.1	3.5	2.5	4.2	3.0	4.9	2.2 (.0, 8.7)	3.7 (.7, 9.4)
	18.5-<25	10.2	9.0	10.3	8.7	14.0	11.9	10.8 (8.2, 13.7)	9.3 (7.4, 11.7)
	25-<30	13.8	17.3	14.4	17.5	18.6	22.5	14.5 (11.7, 17.6)	18.0 (14.9, 21.6)
	30-<35	28.3	26.3	29.8	26.9	37.2	33.8	29.6 (23.8, 36.1)	27.3 (22.0, 33.1)
	35+	33.2	34.9	35.2	35.7	43.6	44.3	34.7 (25.8, 44.5)	36.0 (27.8, 45.0)