

Prevalence of Gestational Diabetes Mellitus Detected by the National Diabetes Data Group or the Carpenter and Coustan Plasma Glucose Thresholds

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OBJECTIVE — In 2000, the American Diabetes Association proposed the adoption of the Carpenter and Coustan criteria for diagnosis of gestational diabetes mellitus (GDM). The Carpenter and Coustan cutoffs are lower than the previously recommended National Diabetes Data Group (NDDG) values and would result in higher prevalence of GDM. Our aim is to estimate the magnitude of change in prevalence of GDM using the Carpenter and Coustan thresholds as compared with the NDDG thresholds by age and ethnicity.

RESEARCH DESIGN AND METHODS — Cross-sectional study of 28,330 women aged 14–49 years who gave birth in 1996 and were members of the Northern California Kaiser Permanente Medical Care Program. Age, ethnicity, screening, and diagnostic test results were assessed from computerized hospitalization and laboratory systems.

RESULTS — A total of 26,481 (94%) women were screened using a 50-g, 1-h oral glucose tolerance test, and 4,190 women underwent a diagnostic 100-g, 3-h oral glucose tolerance test after an abnormal screening. Overall, the GDM prevalence among screened women was 3.2% (95% CI 3.0–3.4) by NDDG and 4.8% (95% CI 4.5–5.1) by Carpenter and Coustan criteria, and based on either threshold, it increased with age ($P < 0.001$). The age-adjusted GDM prevalence by NDDG and Carpenter and Coustan criteria, respectively, was 5.0 and 7.4% in Asians, 3.9 and 5.6% in Hispanics, 3.0 and 4.0% in African-Americans, and 2.4 and 3.8% in whites. Proportional increments were larger in women aged <25 years (70%) and in whites (58%).

CONCLUSIONS — The prevalence of GDM increased, on average, by 50% with use of the Carpenter and Coustan thresholds. Relative increments were greater in low-risk age and ethnic groups. This information would be useful for clinical settings in predicting cost of GDM based on demographic characteristics of the population.

Diabetes Care 25:1625–1630, 2002

Gestational diabetes mellitus (GDM), defined as diabetes first discovered or with onset during pregnancy, is associated with increased risk of several adverse infant and maternal outcomes, and its clinical recognition can reduce these risks (1–3). However, understanding the extent of the prevalence of GDM

and the associated complications is hindered by the lack of homogeneity in the diagnostic criteria used in previous studies and by changes over time in the recommended diagnostic glucose values (4).

In 1964, O'Sullivan and Mahan (5) suggested using pregnancy glucose values obtained during a 100-g, 3-h oral glucose

tolerance test (OGTT) to diagnose GDM. In this landmark study, 752 women underwent a 100-g, 3-h OGTT during the second or third trimester of pregnancy. Blood glucose values obtained during this test were measured using the Somogyi-Nelson technique (a chemical method), and each blood glucose measurement ≥ 2 SDs above the mean was considered abnormal. These threshold values were set based on optimizing predictive ability for subsequent development of maternal diabetes in the nonpregnant state among a second cohort of 1,013 women.

In the years following the O'Sullivan and Mahan study, most laboratories switched from using venous whole-blood samples to using plasma or serum samples when analyzing blood glucose levels. Therefore, in 1979, the National Diabetes Data Group (NDDG) (6) recommended adjusting the diagnostic thresholds upward (by $\sim 15\%$) to reflect this change. The resulting values were recommended by the American Diabetes Association (ADA) as diagnostic cut points for GDM until 1999 (7).

However, in 1982, Carpenter and Coustan (8) published a different set of interpretations of the O'Sullivan and Mahan criteria based on the fact that by the late 1970s, a new enzymatic method had replaced the Somogyi-Nelson technique to measure plasma glucose levels. The Somogyi-Nelson technique did not entirely eliminate the measurement of nonglucose substances as in the enzymatic method. Therefore, the Carpenter-Coustan criteria subtracted 0.28 mmol/l (5 mg/dl) from the original O'Sullivan and Mahan threshold before adding the 14% to compensate for the change from whole blood to plasma. These changes resulted in lower diagnostic plasma glucose thresholds compared with the NDDG thresholds.

In 2000, the ADA revised the recommendation for the GDM diagnostic criteria and proposed the adoption of the Carpenter-Coustan thresholds instead of

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Received for publication 5 February 2002 and accepted in revised form 8 May 2002.

Abbreviations: ADA, American Diabetes Association; GDM, gestational diabetes mellitus; KPMCP, Kaiser Permanente Medical Care Program; NCKP, Northern California Kaiser Permanente; NDDG, National Diabetes Data Group; OGTT, oral glucose tolerance test.

A table elsewhere in this issue shows conventional and Système International (SI) units and conversion factors for many substances.

the NDDG thresholds (9). The rationale for revising downward the glucose threshold for the diagnosis of GDM also included data from small studies (1), suggesting the possibility that plasma glucose levels lower than the NDDG thresholds may be associated with some increase in risk of perinatal complications.

The new criteria based on lower threshold plasma glucose values inevitably result in a higher prevalence of GDM. However, the magnitude of this increment across age and ethnic groups with different risk of carbohydrate intolerance is unknown. The purpose of this study is to evaluate the magnitude of change in prevalence of GDM using the O'Sullivan and Mahan glucose thresholds modified by Carpenter-Coustan, as compared with those modified by the NDDG, and to assess how this change varies by age and ethnicity. The study was conducted in the 26,481 women who gave birth in 1996, who were screened for GDM, and who were members of the Kaiser Permanente Medical Care Program (KPMCP) of Northern California. To our knowledge, this is the first population-based study of GDM prevalence by both NDDG and Carpenter-Coustan thresholds among a large multiethnic cohort.

RESEARCH DESIGN AND METHODS

The KPMCP of Northern California is a large group practice prepaid health plan that in 1996 provided comprehensive medical services to ~2.7 million members in a 14-county region in Northern California (or ~25–30% of the surrounding population). The Kaiser Permanente membership closely approximates the population living in the same geographic area demographically, ethnically, and socioeconomically, except with respect to income, for which KPMCP members under-represent the very poor and the very wealthy (10).

Computerized hospitalization records were reviewed to identify women who gave birth in 1996. KPMCP maintains a complete database of all hospitalizations at any Kaiser hospital; these data are complete within 3 months of discharge. Each member of the health plan receives a medical record number that is a unique identifier and is not reissued when an individual leaves the health plan. Therefore, duplication of study subjects is nearly impossible and linkage of informa-

tion from several databases is considered nearly 100% successful. Age, ethnicity, and gestational age at delivery were available from the computerized hospitalization record.

Gestational age at screening was calculated by using the gestational age at delivery according to the following formula: gestational age at delivery minus the difference between the date at delivery and the date when the screening test was performed.

Six ethnic categories are included in the computerized hospitalization records: white, African-American, Hispanic, Asian, Native American, other, and unknown. Because of the small number of women in the categories of Native American, other, and unknown, the analyses by ethnicity were restricted to the four larger ethnic groups. A random sample of 198 women was selected for medical chart review to validate ethnicity obtained from the computerized record. In the medical charts, women's self-reported ethnicity was assessed from one of two sources: infant's birth certificate (where mother's ethnicity is recorded after delivery; $n = 151$) or mother's prenatal forms (where ethnicity is recorded at women's first prenatal visit; $n = 47$). The agreement between ethnicity found in the computerized record and the self-reported ethnicity found in the medical chart was 92.9%.

In this setting, in accord with ADA (9) and American College of Obstetricians and Gynecologists (11) recommendations, a 50-g, 1-h OGTT is performed to screen for GDM during a routine prenatal visit, regardless of the time or the fasting state. If the results of the screening test are abnormal [1-h plasma glucose ≥ 7.8 mmol/l (140 mg/dl)], a letter is sent to the patient recommending a diagnostic 100-g, 3-h OGTT in the morning after 12-h fast. Instructions about dietary preparation for this OGTT consisting of a minimum of 150 g carbohydrate per day during the 3 days before the test are mailed and patients are reminded when they call to make an appointment for the diagnostic test.

Plasma glucose results for the 50-g, 1-h OGTT and the 100-g, 3-h OGTT were obtained from the laboratory database, a clinical database that captures all laboratory tests and results performed at the KPMCP regional laboratory. All plasma glucose samples from screening and diag-

nostic tests were analyzed using the hexokinase method. Three Hitachi 747 200 machines were used at that time. If a woman underwent more than one screening test or more than one diagnostic test, we used the tests performed latest in her pregnancy.

Two sets of thresholds were applied to the study population: the O'Sullivan-Mahan criteria as modified by the NDDG (6) [plasma glucose thresholds: fasting 5.8 mmol/l (105 mg/dl), 1-h 10.5 mmol/l (190 mg/dl), 2-h 9.1 mmol/l (165 mg/dl), 3-h 8.0 mmol/l (145 mg/dl)] and the O'Sullivan-Mahan criteria as modified by Carpenter and Coustan (8) [plasma glucose thresholds: fasting 5.3 mmol/l (95 mg/dl), 1-h 10.0 mmol/l (180 mg/dl), 2-h 8.6 mmol/l (155 mg/dl), 3-h 7.8 mmol/l (140 mg/dl)]. By both criteria, GDM is defined as at least two plasma glucose measurements during the diagnostic test at or higher than the reported cut points.

The Northern California Kaiser Permanente (NCKP) Diabetes Registry (12) was searched to identify and exclude women with recognized diabetes before the index pregnancy. The NCKP Diabetes Registry systematically excludes women with GDM. In 1996, registry sensitivity was estimated to be 96% with a 2% false-positive rate (12). Women were considered as having diabetes before the index pregnancy if they were identified by the NCKP Diabetes Registry at least 9 months before their delivery date.

Statistical analysis

Mean plasma glucose levels and SD by 5-year age group were calculated, and tests for linear or quadratic trend of plasma glucose values by age were conducted using linear regression techniques.

Age- and ethnicity-specific GDM prevalence and 95% CIs were calculated among all women who were screened. Age-adjusted prevalence was computed by the direct method; the age distribution of the entire study population was used as the standard. Linear or quadratic trends in prevalence of GDM by age were computed by logistic regression.

Pairwise comparisons in the age-adjusted prevalence of GDM between all ethnic groups were performed using logistic regression. We adjusted for multiple comparisons using the Bonferroni method (13) to achieve an overall family error rate of 0.05 for each of the two sets

Table 1—Age- and ethnicity-specific frequency of screening for GDM in 28,330 women who gave birth in 1996 at the KPMCP of Northern California

	Women aged <25 years			Women aged ≥25 years		
	N	n	%	N	n	%
White	3,696	3,412	92.3	10,858	10,321	95.1
African-American	1,132	974	86.0	1,498	1,372	91.6
Hispanic	2,122	1,924	90.7	3,338	3,110	93.2
Asian	787	727	92.4	3,547	3,400	95.7
Other/unknown	495	436	88.1	857	805	93.9
All women	8,232	7,473	90.8	20,098	19,008	94.6

of comparison of GDM prevalence estimates (by NDDG and Carpenter-Coustan).

The SAS statistical software version 6.11 (14) was used for all analyses. All *P* values are for two-tailed tests.

RESULTS

The study included 28,330 women aged 14–49 years (mean 28.0, SD 6.2) who were members of the KPMCP of Northern California, who delivered in 1996, and who were not known to have diabetes before the index pregnancy. The ethnic composition of the cohort was 51.4% white, 19.3% Hispanic, 15.3% Asian, 9.3% African-American, 2.5% other, and 2.2% unknown.

A total of 26,481 (93.5%) women underwent screening for GDM by 50-g, 1-h OGTT. Overall, the mean gestational age at screening was 26.8 weeks (SD 3.9), and most (73%) of these women underwent the screening test at 24–28 weeks of gestation. As shown in Table 1, completion of the screening test was slightly less com-

mon in women aged <25 years. African-American women were also somewhat less likely to be screened.

Among the women who were screened, 4,891 (19%) had a record of an abnormal screening test (1-h plasma glucose ≥7.8 mmol/l) and 4,260 (87%) of these women underwent a diagnostic 100-g, 3-h OGTT. In the analyses related to the diagnostic test, we excluded 27 women for whom two or more plasma glucose values were missing during the diagnostic test and an additional 8 women for whom only one of three values recorded was abnormal.

Table 2 shows the age-specific mean plasma glucose levels for the screening test among the 26,481 screened women and for each glucose measurement obtained during the diagnostic test among the 4,225 women with the 100-g, 3-h OGTT. Mean plasma glucose screening levels and mean plasma glucose levels at each time point of the diagnostic test (fasting, 1 h, 2 h, and 3 h) increased significantly with age.

Table 2—Mean plasma glucose levels (SD) of measurements obtained during the screening and diagnostic tests for GDM by age (KPMCP of Northern California, 1996)

	Age (years)				<i>P</i> linear trend	All
	< 25	25–29	30–34	35+		
Screening (50-g, 1-h OGTT)	7,473	7,622	7,225	4,161		26,481
Plasma glucose mmol/l						
1-h	6.0 (1.4)	6.4 (1.5)	6.6 (1.7)	6.9 (1.8)	<0.001	6.4 (1.6)
Diagnostic (100-g, 3-h OGTT)	660	1,161	1,408	996		4,225
Plasma glucose mmol/l						
Fasting	4.6 (0.8)	4.6 (0.7)	4.7 (0.7)	4.7 (0.6)	<0.001	4.6 (0.7)
1-h	8.6 (1.9)	9.0 (1.9)	9.2 (1.9)	9.3 (1.8)	<0.001	9.1 (1.9)
2-h	7.5 (1.8)	7.9 (1.9)	8.1 (1.9)	8.3 (1.8)	<0.001	8.0 (1.9)
3-h	6.2 (1.7)	6.4 (1.7)	6.4 (1.9)	6.4 (1.8)	0.035*	6.4 (1.8)

Data are *n* or means (SD). **P* value for linear and quadratic term.

Table 3 shows the prevalence of GDM by age and ethnicity according to the O'Sullivan-Mahan criteria modified by the NDDG and modified by Carpenter-Coustan. By both the NDDG and the Carpenter-Coustan thresholds, the prevalence of GDM increased steadily with age (*P* for trend <0.001). By both thresholds, the age-adjusted GDM prevalence observed in Asians was significantly higher than the prevalence observed in any other ethnic group. By both thresholds, the age-adjusted prevalence of GDM in whites was significantly lower than the GDM prevalence observed in Hispanics or Asians; no significant differences in GDM prevalence were observed between whites and African-Americans. Hispanic women had significantly higher prevalence of GDM than African-American women only when the Carpenter-Coustan thresholds were applied.

Overall, the prevalence of GDM increased from 3.2% using the NDDG thresholds to 4.8% (a 50% increment) with the Carpenter-Coustan thresholds. Proportionately, the greatest incremental changes were seen in women aged <25 years (70% increase in prevalence) and among white women (58% increase in GDM prevalence). However, the greatest increases in absolute terms were in women aged ≥35 years, in whom the prevalence of GDM increased from 5.7 to 8.3%, and among Asians, in whom the age-adjusted GDM prevalence increased from 5.0 to 7.4%.

CONCLUSIONS

The prevalence of GDM in our large multi-ethnic population increased by 50% (from

Table 3—Prevalence of GDM detected by NDDG or Carpenter-Coustan diagnostic plasma glucose thresholds by age and ethnicity (KPMCP of Northern California, 1996)

	N	GDM by NDDG			GDM by Carpenter-Coustan			Percent change
		n	%	(95% CI)	n	%	(95% CI)	
Age groups								
<25 years	7,469	77	1.0	(0.8–1.3)	130	1.7	(1.4–2.0)	70.0
25–29 years	7,609	231	3.0	(2.6–3.4)	348	4.6	(4.1–5.0)	53.3
30–34 years	7,215	306	4.2	(3.8–4.7)	450	6.2	(5.7–6.8)	47.6
≥35 years	4,153	237	5.7	(4.9–6.4)	344	8.3	(7.4–9.1)	45.6
P linear trend			<0.001			<0.001		
All women	26,446	851	3.2	(3.0–3.4)	1,272	4.8	(4.5–5.1)	50.0
Ethnic groups								
White	13,714	346	2.5	(2.3–2.8)	542	3.9	(3.6–4.3)	58.3
Age-adjusted			2.4 ^{a*}	(2.2–2.7)		3.8 ^{a*}	(3.5–4.1)	
African-American	2,345	60	2.6	(1.9–3.2)	80	3.4	(2.7–4.1)	33.3
Age-adjusted			3.0 ^{ab*}	(2.2–3.8)		4.0 ^{a*}	(3.1–4.8)	
Hispanic	5,026	169	3.4	(2.9–3.9)	248	4.9	(4.3–5.5)	46.2
Age-adjusted			3.9 ^{b*}	(3.3–4.5)		5.6	(4.9–6.3)	
Asian	4,121	234	5.7	(5.0–6.4)	341	8.3	(7.4–9.1)	48.0
Age-adjusted			5.0	(4.4–5.7)		7.4	(6.6–8.2)	

*Within each column, different superscript letters among age-adjusted ethnic groups indicate significant pairwise difference at $P < 0.0083$ for an overall error rate of 0.05 (i.e., within each diagnostic threshold, ethnic groups containing the same superscript letter are not statistically significantly different from each other).

3.2 to 4.8%) when using the glucose thresholds modified by Carpenter-Coustan instead of the glucose thresholds modified by the NDDG. With both thresholds, the prevalence of GDM increased with age and was more common in Asians, followed by Hispanics, African-Americans, and whites.

Estimates of the prevalence of GDM in the U.S. vary widely from 2% (in a population of primarily white women) (15) to 14% (in Native American women) (16). Variation in prevalence also depends on the screening and diagnostic methods used (4). However, there are unquestionably ethnic differences in the prevalence of GDM; Asians, Hispanics, and African-American women were at higher risk for GDM (17–21).

In our study, the 3.2% prevalence of GDM according to the NDDG criteria is in the middle range of findings from previous studies (20,22–29), which have found the prevalence of GDM to range from 2.0 to 4.9% using the NDDG criteria in populations that did not include Native Americans.

The 4.8% prevalence of GDM we found using the modified Carpenter-Coustan thresholds is also in the middle range of findings from other studies (20,23,29,30) using these criteria, in which prevalence of GDM has been found to range from 4.4 to 7.1%.

The observed overall increase in the prevalence of GDM by 50% when using the more inclusive Carpenter-Coustan thresholds is consistent with previous studies reporting the prevalence according to both criteria (20,23,29). However, none of these previous studies reported the incremental increase in prevalence by age and ethnicity due to the small size of their study populations, which included no more than 205 women with GDM by Carpenter-Coustan thresholds. In our study, proportionately, the magnitude of the incremental increase in prevalence of GDM by Carpenter-Coustan thresholds was highest among low-risk groups, such as women aged <25 years and white. However, in absolute terms, prevalence of GDM increased more among high-risk women (aged >35 years or Asians) when using the more inclusive Carpenter-Coustan criteria.

Obviously, the decision to use the modified Carpenter-Coustan thresholds will result in higher prenatal care costs to monitor and treat the additional women diagnosed with GDM. What is not known is whether the cost of these interventions will be outweighed by the money saved by preventing perinatal complications among women with the lower Carpenter-Coustan thresholds. Recently, the Toronto Tri-Hospital Gestational Diabetes project (31) has shown that women with

untreated GDM by Carpenter-Coustan plasma glucose thresholds who did not meet the NDDG criteria had higher rates of costly adverse outcomes such as cesarean section and macrosomia than normoglycemic women. Preliminary results from our population also suggest that women with GDM by Carpenter-Coustan who did not meet the NDDG criteria had higher rates of perinatal complications such as macrosomia, hypoglycemia, and hyperbilirubinemia (32).

It should be considered that given the current enzymatic method to measure plasma glycemia, the Carpenter-Coustan criteria better reflect the original O'Sullivan-Mahan glucose thresholds (33), which in turn had a 61% predictive value for identifying women in whom overt diabetes would develop in the following 17–23 years (34) and who may benefit from diabetes prevention strategies (35,36). In addition, reducing the incidence of diabetes by 10% in a national cohort of women with GDM was estimated to be associated with a net savings of 32 million health care dollars (1990 dollars) over 10 years (a net savings of \$254.81 per woman with GDM) (37). Finally, there is evidence suggesting that lifestyle intervention among women with abnormal screening tests and normal diagnostic tests according to the NDDG glucose thresholds may be cost-effective in

terms of preventing macrosomia and related health care expenses (38).

To estimate the impact of the Carpenter-Coustan definition of GDM at a national level, we applied the age- and ethnic-specific prevalence of GDM by the NDDG thresholds and the Carpenter-Coustan thresholds observed in our population to the U.S. population of women who gave birth in 1997 (39). We estimate that among the 3,812,812 women, 97,906 women had GDM according to the NDDG thresholds and 148,276 women had GDM according to the Carpenter-Coustan thresholds, an increment of 50,373 (51.5%) women with GDM.

Strengths of this study are the large sample size, the multiethnic composition of our cohort, and the nearly universal screening for GDM practiced in our setting. A few study limitations are worth noting. Although the KPMCP of Northern California membership is representative of the general population living in the same area (10), women in our cohort were more likely to be aged ≥ 25 years (75 vs. 63%) and to belong to U.S. minority ethnic groups (49 vs. 21%) compared with the U.S. population of women who gave birth in 1997 (39). Therefore, they were at higher risk for GDM. However, given our sample size, we were able to calculate age- and ethnic-specific estimates of GDM prevalence that will be useful for comparison with populations demographically different from our cohort.

In conclusion, by using the more inclusive Carpenter-Coustan thresholds, GDM is one of the most common complications of pregnancy. The proportion of women identified as having GDM and therefore targeted for monitoring and treatment to reduce risks of perinatal complications would increase by $\sim 50\%$. The age- and ethnic-specific results reported here would be useful information for clinical settings to help plan screening and treatment guidelines and project the costs of GDM based on the demographic characteristics of the population.

Acknowledgments—The study was supported by a Research Award from the American Diabetes Association and a grant (1-R01-DK-54834) from the National Institute of Diabetes and Digestive and Kidney Diseases.

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