Environmentally Driven Increases in Type 2 Diabetes and Obesity in Pima Indians and Non-Pimas in Mexico Over a 15-Year Period: The Maycoba Project

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EPIDEMIOLOGY/HEALTH SERVICES RESEARCH

OBJECTIVE

The global epidemics of type 2 diabetes and obesity have been attributed to the interaction between lifestyle changes and genetic predisposition to these diseases. We compared the prevalences of type 2 diabetes and obesity in Mexican Pima Indians, presumed to have a high genetic predisposition to these diseases, to those in their non-Pima neighbors, both of whom over a 15-year period experienced a transition from a traditional to a more modern lifestyle.

RESEARCH DESIGN AND METHODS

Prevalence of diabetes, impaired fasting glucose, impaired glucose tolerance, and obesity in Mexican Pimas (n = 359) and non-Pima Mexicans (n = 251) were determined in 2010 using methods identical to those used in 1995.

RESULTS

During this 15-year period, age-adjusted diabetes prevalence was unchanged in Pima men (5.8% in 1995 vs. 6.1% in 2010) yet increased in non-Pima men from 0.0 to 8.6% ($P < 0.05$). Diabetes prevalence tended to increase in both Pima women (9.4 vs. 13.4%) and non-Pima women (4.8 vs. 9.5%). Age-adjusted prevalence of obesity increased significantly in all groups (6.6 vs. 15.7% in Pima men; 8.5 vs. 20.5% in non-Pima men; 18.9. vs 36.3% in Pima women; 29.5 vs. 42.9% in non-Pima women).

CONCLUSIONS

Type 2 diabetes prevalence increased between 1995 and 2010 in non-Pima men, and to a lesser degree in women of both groups, but it did not increase in Pima men. Prevalence of obesity increased among Pimas and non-Pimas of both sexes. These changes occurred concomitantly with an environmental transition from a traditional to a more modernized lifestyle.

During the past three decades, the worldwide prevalence of diabetes has doubled (1,2). A recent estimate predicts the number of people with diabetes will grow from 382 million adults in 2013 to 592 million by 2035 (2). More than two-thirds of this increase (69%) will occur in developing countries. The rates have risen even more

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rapidly in some populations that have experienced very rapid economic development; for example, rates in China have multiplied some ninefold in the past 30 years (3). These dramatic increases have been attributed to an interaction between the global trend of a shift away from traditional lifestyles, as the environment becomes more modernized, and genetic predisposition to type 2 diabetes and obesity (4).

In 1995, we conducted a cross-sectional study to identify the effects of traditional compared with modern lifestyles on the prevalence of type 2 diabetes and obesity in U.S. Pima Indians and Mexican Pima Indians, two populations presumed to be genetically prone to these disorders, and non-Pima Mexicans, who may have a lower genetic risk for these diseases. The Mexican Pimas and their non-Pima neighbors both live in the community of Maycoba and surrounding areas located in a remote region in the Sierra Madre Mountains in Sonora, Mexico, where at the time of the 1995 survey, they practiced a "traditional" lifestyle, with heavy reliance on manual labor and locally produced food (5). In contrast to the Mexican Pimas, the U.S. Pimas from Arizona practice a "modern" lifestyle, with greater use of technology and processed foods, and have a high prevalence of type 2 diabetes and obesity (6).

The 1995 study indicated that the age- and sex-adjusted prevalence of type 2 diabetes in the Mexican Pimas (6.9%) was less than one-fifth that of the U.S. Pimas (38.0%) but similar to non-Pima Mexicans (2.6%). The prevalence of obesity was similar in the Mexican Pimas and non-Pimas yet was dramatically lower than in the U.S. Pimas (6.5% in Mexican Pima men compared with 63.8% in U.S. Pima men; 19.8% in Mexican Pima women compared with 74.8% in U.S. Pima women) (5). Mexican Pimas had a higher level of physical activity (PA) (7), and a diet lower in fat and higher in fiber and complex carbohydrates (5,8), than U.S. Pimas. These results suggested that the development of these chronic diseases is largely influenced by environmental circumstances. Assuming that genetic predisposition to type 2 diabetes and obesity of the Mexican and U.S. Pima is similar, the study also provided compelling evidence that changes in lifestyle associated with modernization play a major role the worldwide epidemic of these disorders. However, due to its cross-sectional nature, it was not possible to determine the effect of the actual transition in lifestyle on development of type 2 diabetes and obesity.

Over the ensuing 15 years, the community of Maycoba experienced marked changes in the socioeconomic and built environment, including the introduction of paved roads, piped drinking water, electricity, retail food, clothing, and hotel establishments; changes in land usage; and increased transportation options (9–11). In 2010, another survey was undertaken in Maycoba to examine the impact of these environmental changes on the prevalence of type 2 diabetes and obesity (12). The aims of the present analysis are to describe changes in the prevalence of diabetes, glucose tolerance, and obesity among Mexican Pimas and non-Pima Mexicans living in Maycoba and the surrounding area in the year 2010 with respect to the 1995 study, to test whether the prevalence in 2010 is different from 1995, and to test whether diabetes and obesity are associated with features of modernization.

RESEARCH DESIGN AND METHODS

Study Population

The Mexican Pimas and their non-Pima neighbors live in a remote area on the eastern border of the Mexican state of Sonora in the region around the village of Maycoba. For the 2010 study, the census conducted in 1994 was updated to enumerate all residents of the area and establish their ethnicity, dates of birth, and familial relationships (12). Participants were considered Pima if they reported at least one parent with Pima heritage. Those who reported no parental Amerindian heritage (5,13) were considered non-Pima. Based on analysis of ancestry-informative markers, we estimate the genetic ancestry of the non-Pima Mexicans is, on average, ~40% Amerindian and ~60% European, whereas that of the Pimas is ~80% Amerindian and ~20% European.

All residents over age 20 years were invited to participate in a health examination at our clinic in the village of El Kipor, 10 km east of Maycoba. These examinations, conducted in the morning by Spanish-speaking interviewers and technicians, included a brief medical history, socioeconomic, dietary (24-h recall), and PA questionnaires, measurements of anthropometry, and a 75-g oral glucose tolerance test. Methodological details have been reported previously (12). The current survey was performed from August 2010 to April 2011. Identical analyses and methods were used in both surveys (1995 and 2010) (5,12).

The study was approved by the Institutional Review Boards for the Protection of Human Subjects at the Northern Arizona University (no. 10.0016), the National Institute of Diabetes and Digestive and Kidney Diseases Institutional Review Board (protocol 10-DK-N161), and Centro de Investigación en Alimentación y Desarrollo in Hermosillo, México. All of the subjects gave written informed consent.

Oral glucose tolerance tests were performed using a 75-g oral glucose load after 10–12 h of fasting according to World Health Organization recommendations (14). Plasma glucose concentrations were measured in fasting and 2-h postload venous blood using a hexokinase method (Ciba Corning Express, Norwood, MA).

Diabetes was diagnosed on the basis of fasting plasma glucose (FPG) $\geq$126 mg/dL or 2-h plasma glucose (2hPG) $\geq$200 mg/dL or previous physician diagnosis with current treatment with insulin or oral hypoglycemic agents. (Injectable diabetes medicines other than insulin were not available.) Impaired fasting glucose (IFG) was defined as FPG $\geq$100 mg/dL but $<$126 mg/dL and 2hPG $<$200 mg/dL, and impaired glucose tolerance (IGT) was defined as 2hPG $\geq$140 mg/dL but $<$200 mg/dL and FPG $<$126 mg/dL. Participants not fulfilling these criteria were considered to have normal glucose tolerance (15).

Obesity was assessed by BMI (weight in kilograms divided by the square of height in meters) with weight measured on a battery-operated electronic scale (Ohaus Defender 3000, Columbia MD) and height with a portable stadiometer (Harpenden Stadiometer; Holtain Ltd., U.K.). Subjects were classified as obese if BMI was $\geq$30 kg/m^2 and overweight if 25 kg/m^2 $\leq$ BMI $<$30 kg/m^2. Waist circumference was measured with subjects in the supine position at the level of the umbilicus. Subjects were classified as having abdominal obesity if they had waist circumference $>$102 cm in men and $>$88 cm in women.

Statistical Analysis

Differences in means for physical and biochemical characteristics between

1995 and 2010 surveys were tested for statistical significance by linear regression or by the Wilcoxon rank sum test. Age-standardized and age- and sex-standardized prevalence ratios of type 2 diabetes, IFG, IGT, obesity, and central obesity and their 95% CIs were calculated in both surveys (1995 vs. 2010) by the direct method using as the standard population the sex- and age-specific distribution of the combined Pimas and non-Pimas examined in the 2010 survey.

In the 2010 survey, individuals were asked if they had access to a number of modern technological features (refrigerator, television, car, washer, telephone, cell phone, iron, DVD player, mixer, furnace, fan, electricity, internet, solar, and radio). A "modernization index" was constructed based on simply adding the number of such features to which an individual reported access. The associations of ethnicity, dietary macronutrients (energy, carbohydrates, fat, and protein), PA (total occupational and total hard PA), and the "modernization index" with the odds of type 2 diabetes were analyzed by multiple logistic regression. Similar associations were analyzed with BMI using multiple linear regression. In these multivariable models, we present linear (continuous variable) models for BMI rather than logistic (dichotomous variable) models for overweight/obesity, since the former will generally be more powerful. All models were adjusted by age, sex, and ethnicity (Pima vs. non-Pima) in the whole population and by age and ethnicity when the association was stratified by sex. Analyses were performed using STATA software (version 11.0; Stata Corp., College Station, TX) and SAS (Cary, NC); two-sided *P* values $\leq$0.05 were considered significant.

RESULTS

In the 2010 census of Maycoba and the surrounding area, a total of 1,270 individuals were enumerated, of whom 720 were aged 20 years and older (417 Pima Indians and 303 non-Pimas). Among those aged 20 years and older, 359 Pimas (response rate 86%) and 251 non-Pimas (response rate 83%) participated in the 2010 survey. Table 1 presents anthropometrics, biochemical characteristics, and assessment of PA and dietary intake of the two groups (Pimas and non-Pimas age 20 years and older) who participated in either the 1995 or 2010 survey.

Prevalence of Abnormal Glucose Tolerance

The crude and age-specific abnormal glucose tolerance rates among Mexican Pima Indians and non-Pimas aged 20 years and older, stratified by sex, BMI, and waist circumference, are presented in Table 2 for the 2010 survey. Among the Pimas, the crude type 2 diabetes prevalence in the 1995 survey was 7.1% in the overall population, 8.5% in women, and 5.6% in men. The overall crude type 2 diabetes prevalence in the non-Pimas was 2.6%; however, none of the non-Pima men and 4.9% of the women had diabetes. In the 2010 survey among Pimas, the prevalence of type 2 diabetes was 9.0% in the overall population, 11.8% in women, and 6.0% in men, whereas among non-Pimas, it was 10.9% of the overall population, 10.8% in women, and 10.9% in men. In both groups, type 2 diabetes increased with age. Compared with those with normal weight, prevalence of diabetes was higher in those with abdominal or total obesity in the non-Pimas and in those with abdominal obesity in the Pimas.

Changes in age-adjusted type 2 diabetes, isolated IGT, and isolated IFG prevalence are depicted in Fig. 1*A–C* over the 15-year study period. Overall age- and sex-adjusted diabetes prevalence increased from 7.8 to 10.1% among the Pimas ($P > 0.05$) and from 2.5 to 9.6% among the non-Pimas ($P = 0.0016$) during the same time period. As shown, the age-adjusted prevalence of diabetes did not change in Pima men (5.8% in 1995 compared with 6.1% in 2010; $P > 0.05$), whereas the prevalence increased significantly ($P = 0.0019$) in non-Pima men (0.0% in 1995 compared with 8.6% in 2010). Prevalence of diabetes increased in both Pima (9.4 vs. 13.4%) and non-Pima women (4.8 vs. 9.5%), yet neither increase was statistically significant ($P > 0.05$) (Fig. 1*A*).

Overall age- and sex-adjusted isolated IGT rates increased from 4.7 to 10.4% ($P = 0.0089$) among the Pimas and from 6.6 to 7.5% among the non-Pimas ($P < 0.05$) over the 15-year study period. Among Pimas, age-adjusted isolated IGT rates increased from 3.4 to 7.7% ($P = 0.152$) in men and from 5.2 to 11.9% among women ($P = 0.0278$). Among non-Pimas, isolated IGT rates increased from 1.6 to 3.5% ($P > 0.05$) in men and from 10.7 to 11.2% ($P > 0.05$) in women (Fig. 1*B*).

Overall age- and sex-adjusted isolated IFG rates increased from 13.8 to 19.8% ($P = 0.0180$) among the Pimas and from 3.6 to 12.7% ($P = 0.0010$) among the non-Pimas over the 15-year study period. Among Pimas, age-adjusted isolated IFG rates increased from 18.0 to 29.3% ($P = 0.0312$) in men and from 9.5 to 11.4% in women ($P > 0.05$). Among non-Pimas, age-adjusted isolated IFG rates increased from 4.4 to 19.4% ($P = 0.0012$) in men and from 2.8 to 6.1% ($P > 0.05$) in women (Fig. 1*C*).

Overall age- and sex-adjusted rates of concomitant IGT and IFG increased from 2.7 to 7.5% ($P = 0.0099$) among the Pimas and from 2.7 to 8.1% ($P = 0.0192$) among the non-Pimas over the 15-year study period. Among Pimas, age-adjusted IFG and IGT rates increased from 2.8 to 6.5% ($P > 0.05$) in men and from 2.4 to 8.4% among women ($P = 0.0259$). Among non-Pimas, the rates increased from 2.0 to 8.2% ($P = 0.0614$) in men and from 3.3 to 7.9% ($P > 0.05$) in women (data not shown).

Prevalence of Overweight and Obesity

Age-specific rates of overweight and obesity in Pimas and non-Pimas in 1995 and 2010 are presented in Supplementary Table 1. Crude obesity prevalence increased from 13.3 to 26.7% ($P = 0.0001$) among Pimas and from 19.0 to 31.3% among non-Pimas ($P = 0.003$). Crude obesity prevalence in Pima men showed an increase from 6.6 to 15.3% ($P = 0.027$) and from 19.4 to 37.0% in Pima women ($P = 0.001$). Non-Pima men showed an increase in obesity from 8.8 to 20.3% ($P = 0.020$) and non-Pima women from 27.9 to 41.8% ($P = 0.018$). Crude overweight prevalence increased from 32.0 to 37.4% ($P > 0.05$) among Pimas and from 34.4 to 42.3% among non-Pimas ($P = 0.09$). Pima men showed an increase in overweight from 25.0 to 39.4% ($P = 0.013$), whereas no increase was noted in Pima women (38.5% in 1995 compared with 35.5% in 2010). Non-Pima men showed an increase in overweight from 34.1 to 46.9% ($P = 0.06$), and it increased from 36.6 to 37.3% ($P = 0.68$) in non-Pima women.

Age- and sex-adjusted obesity prevalence increased from 13.2 to 26.6% ($P = 0.0001$) among the Pimas and from 19.4 to 32.1% among the non-Pimas ($P = 0.0017$) over the 15-year study period. Among Pima men, age-adjusted obesity rates increased from 6.6 to 15.7% ($P = 0.0214$), and they increased from 18.9 to 36.3% among Pima women ($P = 0.0012$). Among non-Pima men, obesity rates

Table 1—Anthropometrics, biochemical characteristics, and PA among Mexican Pimas and non-Pimas by survey years (1995 and 2010)

	Non-Pimas			Pimas		
Characteristics	1995	2010	*P*	1995	2010	*P*
Male (*n*)	91	128	—	108	170	—
Age (years)	41.7 ± 16.5	45.0 ± 16.9	—	40.5 ± 16.8	40.0 ± 16.1	—
Weight (kg)	72.0 ± 12.4	79.2 ± 14.3	<0.0001	66.1 ± 11.3	73.6 ± 14.7	<0.0001
Height (m)	171.7 ± 6.1	171.9 ± 6.0	0.5038	166.5 ± 6.0	168.4 ± 6.4	0.0145
BMI (kg/m^2)	24.4 ± 3.7	26.8 ± 4.5	<0.0001	23.8 ± 3.4	25.8 ± 4.4	<0.0001
Waist circumference (cm)	86.4 ± 9.8	92.2 ± 11.1	0.0002	82.9 ± 9.0	88.7 ± 11.1	<0.0001
Fasting glucose (mg/dL)	87.4 ± 8.1	104.1 ± 26.9	<0.0001	97.2 ± 29.9	101.4 ± 21.3	0.1333
2-h glucose (mg/dL)	87.2 ± 27.1	122.0 ± 73.5	<0.0001	107.1 ± 74.2	123.4 ± 54.8	0.0246
HbA_{1c} (%)	5.1 ± 0.4	6.0 ± 1.2	<0.0001	5.2 ± 1.3	5.7 ± 0.9	0.0004
HbA_{1c} (mmol/mol)	32 ± 4	42 ± 13	<0.0001	33 ± 14	39 ± 10	0.0004
HOPA (h/week)*	13.7 (9.1–16.2)	9.0 (7.0–15.5)	0.0203	19.2 (16.6–21.9)	17.7 (14.5–20.3)	0.0127
TV (h/week)*	—	6.9 (6.9–7.6)	—	—	6.9 (3.7–6.9)	—
Energy from fat (%)	26.5 ± 5.4	33.1 ± 8.2	<0.0001	27.5 ± 5.9	31.0 ± 9.3	0.0006
Energy from carbohydrate (%)	60.7 ± 6.1	51.9 ± 9.3	<0.0001	60.7 ± 5.9	55.9 ± 9.7	<0.0001
Energy from protein (%)	12.7 ± 2.6	14.5 ± 3.5	0.0011	11.8 ± 2.2	13.6 ± 5.6	0.0067
Modernization index	—	8.6 ± 3.5		—	4.5 ± 3.4	—
Female (*n*)	104	123	—	118	189	—
Age (years)	39.8 ± 14.2	41.9 ± 16.1	—	35.9 ± 12.7	38.6 ± 14.8	—
Weight (kg)	66.4 ± 14.4	73.4 ± 15.8	0.0004	61.9 ± 11.8	68.8 ± 13.4	<0.0001
Height (m)	155.8 ± 5.7	158.1 ± 6.0	0.0002	154.4 ± 5.8	155.1 ± 5.7	0.2173
BMI (kg/m^2)	27.3 ± 5.5	29.5 ± 5.5	0.0053	26.0 ± 4.4	28.6 ± 5.0	<0.0001
Waist circumference (cm)	84.3 ± 12.7	94.6 ± 11.6	<0.0001	85.4 ± 12.8	94.7 ± 11.7	<0.0001
Fasting glucose (mg/dL)	90.5 ± 21.6	99.9 ± 35.1	0.0291	96.0 ± 32.9	102.7 ± 38.5	0.2773
2-h glucose (mg/dL)	113.6 ± 59.3	137.4 ± 78.5	0.0276	125.8 ± 82.4	147.8 ± 90.2	0.0871
HbA_{1c} (%)	5.3 ± 0.9	5.9 ± 1.2	0.0001	5.5 ± 1.6	6.0 ± 1.5	0.0163
HbA_{1c} (mmol/mol)	34 ± 10	41 ± 13	0.0001	37 ± 18	42 ± 16	0.0001
HOPA (h/week)*	0.8 (0.3–1.9)	1.6 (0.7–3.3)	0.1167	0.9 (0.6–1.9)	1.2 (0.9–2.0)	0.0016
TV (h/week)*	—	13.9 (6.9–13.9)	—	—	13.9 (6.9–13.9)	—
Energy from fat (%)	26.5 ± 4.6	31.6 ± 9.5	<0.0001	27.1 ± 5.2	29.3 ± 9.5	0.0279
Energy from carbohydrate (%)	61.0 ± 5.2	53.8 ± 9.9	<0.0001	61.0 ± 5.4	58.3 ± 9.9	0.0074
Energy from protein (%)	12.5 ± 2.1	14.5 ± 4.4	<0.0001	11.9 ± 1.8	12.4 ± 3.8	0.0996
Modernization index	—	7.2 ± 3.1	—	—	4.0 ± 3.1	—

Data are means ± SD. Modernization index represents the number of technological features to which an individual reported having access (see text). *P* values are for the comparison between time periods and were calculated by linear regression with adjustment for age, except that for HOPA, which was calculated by the Wilcoxon rank sum test. Twenty-five percent of individuals in the 2010 survey are lacking dietary information because the 24-h recall was not performed. HOPA, hard occupational PA. *Median and 95% CI.

increased from 8.5 to 20.5% (*P* = 0.0159), and they increased from 29.5 to 42.9% (*P* = 0.0317) among non-Pima women (Fig. 1D).

Age- and sex-adjusted overweight rates increased from 33.6 to 37.7% (*P* > 0.05) among Pimas and from 34.5 to 40.5% among non-Pimas (*P* = 0.0910) over the 15-year study period. Among Pima men, age-adjusted overweight rates increased from 26.3 to 40.1% (*P* = 0.0126), whereas they decreased from 41.1 to 36.2% among Pima women (*P* > 0.05). Among non-Pima men, overweight rates increased from 34.9 to 45.0% (*P* = 0.0625), and they increased from 34.3 to 37.0% (*P* > 0.05) among non-Pima women (Fig. 1*D*).

Association of Modernization Index, PA, and Diet With BMI and Type 2 Diabetes (2010 Survey)

Associations between BMI and PA, dietary variables, and modernization index are shown in Table 3A. A higher modernization index was strongly associated with higher BMI in both men and women. The modernization index also differed significantly between Pimas and non-Pimas, but the relationship between BMI and modernization index remained statistically significant when each ethnic group was analyzed separately (data not shown). None of the other variables had a statistically significant association with BMI.

Associations between type 2 diabetes and PA, dietary variables, and modernization index are shown in Table 3B. A higher level of "heavy" occupational PA was associated with lower odds of type 2 diabetes in men and in men and women combined. When diet, hard occupational PA, and modernization index were all included in a single model, the associations of each of these variables with BMI and diabetes were essentially unchanged. The correlation between modernization index and hard occupational PA level was −0.12 in men (*P* = 0.04) and −0.06 in women (*P* = 0.28). When modernization index and hard occupational PA were included in a model for both men and women, there was no significant association of ethnicity with either BMI or diabetes (although there was a slightly higher prevalence of diabetes among Pimas compared with non-Pimas; odds ratio [OR] 1.49 [95% CI 0.73–3.01]; *P* = 0.28). There were no significant interactions between modernization index and ethnicity for either BMI or diabetes (*P* = 0.97 and *P* = 0.66, respectively).

CONCLUSIONS

This study presents changes in the prevalence of type 2 diabetes and obesity

Table 2—Abnormal glucose tolerance among Mexican Pimas and non-Pimas in the 2010 survey

	Pima (# examined [% with abnormal glucose])				Non-Pima (# examined [% with abnormal glucose])			
Categories	Isolated IFG	Isolated IGT	IFG and IGT	Diabetes	Isolated IFG	Isolated IGT	IFG and IGT	Diabetes
Overall	354 (19.8)	354 (9.9)	354 (7.4)	354 (9.0)	248 (13.7)	248 (8.1)	248 (8.5)	248 (10.9)
Men (years)								
20–34	81 (30.9)	81 (2.5)	81 (7.4)	81 (1.2)	41 (14.6)	41 (2.4)	41 (7.3)	41 (2.4)
35–54	57 (31.6)	57 (7.0)	57 (5.3)	57 (8.8)	51 (23.5)	51 (3.9)	51 (7.8)	51 (9.8)
≥55	30 (20.0)	30 (23.3)	30 (6.7)	30 (13.3)	36 (22.2)	36 (5.6)	36 (11.1)	36 (22.2)
Total	168 (29.2)	168 (7.7)	168 (6.5)	168 (6.0)	128 (20.3)	128 (3.9)	128 (8.6)	128 (10.9)
Women (years)								
20–34	94 (6.4)	94 (10.6)	94 (5.3)	94 (1.1)	45 (2.2)	45 (2.2)	45 (4.4)	45 (2.2)
35–54	66 (22.7)	66 (13.6)	66 (9.1)	66 (15.2)	50 (10.0)	50 (18.0)	50 (12.0)	50 (10.0)
≥55	26 (0.0)	26 (11.5)	26 (15.4)	26 (42.3)	25 (8.0)	25 (20.0)	25 (8.0)	25 (28.0)
Total	186 (11.3)	186 (11.8)	186 (8.1)	186 (11.8)	120 (6.7)	120 (12.5)	120 (8.3)	120 (10.8)
BMI (kg/m^2)								
<25	124 (16.9)	124 (7.3)	124 (0.8)	124 (8.1)	67 (13.4)	67 (6.0)	67 (4.5)	67 (3.0)
≥25	230 (21.3)	230 (11.3)	230 (10.9)	230 (9.6)	181 (13.8)	181 (8.8)	181 (9.9)	181 (13.8)
Central obesity								
No	202 (23.8)	202 (6.4)	202 (5.0)	202 (6.9)	138 (18.8)	138 (6.5)	138 (5.1)	138 (7.2)
Yes	152 (14.5)	152 (14.5)	152 (10.5)	152 (11.8)	109 (7.3)	109 (10.1)	109 (12.8)	109 (14.7)

Central obesity, yes if waist circumference >102 cm in men or >88 cm in women.

of a 15-year transition from a traditional to more modern lifestyle in two populations with presumed differences in genetic predispositions to these diseases living in Maycoba, Mexico. Both Mexican Pimas and non-Pimas were living a traditional lifestyle at the time of the first survey in 1995 but have experienced marked socioeconomic environmental changes since then. Results from the 1995 study showed a relatively low prevalence of diabetes in both the Pimas and non-Pimas from Maycoba (5). In 2010, obesity had increased in Pimas and non-Pimas, among both men and women. Type 2 diabetes increased in both groups of women, but a different pattern was observed in men; diabetes prevalence was unchanged over the 15 years in Pima men yet rose dramatically in non-Pima men. As a consequence, the prevalence of diabetes in Pimas is higher in women than in men, whereas there is little sex difference among non-Pimas. IFG prevalence, however, is higher among men in both groups.

Few detailed studies have examined the effect on type 2 diabetes prevalence of lifestyle changes occurring over a limited time period. Taylor et al. (16) compared diabetes prevalence in Wallisians in Wallis Island in the South Pacific, a population with a very traditional island lifestyle, and first-generation Wallisian migrants who had been living for ~5–10 years in the modernized urban center of Noumea, New Caledonia. The prevalence of type 2 diabetes in Noumea was seven times higher than in Wallis Island among the men and four times higher in the women, differences that were explained by differences in obesity and environmental factors, such as diet and PA. In a similar analysis of two population-based surveys to study secular trends of diabetes in Mauritius over a period of 22 years (from 1987 to 2009), a marked increase in diabetes was seen both among men (a 1.64-fold increase) and women (a 1.62-fold increase) (17). The authors explained the increase as due to concurrent changes in the distribution of usual risk factors, such as age, ethnicity, waist circumference, BMI, PA, smoking, family history of diabetes, and hypertension. By contrast, among adult U.S. Pima Indians from Arizona, incidence rates of type 2 diabetes were remarkably stable during three time periods of observation, 1965–1977, 1978–1990, and 1991–2003 (18). During these time periods, however, the incidence of type 2 diabetes in people aged 5–14 years increased almost sixfold.

Specific assessments of environmental change in Maycoba over the 15-year time span have been previously described and included aspects of the changing food environment (9,11) and changes in land use and land cover (10). Chaudhari et al. (11) found the food environment, with regard to food availability and food acquisition behaviors, had transitioned from a subsistence-based diet with very limited processed food items to one that incorporates more purchased foods. Yet these studies underscore that a subsistence-based lifestyle is still prevalent. Purchased foods consisted of mainly processed items but comprise a small portion of total household food intake. Between 1995 and 2010, the number of grocery stores increased from 6 to 11, along with a notable growth in the quantity and variety of processed food available for sale. The introduction of refrigeration allowed for perishable items to be sold, such as cheese and milk, and also made highly processed microwavable foods available.

A wider examination of food resources offered insight into household-level changes in the food environment. The number of home gardens (9) is virtually unchanged, although there has been a decrease in the size and variety of plants cultivated. Animal husbandry, hunting, and gathering are still important food-producing activities, but their contribution to total household food intake has diminished over the last 15 years. Compared with 1995, both the amount of food cultivated and the work effort put into growing food by families have decreased. Changes in land use and land cover in the Maycoba region over the study period have been documented by Giraldo et al. (10) based on aerial photographs from 1994 and 2007 satellite images. The land-use change findings

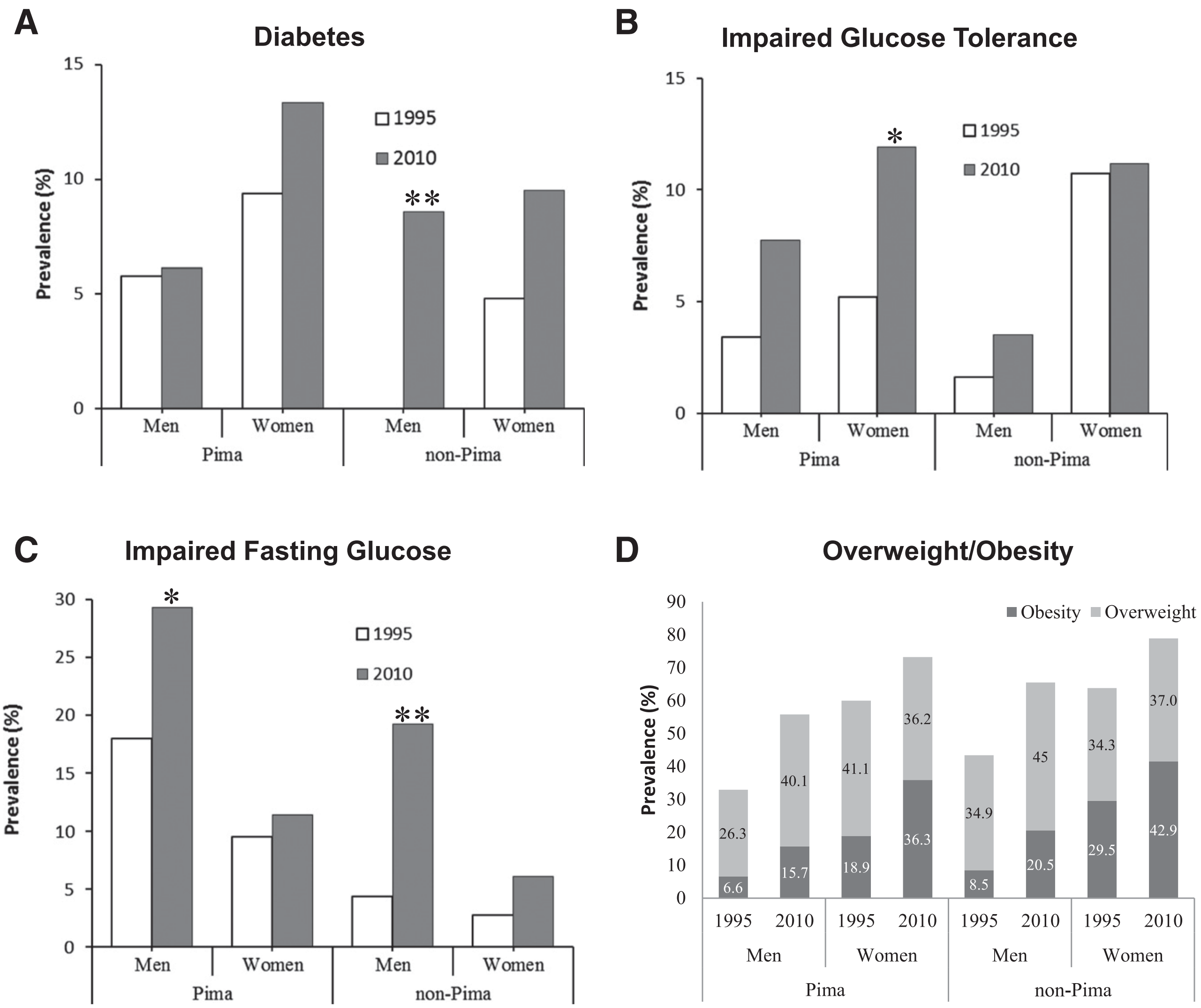

Figure 1—Age-standardized prevalence of type 2 diabetes, IGT, and IFG and distribution of overweight and obesity among Mexican Pimas and non-Pimas according to sex and study year. *A*: Type 2 diabetes. *B*: Isolated IGT. *C*: Isolated IFG. *D*: Overweight and obesity. *$P < 0.05$ and **$P < 0.001$, for significant increase from 1995 to 2010 by sex.

showed a decrease or no change in agricultural or ranching areas, a decrease in farmland due to reforestation or revegetation, and a small proportion of the area under human intervention (7%). Three variables were used as proxies to examine lifestyle change, including the road network, dwelling-unit density, and urban development. Both the amount of urbanization and the number and density of dwelling units increased, although modestly, between 1994 and 2007. The most notable changes were in the town of Maycoba, the largest settlement in the study area. The extent to which these changes in the built environment have contributed to changes in obesity and diabetes prevalence is speculative.

In the present survey, the proportion of dietary calories derived from fat increased between 1995 and 2010 for all groups, whereas the proportion derived from carbohydrate declined. Self-reported "hard" occupational PA was largely confined to the men, and the number of hours in which individuals engaged in such activity declined between 1995 and 2010, both in Pima and non-Pima men. However, the number of hours of "hard" occupational activity was on average greater in Pima men than in non-Pima men, and higher levels of "hard" occupational activity were associated with a lower prevalence of type 2 diabetes. Given the apparent protective effect of hard PA, the higher levels of activity in Pima men are consistent with the hypothesis that they have retained protection from diabetes on account of their PA pattern. PA has been shown to prevent type 2 diabetes by preventing obesity and, independently of obesity, by improving insulin resistance (19,20). In general, the socioeconomic status of the Mexican Pimas remains very low. They still grow most of their own food, plowing with the aid of oxen or mules and planting and harvesting their crops by hand. Complementary activities mainly among men are woodcutting, activities related to the process of making charcoal, and working at a local private sawmill. Thus, at least in the Pima men, much of their PA is occupational in nature and relates to providing food and sustenance for their families. Non-Pima Mexicans, on the other hand, are the main owners of the services in Maycoba. Additionally, many are ranchers and

Table 3—Associations of PA, dietary variables, and modernization index with BMI and diabetes

A: Associations with BMI (kg/m^2)

	Men			Women			Men + women		
	Beta	SE	*P*	Beta	SE	*P*	Beta	SE	*P*
Age (years)	−0.023	0.015	0.1301	−0.016	0.019	0.4040	−0.020	0.012	0.1044
Ethnicity (Pima vs. non-Pima)	−1.06	0.52	0.0426	−0.84	0.60	0.1632	−0.95	0.40	0.0176
Sex (male vs. female)	—	—	—	—	—	—	−2.63	0.39	<0.0001
"Hard" occupational activity (SD)	−0.15	0.22	0.4900	−0.59	1.56	0.7048	−0.17	0.24	0.4830
Total occupational activity (SD)	0.43	0.29	0.1379	0.28	0.30	0.3489	0.35	0.21	0.0942
Total fiber intake (SD)	0.13	0.32	0.6903	−0.44	0.35	0.2106	−0.16	0.24	0.5049
Percentage calories from fat (SD)	−0.14	0.37	0.6997	0.07	0.31	0.8128	0.01	0.23	0.9560
Percentage calories from carbohydrate (SD)	−0.07	0.36	0.8412	−0.05	0.32	0.8737	−0.08	0.24	0.7438
Percentage calories from protein (SD)	0.27	0.34	0.4309	−0.06	0.32	0.8641	0.08	0.23	0.7192
Modernization index (SD)	1.30	0.28	<0.0001	0.74	0.35	0.0377	1.03	0.22	<0.0001

B: Associations with diabetes

	Men			Women			Men + women		
	OR	95% CI	*P*	OR	95% CI	*P*	OR	95% CI	*P*
Age (years)	1.05	1.02–1.07	0.0003	1.07	1.04–1.09	<0.0001	1.06	1.04–1.08	<0.0001
Ethnicity (Pima vs non-Pima)	0.66	0.27–1.59	0.3515	1.56	0.71–3.45	0.2751	1.07	0.90–1.90	0.8305
Sex (male vs. female)	—	—	—	—	—	—	0.56	0.32–1.01	0.0524
"Hard" occupational activity (SD)	0.53	0.29–0.94	0.0296	0.58	0.05–7.64	0.6817	0.54	0.31–0.95	0.0311
Total occupational activity (SD)	0.75	0.44–1.28	0.2923	0.90	0.62–1.31	0.5676	0.86	0.64–116	0.3213
Total fiber intake (SD)	1.13	0.68–1.86	0.6418	1.15	0.73–1.82	0.5360	1.17	0.84–1.63	0.3669
Percentage calories from fat (SD)	0.62	0.34–1.12	0.1130	0.70	0.46–1.04	0.0796	0.71	0.51–0.99	0.0406
Percentage calories from carbohydrate (SD)	1.13	0.62–2.05	0.6903	1.52	0.99–2.32	0.0553	1.31	0.94–1.83	0.1178
Percentage calories from protein (SD)	1.70	1.10–2.62	0.0173	0.87	0.54–1.38	0.5484	1.17	0.85–1.60	0.3445
Modernization index (SD)	1.22	0.74–2.00	0.4419	1.16	0.72–1.84	0.5452	1.22	0.87–1.71	0.2457

In the analysis of BMI, "beta" represents the regression coefficient (i.e., the difference in BMI in kg/m^2 per SD of the explanatory variable). In the analysis of diabetes, OR is for diabetes per SD difference in the explanatory variable. All results are adjusted for age, sex, and ethnicity (Pima vs. non-Pima).

herd cattle and provide employment for the Pima men. Given the contrasting nature of the PA patterns between Pima and non-Pima men, we suspect that differences in their occupational PA may explain much of the difference in change in prevalence of type 2 diabetes between 1995 and 2010. Women of both groups are mainly housewives and prepare most of their meals at home. Thus, the similarity in increased type 2 diabetes in Pima women and non-Pima men and women (1.7 times in Pimas and 2.0 times in non-Pimas) may be explained by the increased obesity and the reduction in PA given the nature of their lifestyle patterns.

Increases in total and central obesity were similar in Pima men (total obesity, 2.4-fold; central obesity, 3.6-fold) and non-Pima men (total obesity, 2.3-fold; central obesity, 3.7-fold), as well as in Pima women (total obesity, 1.9-fold; central obesity, 1.7-fold) and non-Pima women (total obesity, 1.5-fold; central obesity, 2.4-fold). We also found a strong association of BMI with the number of modern technological features to which an individual had access, as represented in the "modernization" index, and this association was consistent across groups defined by sex and ethnicity. It is likely that these modern technological devices do not increase obesity directly, but that the modernization index represents a proxy for socioeconomic or behavioral factors, such as more subtle changes in diet or energy expenditure, which are not otherwise identified with the current data. Modernization index and PA levels were only modestly correlated, and thus they may represent different features of modernization, perhaps with different effects on diabetes and obesity. The higher levels of PA and lower levels of modernization index among Pimas suggest that modernization may be slower than in non-Pimas; once these variables were taken into account, there were no significant differences between the two groups in obesity or diabetes. Regardless of the mechanism, the findings that prevalence of obesity has increased in all groups between 1995 and 2010 and that greater exposure to features of modern technology is associated with higher BMI are consistent with the hypothesis that modernization is strongly associated with increased risk of obesity.

Although comparable survey data from communities undergoing rapid transition from a traditional to a modern lifestyle are rare, the current study is subject to a number of limitations. Since data derive from two cross-sectional surveys conducted 15 years apart, we were unable to document the time course of modernization or relate it more directly to development of obesity. We were also unable to assess the impact of episodic temporary migration from the community (e.g., when an individual leaves to work for a short time in a more modernized environment and then returns). The diet questionnaire was limited to a single 24-h recall in a subset of individuals. Thus, although it was administered in the same way in the 1995 and 2010 surveys, there may have been insufficient precision to capture effects on diabetes and obesity. Finally, the number of individuals with diabetes was small, so the statistical power to detect association with modernization is limited (as indicated by the wide CIs on the ORs).

In summary, the prevalence of type 2 diabetes has increased between 1995 and 2010 among non-Pima men, and to a lesser degree in women of both groups, but it has not increased among Pima men. The prevalence of obesity has increased among Pimas and non-Pimas of both sexes. These changes have occurred concomitantly with an environmental transition from a traditional to a more modernized lifestyle.

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