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

Diabetes Care 2015;38:2075–2082 | DOI: 10.2337/dc15-0089

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...
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 technic.

**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 ≤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. 1A–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 6.6% 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. 1A).

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. 1B).

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. 1C).

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
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. 1D).

### 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
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

| Table 2—Abnormal glucose tolerance among Mexican Pimas and non-Pimas in the 2010 survey |
|----------------------------------|----------------------------------|----------------------------------|----------------------------------|----------------------------------|
| Categories                        | Isolated IFG | Isolated IGT | IFG and IGT | Diabetes                        |
| Overall                           | Isolated IFG | Isolated IGT | IFG and IGT | Diabetes                        |
|                                    | 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)                       |              |              |              |                                | 354 (19.8)                      | 354 (9.9)                        | 354 (7.4)                        | 354 (9.0)                       |
| 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)                     |              |              |              |                                | 354 (19.8)                      | 354 (9.9)                        | 354 (7.4)                        | 354 (9.0)                       |
| 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/m²)                       |              |              |              |                                | 120 (11.8)                      | 120 (11.8)                       | 120 (11.8)                       | 120 (11.8)                      |
| <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 (9.6)   | 230 (9.6)                      | 181 (13.8)                      | 181 (8.8)                        | 181 (9.9)                        | 181 (13.8)                      |
| Central obesity                   |              |              |              |                                | 354 (19.8)                      | 354 (9.9)                        | 354 (7.4)                        | 354 (9.0)                       |
| 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.
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/m²)

|                        | Men (β) |        |        | Women (β) |        |        | Men + women (β) |        |        |
|------------------------|---------|--------|--------|-----------|--------|--------|----------------|--------|--------|
| 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 |        |        |
|------------------------|-----|--------|--------|-------|--------|--------|------------|--------|--------|
| 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)  | —   | —      | —      | —     | —      | —      | —          | —      | —      |
| "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 | 0.64–1.16| 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, "β" represents the regression coefficient (i.e., the difference in BMI in kg/m² 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.

Acknowledgments. The authors thank Carmen Maria Lugo Flores, Erika Yomaira Salazar Padilla, Dr. Diana Soto Contreras, Arturo Coronado Pérez, Hernán Fernando Valdez Goycolea, and Marisol Riestra Riestra (all from Centro de Investigación en Alimentación y Desarrollo A.C.) for data collection and the staff of the Phoenix Epidemiology and Clinical Research Branch, National Institute of Diabetes and Digestive and Kidney Diseases for the biochemical analyses. Special thanks are extended to Raúl Antonio Pérez Peña (Secretaria de Salud de Sonora) for his help in updating the census, participant recruitment, and facilitating work with the Mexican communities and Comisión Nacional para el Desarrollo de los Pueblos Indígenas for providing space in El Kipor for the clinic facilities. The authors thank the residents of Maycoba for participating in these studies.

Funding. The Maycoba Project was funded by the U.S. National Institutes of Health (grant 1R01DK082568-01A1 to L.O.S.). The study was also supported in part by the intramural research program of the U.S. National Institute of Diabetes and Digestive and Kidney Diseases.

Duality of Interest. No potential conflicts of interest relevant to this article were reported.

Author Contributions. J.E.-R. wrote the manuscript, researched data, and contributed to the discussion. M.E.V., R.U.-R., L.S.C., R.H.W., W.C.K., E.R., P.H.B., and L.O.S. all researched data, contributed to the discussion, and reviewed and edited the manuscript. L.O.S. is the guarantor of this work and, as such, had full access to all the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis.

Prior Presentation. Parts of this study were presented in abstract form at the 72nd Scientific Sessions of the American Diabetes Association, Philadelphia, PA, 8–12 June 2012.

References
1. Whiting DR, Guariguata L, Weil C, Shaw J. IDF diabetes atlas: global estimates of the prevalence of diabetes for 2011 and 2030. Diabetes Res Clin Pract 2011;94:311–321
2. Guariguata L, Whiting DR, Hambleton I, Beagley J, Linnenkamp U, Shaw JE. Global estimates of diabetes prevalence for 2013 and projections for 2035. Diabetes Res Clin Pract 2014;103:137–149
3. Zuo H, Shi Z, Hussain A. Prevalence, trends and risk factors for the diabetes epidemic in China: a systematic review and meta-analysis. Diabetes Res Clin Pract 2014;104:63–72
4. Hu FB. Globalization of diabetes: the role of diet, lifestyle, and genes. Diabetes Care 2011;34:1249–1257
5. Schulz LO, Bennett PH, Ravussin E, et al. Effects of traditional and western environments on prevalence of type 2 diabetes in Pima Indians in Mexico and the U.S. Diabetes Care 2006;29:1866–1871
6. Knowler WC, Pettitt DJ, Saad MF, Bennett PH. Diabetes mellitus in the Pima Indians: incidence, risk factors and pathogenesis. Diabetes Metab Rev 1990;6:1–27
7. Esparza J, Fox C, Harper IT, et al. Daily energy expenditure in Mexican and USA Pima Indians: low physical activity as a possible cause of obesity. Int J Obes Relat Metab Disord 2000;24:55–59
8. Valencia ME, Bennett PH, Ravussin E, Esparza J, Fox C, Schulz LO. The Pima Indians in Sonora, Mexico. Nutr Rev 1999;57:S55–S57; discussion S57–S58
9. Begay RC, Chaudhari LS, Esparza-Romero J, Romero RU, Schulz LO. An exploration of gardens in Maycoba, Mexico: change in the environment of a population genetically prone to diabetes. Int J Health Wellness Soc 2011;1:89–102
10. Giraldo MA, Chaudhari LS, Schulz LO. Land-use and land-cover assessment for the study of lifestyle change in a rural Mexican community: the Maycoba project. Int J Health Geogr 2012;11:27
11. Chaudhari LS, Begay RC, Schulz LO. Fifteen years of change in the food environment in a rural Mexican community: the Maycoba project. Rural Remote Health 2013;13:2404
12. Urquidez-Romero R, Esparza-Romero J, Chaudhari LS, et al. Study Design of the Maycoba Project: obesity and diabetes in Mexican Pimas. Am J Health Behav 2014;38:370–378
13. Franks PW, Hanson RL, Knowler WC, Sievers ML, Bennett PH, Looker HC. Childhood obesity, other cardiovascular risk factors, and premature death. N Engl J Med 2010;362:485–493
14. World Health Organization. Definition, Diagnosis and Classification of Diabetes Mellitus and Its Complications. Part 1. Diagnosis and Classification of Diabetes Mellitus. Geneva, World Health Org, 1999, p. 59
15. American Diabetes Association. Diagnosis and classification of diabetes mellitus. Diabetes Care 2009;32(Suppl. 1):S62–S67
16. Taylor R, Bennett P, Uli R, et al. Diabetes in Wallis Polynesians: a comparison of residents of Wallis Island and first generation migrants to Noumea, New Caledonia. Diabetes Res Clin Pract 1985;1:169–178
17. Magliano DJ, Söderberg S, Zimmet PZ, et al. Explaining the increase of diabetes prevalence and plasma glucose in Mauritius. Diabetes Care 2012;35:87–91
18. Pavkov ME, Hanson RL, Knowler WC, Bennett PH, Kraoff J, Nelson RG. Changing patterns of type 2 diabetes incidence among Pima Indians. Diabetes Care 2007;30:1758–1763
19. Esparza-Romero J, Valencia ME, Martinez ME, Ravussin E, Schulz LO, Bennett PH. Differences in insulin resistance in Mexican and U.S. Pima Indians with normal glucose tolerance. J Clin Endocrinol Metab 2010;95:E358–E362
20. Kriska AM, Pereira MA, Hanson RL, et al. Association of physical activity and serum insulin concentrations in two populations at high risk for type 2 diabetes but differing by BMI. Diabetes Care 2001;24:1175–1180