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Changes in energy expenditure and physical activity over 15 years of environmental changes: The Maycoba project

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Abstract

Objective: This work aimed to parse out the role of changing environments on body composition, total energy expenditure, and physical activity in the Mexican Pima, a population experiencing rapid industrialization.

Methods: Using doubly labeled water, we compared energy expenditure and physical activity in a longitudinal cohort of Mexican Pima ($n = 26$; female: 12) in 1995 and 2010. Body mass and composition were assessed by bioimpedance analysis. To determine the effects of environmental factors on body weight independent of age, we compared the 1995 longitudinal cohort with an age- and sex-matched cross-sectional cohort ($n = 26$) in 2010.

Results: Body mass, fat mass, and fat-free mass all significantly increased between 1995 and 2010. Despite a 13% average increase in body weight, weight-adjusted total daily energy expenditure decreased significantly. Measured physical activity levels also decreased between 1995 and 2010, after we adjusted for weight.

Conclusions: Our results suggest that the recent industrialization of the Maycoba region in Sonora, Mexico, has contributed to a decrease in physical activity, in turn contributing to weight gain and metabolic disease among the Mexican Pima.

INTRODUCTION

Obesogenic environments, the environmental factors contributing to obesity, are spreading across the globe, driving the continued rise in the global obesity epidemic [1, 2]. Industrialization exposes countries to rapid economic growth, creating novel obesogenic environments resulting in increased incidence rates of obesity and associated chronic diseases such as type 2 diabetes. Comparisons between industrialized and less industrialized populations provide evidence of a large decrease in physical activity stemming from increased sedentary behaviors. Accompanied by ready access to high-calorie foods, such environments promote weight gain and metabolic disease among those moving away from traditional lifestyles [3–5]. It is unclear, however, how environmental changes over time within a population affect physical activity level (PAL), in turn contributing to increased weight gain and the risk of obesity and metabolic diseases. In this very unique but small longitudinal study conducted in Mexican Pima living in a remote location in the region of Maycoba situated in the Sierra Madre Mountains 340 km southeast of Hermosillo in northwestern Mexico, we objectively measured the changes in energy expenditure, physical activity, and body weight between 1995 and 2010. During this 15-year period, the region underwent substantial "modernization" contributing to the Pima's rapid transition from a very traditional lifestyle toward a more Westernized lifestyle. We originally reported on this population as early as 1994 [6].

In 1995, a large cross-sectional survey conducted among Mexican Pima revealed that sex- and age-adjusted prevalence of type 2 diabetes was similar in Pima and non-Pima Mexicans in Maycoba yet the prevalence of type 2 diabetes in Mexican Pima was less than a fifth of that among US Pima residing on the Gila River Indian reservation in Arizona [5]. Between 1995 and 2010, the Maycoba region and surrounding areas underwent substantial industrialization, including the construction of roads and access to electricity and running water in most households [7]. These shifts away from a more traditional lifestyle resulted in greater access to processed foods, leading to population-wide weight gain and increased prevalence of type 2 diabetes [8-10].

While environmental changes likely play a critical role in the marked increases in obesity and type 2 diabetes among populations transitioning from traditional to Western lifestyles, it is unclear what factors influence the changes in energy balance contributing to weight gain and increased risk of chronic diseases [5]. Research comparing US and Mexican Pima highlights the stark differences between populations with a shared genetic background but various degrees of environmental industrialization [11, 12]. The greater prevalence of obesity, kidney disease, and type 2 diabetes in US Pima compared to their less industrialized counterparts in Mexico demonstrates the effects of environmental differences on health outcomes [13]. The greater PAL measured in Mexican Pima compared to US Pima likely contributes to the differences in cardiometabolic health between the two populations [14]. Reduced physical activity may thus play an important role in contributing to the positive energy balance promoting weight gain, obesity, and associated diseases in more industrialized communities.

To determine whether the cross-sectional differences in physical activity observed between US and Mexican Pima are due to major changes in environmental conditions, we collected longitudinal data in Mexican Pima. We measured total energy expenditure and PAL using doubly labeled water (DLW) 15 years apart in a cohort of 26 Mexican Pima from Maycoba. Using this longitudinal design in comparison to a new cohort of 26 Mexican Pima similar in age and sex to the original cohort, we aimed to examine prospectively the impact of environmental transitions on total energy expenditure, PAL, and weight gain among Mexican Pima while correcting for a potential birth cohort effect.

Study Importance

What is already known?

- Industrialization promotes weight gain.
- The Mexican Pima had increased rates of type 2 diabetes between 1995 and 2010.

What does this study add?

- Body mass, fat mass, and fat-free mass increased among Mexican Pima from 1995 to 2010.
- Weight-adjusted total daily energy expenditure and resting metabolic rate decreased.
- Physical activity decreased in Mexican Pima from 1995 to 2010.

How might these results change the direction of research or the focus of clinical practice?

- The disruption to traditional lifestyles needs to be considered in obesity research.
- Future efforts should focus on the effects of physical activity rather than effects of changes in body composition on risk of type 2 diabetes.

METHODS

Study sample

A cohort of Pima individuals was recruited in 1995 in the village of Maycoba, a remote region in the Sierra Madre Mountains of Mexico, to investigate the effect of environmental transition from a traditional to a more modernized lifestyle on the prevalence and incidence of obesity and type 2 diabetes [7]. Demographic, physical, and metabolic characteristics have been previously fully described [10, 14]. A sugroup of the cohort ($N = 26$; 14 male/12 female) had energy expenditure measured (total daily energy expenditure [TDEE] and resting metabolic rate [RMR]) to assess PAL (DLW and questionnaires), as well as habitual dietary intake, both in 1995 and in 2010. We called this cohort the "1995/2010 longitudinal cohort." To compare changes in anthropometrics and energy expenditure among Pima between 1995 and 2010, we recruited a cohort of Pima individuals in 2010 ($N = 26$; 14 male/12 female) from the same geographic location, who were both sex- and aged-matched to the longitudinal cohort back in 1995, which we called the "2010 cross-sectional cohort." The exact same set of energy metabolism, dietary intake, and physical activity assessments were completed in all cohorts. The study was approved by the Institutional Review Board for the Protection of Human Subjects at Northern Arizona University (no. 10.0016), the National Institute of Diabetes and Digestive and Kidney Diseases (protocol 10-DK-N161), and the Centro de Investigacion en Alimentacion y Desarrollo in Hermosillo, Mexico. All participants gave written informed consent.

Clinical assessments

Weight and height were obtained using a battery-operated electronic scale (Ohaus Defender 3000, Columbia, MD) and a portable stadiometer

(Harpenden Stadiometer, Holtain Ltd.), respectively. Body mass index (BMI) was calculated by dividing weight in kilograms by height in meters squared, allowing us to classify participants as having obesity if BMI ≥ 30 kg/m^2 or having overweight if 25 ≤ BMI < 30 kg/m^2. Body composition measurements including body fat percentage, fat-free mass (FFM; in kilograms), and fat mass (FM; in kilograms) were obtained by bioimpedance analysis (BIA-103, RJL Systems) using an equation developed for the Arizona Pima [14–16].

Energy expenditure, physical activity, and dietary intake assessments

Seven-day TDEE (kilocalories per day) was measured for all 26 participants of the 1995/2010 longitudinal cohort and for the 26 participants of the 2010 cross-sectional cohort. Seven-day TDEE was obtained using the DLW method as previously described [13]. More specifically, in both 1995 and 2010, participants ingested a 1:20 dose mixture of 99.9% ^2H_2O and 10% H_2O^{18} (Cambridge Isotope Laboratories Inc.). DLW quality control strategies were consistent across the years. They relied on the use of the same equipment and the use of the same three water standards, the Vienna standard mean ocean water, a stock of tap water, and a unique stock of stable isotope–enriched water all used in each analytical run. This guaranteed minimal differences in DLW measurement errors even across a 15-year period. Female participants were administered 1.9 g per kilogram of total body mass, and male participants received 2.1 g per kilogram of total body mass. Urine was collected at 1.5 h (discarded), 3.0 h, and 4.5 h after dosing on the first day and then twice over a 4-h period for the remainder of the 7 days. The food quotient (FQ) used to calculate energy expenditure from CO_2 production and the disappearance rates of the stable isotopes were determined as previously described [14, 17].

Similarly to TDEE, RMR (kilocalories per day) was measured in all 1995 and 2010 participants through indirect calorimetry using the same Deltatrac metabolic cart (Sensor Medics Corp.). Measurements were taken for 30 min after 10 min of rest as previously described [7, 18].

Activity energy expenditure (AEE; kilocalories per day) was obtained using the following equation AEE = TDEE − (RMR + 10% TDEE), while PAL was calculated as TDEE divided by RMR. However, given the inherent issue using ratios from two variables with intercepts not equal to zero, we also calculated physical activity as the residual value of the regression between TDEE and RMR [19, 20]. Physical activity was further assessed by a questionnaire adapted for the Mexican Pima population to evaluate weekly occupational and leisure activity in the past year as described elsewhere [14, 15].

Finally, all study participants were given one 24-h dietary recall questionnaire, including regional food items found at local grocery stores and street vendors. The nutrient and energy count contained in each food was obtained using protocol designed by Ortega and colleagues [21]. The FQ was determined for each cohort based on percentage macronutrient intake computed using the FQ equation by Labayen and colleagues [22].

Statistical analyses

Statistical analyses were conducted using the open access software RStudio (version 3.6.2). Paired *t* tests were used to compare anthropometrics, energy metabolism, and physical activity measures in the 1995/2010 longitudinal cohort. Linear regression analyses were used to determine changes in TDEE, RMR, AEE, and PAL after adjusting for weight. Pairwise comparisons were then used to determine significant changes within the longitudinal cohort and between the longitudinal and cross-sectional cohorts.

TDEE was adjusted for RMR both in 1995 and 2010 to obtain residuals, which were used as additional indices of physical activity and identified as activity-related energy expenditure (AREE). A ranked Spearman correlation test was performed to determine individual changes in AREE between 1995 and 2010.

A sensitivity analysis was conducted using linear regression analyses to determine whether physical activity indices in 1995 could predict changes in weight after 15 years, and predicted TDEE and RMR were compared to measured TDEE and RMR using paired-sample *t* tests. Linear regression models, accounting for the correlation between the 1995 and 2010 longitudinal cohorts, were used to determine the interactions between time and FFM for TDEE, RMR, and AEE between the longitudinal cohorts.

To determine the environmental effects on body composition (FFM and FM) and energy expenditure (TDEE, AEE, AREE, and PAL), we used unpaired *t* tests to compare the age-, sex-, and weight-matched 1995 longitudinal and 2010 cross-sectional cohorts; *t* tests were also used to compare the 2010 cross-sectional and 2010 longitudinal cohorts to examine the effects of age on physical activity independent of environmental factors (i.e., the birth cohort effect). Results are presented as mean ± standard deviation and were considered significant at $p < 0.05$.

RESULTS

Longitudinal data: intracohort comparisons

Anthropometry, body composition, energy expenditure, physical activity, and energy intake data of the longitudinal cohort ($N = 26$; 14 male/12 female) are summarized in Table 1. From 1995 to 2010, there was a significant increase in body weight (8.5 ± 9.2 kg or 13% ± 14%; $p < 0.0001$) and BMI (3.3 ± 3.6 kg/m^2; $p < 0.001$), with no change in FFM ($p = 0.23$) but a significant increase in FM (7.5 ± 5.6 kg; $p < 0.001$). In 1995, the longitudinal cohort reported an FQ of 0.899, whereas in 2010, their FQ was 0.892. Despite an average 13% body weight increase, neither absolute TDEE nor RMR changed between 1995 and 2010, with a tendency to decrease. When adjusted for weight, both TDEE (3139 ± 121 kcal/day vs. 2787 ± 125 kcal/day, $p = 0.050$) and RMR (1561 ± 31 kcal/day vs. 1503 ± 31 kcal/day, $p = 0.014$) significantly decreased in 2010 compared to 1995 (Figure 1). As expected, body fat percentage significantly increased ($p = 0.005$) between 1995 (mean: 29.8% ± 9.3%) and 2010 (mean:

TABLE 1 Longitudinal and cross-sectional comparisons between 1995 and 2010.

Measurements	Longitudinal 1995	Longitudinal 2010	*p* value	Cross-sectional 2010	vs. Longitudinal 1995: Mean difference (L1995–C2010)	vs. Longitudinal 1995: Standard error of the difference	vs. Longitudinal 1995: *p* value	vs. Longitudinal 2010: Mean difference (L2010–C2010)	vs. Longitudinal 2010: Standard error of the difference	vs. Longitudinal 2010: *p* value
Sex (M/F; same cohort in 1995 and 2010)	14/12	14/12	—	14/12						—
Age (y)	34.9 ± 9.8	50.0 ± 9.8	—	35.2 ± 9.8	−0.3	2.7	0.899	14.8	2.7	—
Weight (kg)	68.0 ± 14.2	76.6 ± 17.3	**<0.001**	69.2 ± 9.5	−1.2	3.3	0.730	7.4	3.9	0.063
BMI (kg/m^2)	25.2 ± 3.8	28.6 ± 5.1	**<0.001**	26.8 ± 3.9	−1.6	1.1	0.137	1.7	1.3	0.183
Body composition										
Body fat (%)	29.8 ± 9.3	32.0 ± 8.6	**0.005**	26.8 ± 9.0	3.1	2.5	0.233	5.3	2.4	**0.036**
Fat-free mass (kg)	50.6 ± 10.8	51.6 ± 11.1	0.229	50.5 ± 7.8	0.1	2.6	0.968	1.1	2.7	0.683
Fat mass (kg)	17.5 ± 7.0	25.0 ± 10.0	**<0.001**	18.7 ± 7.4	−1.2	2.0	0.557	6.3	2.4	**0.013**
Energy metabolism (objective measures)										
Total daily energy expenditure (kcal/d)[a]	3139 ± 121	2787 ± 125	**0.050**	3007 ± 120	132	—	0.440	−220	—	0.213
RMR (kcal/d)[a]	1561 ± 31	1503 ± 31	**0.014**	1572 ± 31	−11	—	0.788	−69	—	0.118
Activity energy expenditure (kcal/d)[a]	1265 ± 91	996 ± 94	**<0.001**	1134 ± 91	131	—	0.307	−138	—	0.293
PAL[a]	2.00 ± 0.06	1.84 ± 0.06	**0.006**	1.90 ± 0.06	0.10	—	0.192	−0.06	—	0.492
Respiratory quotient during RMR	0.87 ± 0.04	0.83 ± 0.08	**0.035**	0.80 ± 0.06	0.06	0.01	**<0.001**	0.03	0.02	0.151
Dietary intake (questionnaires)										
Total energy (kcal)	2762 ± 579	2219 ± 676	**0.004**	2060 ± 609	703	174	**<0.001**	160	201	0.430
Carbohydrate (% total energy)	60.9 ± 4.9	56.8 ± 9.2	0.182	54.9 ± 7.8	6.1	1.9	**0.002**	1.9	2.7	0.479
Protein (% total energy)	11.3 ± 1.7	12.3 ± 2.5	0.126	13.1 ± 3.5	−1.9	0.8	**0.019**	−0.9	0.9	0.327
Fat (% total energy)	27.6 ± 4.7	31.1 ± 8.3	0.240	31.8 ± 7.3	−4.1	1.8	**0.023**	−0.7	2.4	0.788
Physical activity (questionnaires)										
Total duration (h/wk)	4.9 ± 2.2	4.0 ± 2.0	0.107	3.5 ± 2.0	1.4	0.6	**0.021**	0.5	0.6	0.369
Leisure: total (h/wk)	0.8 ± 1.1	0.7 ± 0.7	0.805	0.4 ± 0.4	0.4	0.2	0.078	0.4	0.17	**0.040**
Leisure: low intensity (h/wk)	0.0 ± 0.0	0.0 ± 0.1	0.206	0.0 ± 0.1	−0.04	0.03	0.150	−0.02	0.03	0.388
Leisure: moderate intensity (h/wk)	0.8 ± 0.9	0.7 ± 0.7	0.863	0.3 ± 0.3	0.4	0.2	**0.042**	0.4	0.2	**0.021**
Leisure: high intensity (h/wk)	0.0 ± 0.0	0.0 ± 0.0	—	0.0 ± 0.0	0	0	1	0	0	1
Occupational: total (h/wk)	4.1 ± 2.2	3.3 ± 1.9	**<0.001**	3.1 ± 1.8	1.0	0.6	0.086	0.2	0.5	0.770

TABLE 1 (Continued)

Measurements	Longitudinal 1995	Longitudinal 2010	*p* value	Cross-sectional 2010	vs. Longitudinal 1995			vs. Longitudinal 2010		
					Mean difference (L1995–C2010)	Standard error of the difference	*p* value	Mean difference (L2010–C2010)	Standard error of the difference	*p* value
Occupational: low intensity (h/wk)	0.7 ± 0.7	1.0 ± 1.6	0.262	0.7 ± 0.9	−0.4	0.2	0.862	0.3	0.4	0.463
Occupational: moderate intensity (h/wk)	1.2 ± 0.9	1.0 ± 0.8	0.606	1.0 ± 0.7	0.1	0.2	0.567	−0.01	0.22	0.966
Occupational: high intensity (h/wk)	2.3 ± 2.5	1.3 ± 1.6	**0.034**	1.4 ± 2.1	0.9	0.6	0.163	−0.1	0.5	0.819

Note: Comparison of the longitudinal (1995 to 2010) cohort and the cross-sectional 2010 cohort ($N = 26$; 14 M/12 F) vs. the longitudinal cohort in 1995 and 2010 ($N = 26$; 14 M/12F). All values are recorded as mean ± standard deviation unless otherwise specified. Statistically significant results ($p < 0.05$) are bolded.

Abbreviations: C2010, 2010 cross-sectional cohort; L1995, 1995 longitudinal cohort; PAL, physical activity level; RMR, resting metabolic rate.

[a]Values are adjusted for weight (kg) and are recorded as mean ± standard error.

32.0% ± 8.6%), resulting in a 43% increased FM. The relationship between weight and energy expenditure (TDEE and RMR) for the 1995 and 2010 longitudinal cohorts is depicted in Figure 2. For a 1-kg increase, the 1995 longitudinal cohort showed a TDEE increase of 32 kcal/day, whereas the 2010 longitudinal cohort showed an increase of 25 kcal/day. A 1-kg increase showed an increase of 14 kcal/day in RMR for both the 1995 and the 2010 cohorts. Within-sex differences were only noted in male participants, in whom significant increases ($p = 0.027$) in body weight between 1995 (mean: 59.72 ± 9.68 kg) and 2010 (mean: 70.50 ± 11.63 kg) were seen.

Between 1995 and 2010, measures of physical activity decreased within the longitudinal cohort. In the 15-year period, AEE decreased, on average, 169 ± 387 kcal/day ($p = 0.04$). After adjusting for body weight, AEE (1265 ± 91 kcal/day vs. 996 ± 94 kcal/day; $p < 0.001$) and PAL, defined as the ratio between TDEE and RMR (2.0 ± 0.06 vs. 1.84 ± 0.06; $p = 0.006$), significantly decreased between 1995 and 2010 (Figure 3). Self-reported duration of weekly physical activity decreased by 0.9 ± 2.8 h/week ($p = 0.11$), with the latter primarily being driven by decreased occupational physical activity of high intensity (−1.0 ± 2.3 h/week; $p = 0.03$). The residual of TDEE adjusted for RMR by linear regression analysis represents another expression of AREE. However, it was not significantly different between 1995 and 2010. Spearman rank correlation between 1995 and 2010 AREE is 0.030, suggesting a weak relationship between individual physical activity behaviors in 1995 and 2010. However, baseline (1995) AEE ($p = 0.05$) and PAL ($p = 0.05$) were correlated with percentage change in weight between 1995 and 2010. The 1995 PAL was similarly correlated with the raw difference in weight between 1995 and 2010 ($p = 0.05$), yet AEE was not ($p = 0.11$). Testing for an interaction effect between time and FFM, the relationship between cohorts and FFM was not different in predicting either TDEE ($p = 0.72$), RMR ($p = 0.45$), or AEE ($p = 0.58$). The sensitivity analysis revealed no differences between predicted and measured RMR ($p = 0.16$), yet predicted TDEE was significantly greater than measured TDEE ($p < 0.001$).

Cross-sectional data: intercohort comparisons

Table 1 compares differences in anthropometrics and energy expenditure between the 1995 longitudinal cohort and the age- and sex-matched 2010 cross-sectional cohort. Since, by design, participants in both the 1995 longitudinal and the 2010 cross-sectional cohorts averaged 35 years of age, we were able to determine the effects of environmental factors (2010 vs. 1995) on body weight independent of age. The 2010 cross-sectional cohort was similar in body weight ($p = 0.73$), body composition ($p = 0.23$), and TDEE ($p = 0.64$), even after adjusting for weight ($p = 0.46$), compared to the longitudinal cohort in 1995. The computed FQ for the cross-sectional cohort was 0.884.

Neither PAL ($p = 0.25$) nor AEE ($p = 0.43$) was significantly different between the 1995 longitudinal cohort and the 2010 cross-sectional cohort, even after adjusting for weight. No differences were noted within the sexes, except for male participants who in the 2010

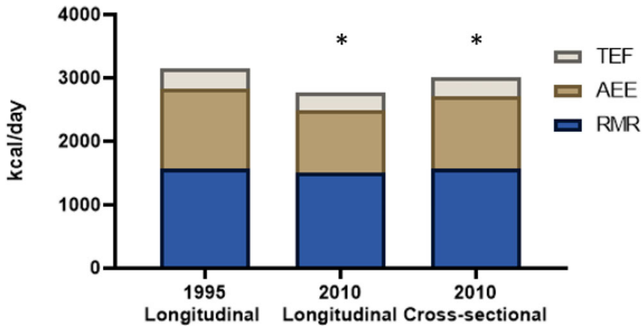

FIGURE 1 Changes in energy expenditure between 1995 and 2010. Energy expenditure adjusted for body weight (kg) comprising average RMR, AEE, and TEF (10% TDEE) at baseline (1995) and 2010 for the longitudinal and the cross-sectional cohorts. Asterisk (*) shows significance in relation to 1995 longitudinal. AEE, activity energy expenditure; RMR, resting metabolic rate; TDEE, total daily energy expenditure; TEF, thermic effect of food. [Color figure can be viewed at wileyonlinelibrary.com]

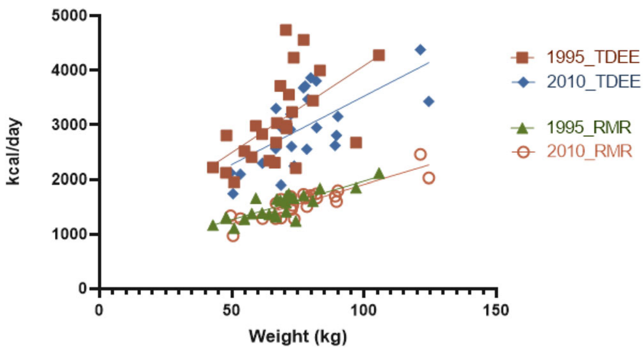

FIGURE 2 The relationship between weight and measures of energy expenditure (TDEE and RMR). Depiction of the association between weight changes and increases in TDEE and RMR for the 1995 and 2010 longitudinal cohorts. RMR, resting metabolic rate; TDEE, total daily energy expenditure. [Color figure can be viewed at wileyonlinelibrary.com]

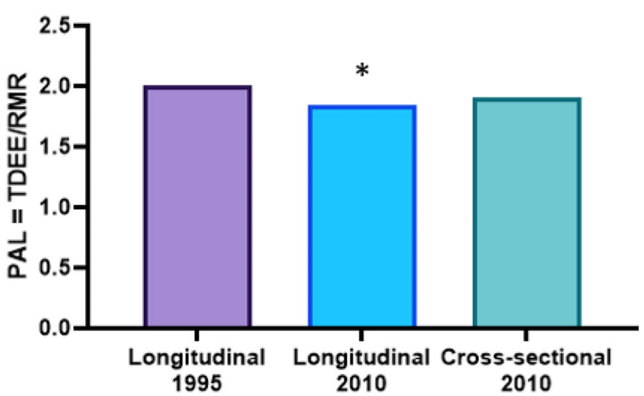

FIGURE 3 Changes in PAL between 1995 and 2010. PAL adjusted for body weight (kg) at baseline (1995) and 2010 for the longitudinal and the cross-sectional cohorts. Asterisk (*) shows significance in relation to 1995 longitudinal. PAL, physical activity level; RMR, resting metabolic rate; TDEE, total daily energy expenditure. [Color figure can be viewed at wileyonlinelibrary.com]

cross-sectional cohort (1.68 ± 0.14) had significantly decreased PAL ($p = 0.01$) compared to male participants in the 1995 longitudinal cohort (1.86 ± 0.18).

Self-reported PAL was reduced in 2010, with the 1995 longitudinal cohort participants spending 1.4 h/week ($p = 0.02$) doing more leisure/occupational activities than their age-matched counterparts in 2010. This difference was mostly driven by higher occupational activity at high intensity in 1995 (1.0 h/week more; $p = 0.03$) compared to 2010 (data not shown).

DISCUSSION

In a small but unique longitudinal cohort of 26 participants, we found that physical activity decreased among Pima from the Maycoba region in Sonora, Mexico, in the 15-year span between 1995 and 2010. While body weight increased by 13% during that time period, TDEE decreased. Despite increases in body mass between 1995 and 2010, associated changes in TDEE are likely buffered by changes in PAL in that same 15-year span. Our results and interpretation of the data differ from a recent paper summarizing TDEE, RMR, and PAL in a large meta-analysis in male and female individuals across different studies [23]. Their results showed that TDEE has decreased in US and European populations in the past 30 years whereas RMR has only decreased in male individuals but has not changed in female individuals. AEE has increased among both male and female individuals after adjusting for age and body composition since the early 1990s [23]. While the present study examined changes in energy expenditure within that same time frame, results are not comparable given the longitudinal (albeit small) sample. Furthermore, the environmental context of Maycoba greatly differs from European and US contexts as industrialization has promoted significant lifestyle shifts not reflected in Western societies over the past three decades. Our results suggest that drastic environmental changes, such as a shift away from traditional lifestyles, contributed to reduced physical activity, in turn promoting weight gain and increasing the risk of obesity and type 2 diabetes in Mexican Pima.

Decreased physical activity is commonly associated with increased obesity [24–26]. While physical activity may not contribute to weight loss, it plays an important role in weight loss maintenance and energy balance [27, 28]. Increased obesogenic environments favor sedentary behaviors contributing to the obesity epidemic in adults, which is also reflected in children and adolescents [29]. Given the 15-year gap in our data, it is likely that the younger members of our 2010 cross-sectional cohort were exposed to increasingly obesogenic environments during childhood and adolescence, compared to their older counterparts in the study. These environmental differences likely contribute to differences in behaviors such as increased sedentary patterns in the younger generation compared to the 1995 longitudinal cohort.

In the 15-year span between 1995 and 2010, the Sierra Madre region of Mexico experienced significant changes to its socioeconomic landscape. The introduction of paved roads, electricity, and greater access to running water and motorized vehicles increased the modernization index, a score based on the use of household technological features such as refrigerators, televisions, or cars, as previously described [10]. This "modernization" of a community's environment leads to greater sedentary behaviors reflected in the reduced time spent in moderate-intensity leisure activities, as was observed in the 2010 cross-sectional cohort compared to the 1995 longitudinal age-matched group as well as in reduced high-intensity occupational activities within the longitudinal cohort over 15 years. RMR and TDEE were similar between the age- and sex-matched 1995 longitudinal and 2010 cross-sectional cohorts, despite lower self-reported calorie intake in the younger generation. This potential underconsumption of the cross-sectional cohort may be related to the reduced respiratory quotient resulting in an increased preference for fat oxidation.

A survey comparing Mexican Pima with US Pima from Arizona highlighted that, despite being genetically closely related, US Pima had significantly higher rates of obesity, type 2 diabetes, and kidney disease than Mexican Pima [5, 13]. The genetic relatedness between US and Mexican Pima suggests a similar predisposition to diabetes in the Pima from Maycoba [11, 12]. Early comparisons between US and Mexican Pima emphasized the environmental influences on disease risk, as the Mexican Pima's traditional lifestyle promoted more moderate- and high-intensity activities in addition to less consumption of processed foods compared to the more industrialized US group [5, 6]. However, as the progression of industrialization of the Sierra Madre region persists over the years, Mexican Pima are becoming increasingly at greater risk for obesity and type 2 diabetes.

CONCLUSION

This study provides evidence of the effects of modernization and Westernization on physical activity among Mexican Pima from the Sonora region of Mexico. Despite its relatively small sample size, this study had a focus on objective measures of energy expenditure, and it provides unique results on the effects of changes in the environment on health 15 years apart by using the gold standard method of DLW on a longitudinal sample as well as including a cross-sectional control cohort. Our results show that physical activity decreased over the span of 15 years between 1995 and 2010, a period marked by a shift away from traditional lifestyles toward greater sedentary behaviors and processed food consumption. During this period, the prevalence of obesity increased in Pima men and women, whereas type 2 diabetes only increased in women [10]. Despite going through important socioeconomic and environmental transitions, most men were still involved in heavy agricultural activities in 2010. However, as the Sonora region continues to undergo economic development, it can be expected that rates of obesity and associated metabolic diseases will continue to rise in this predisposed population, exposing the community to greater risks of type 2 diabetes.

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CONFLICT OF INTEREST STATEMENT

The authors declared no conflict of interest.

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