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Proximity and high density of convenience stores was associated with obesity in children of a rural community of Mexico; using a Geographic Information System (GIS) approach

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Abstract

Background: Food environment (FE) has been linked to obesity in urban areas, but there is limited information in rural areas, particularly in developing countries, where prevalence of obesity is high. **Objective:** To determine the association between FE and childhood obesity using Geographic Information Systems (GIS). **Methods:** A total of 218 children (8 10 y) participated in a cross-sectional study. Weight, height and body fat were measured. Geolocation of convenience stores (CS) and participants' households was collected and the amount of processed food (PF) in the stores was measured. The proximity to the nearest CS and the number of CS within a 250m buffer from each participant's household was calculated using GIS. Linear regression models between obesity measurements and food environment were performed. **Results:** The combined prevalence of overweight and obesity was 32%. A total of 91% of the children had access to a CS within 250 m. On average, 48% of the shelf space of the CS were occupied with PF. A positive association between the density of CS with body fat % (β=0.145; 95CI: 0.048, 0.241, p=0.004), abdominal fat % (β=0.206; 95%CI: 0.048, 0.241, p=0.003) and BMI-for-age z-score (β=0.028; 95%CI: 0.005, 0.062, p=0.005) was found. Living closer to CS was associated with increases in body fat% (β=-0.009; 95CI: -0.017, -0.001, p=0.025), abdominal fat % (β=-0.012; 95%CI: -0.023, -0.001, p=0.033) and BMI-for-age z-score (β= -0.002, 95%CI: -0.004, -0.001, p=0.003). **Conclusion:** In a rural community in Mexico, a high density and low proximity to CS is associated with obesity in school-aged children.

Key Words: Childhood obesity, food environment, GIS, rural areas

Introduction

Almost thirty percent of Mexican children are either obese or overweight. According to nutrition and health surveys, prevalence of childhood obesity has stabilized in urban areas while it still rising in rural areas of Mexico [1,2]. Overweight and obese children have an increased risk of oxidative stress, inflammation and insulin resistance and they are more likely to remain obese throughout their life [3]. Obesity is the result of the balance between energy intake and expenditure and a complex interaction with socioeconomic, physiological and genetic factors[4]. In addition, new insight has proved that food environment, which has been defined as the entire environment that influence food selection and food intake[5], plays a key role in the etiology of obesity[6,7]. The food environment includes food stores and food service establishments, such as convenience stores (CS), supermarkets, local markets, restaurants, fast food stands, among others [8,9]. In the developing world, it is also possible to find small CS or neighborhood CS, and these stores represent an important economic model for the retailing business[10]. In Mexico and some parts of Central America, these small CS are called “tienditas” or “misceláneas”, are usually family-owned, and are mainly run by the women in the households[11]. By definition, “tienditas” are convenience stores that provide rapid access to essential products such as food staples (tortillas, rice, beans, eggs, bread, sugar, vegetables, canned foods), toiletries (soap, detergents, toothpaste, toilet paper), processed foods (candy, chips, cookies), and some sell other items such as school supplies[11].

Studies addressing the association between food environment and obesity have shown contrasting results among ethnicities, age groups, areas (urban vs rural) and countries [12-18]. For instance, proximity to supermarkets in Indiana, USA, has been associated with a healthier diet and negatively associated with overweight and obesity in children in adolescents (3 – 18 y) [14-16]. In contrast, availability of CS within a 0.25 mile (400m) buffer was associated with a greater risk of overweight and obesity in 6-7 year old girls living in Northern California [17]. In addition, it has been observed that income and ethnicity are not only associated with the location, size and number of stores present in the food environment, but also with the selection of available food[18]. It is important to consider that most of the studies on this topic have come from developed countries, in urban settings, and have been done in adult populations. Interestingly, even though Mexico has one of the highest rates of obesity worldwide, there is limited information concerning the association between food environment and obesity, and the available information is from urban areas. For instance, one study in two urban settings found that the number of mobile food vendors around schools was positively related with children's BMI[19] . In rural settings from developing countries, most families get their food from CS and it is common for children to play a role in household food purchasing [11].

Using Geographic Information Systems (GIS) provides a reliable and objective measurement on food environment [20]. A large list of proxies have been used to evaluate food environment, such as the stores within a given radius, the proximity to the nearest food store and the shelf-length of highly processed food and non-processed foods [21]. A major challenge is to identify proxies that better represent food environment and that consider social, racial, physical and age-related factors in a community or an individual. [20,22].

Given the high rates of overweight and obesity in Mexico and the large proportion of the population living in rural communities, the main objective of this cross-sectional study is to assess the association between obesity and food environment in children of rural Mexico.

Methods

Population and study design

A cross sectional study was conducted among 218 children (8 -10 years) from a rural community named Santa Cruz in the municipality of El Marques within the state of Queretaro, Mexico. The community has a population of 3902, the ethnicity is predominantly mestizo (mixed-race individual), and agriculture is the main economic activity. The nearest supermarket is in the city of Queretaro (nearest metropolitan center), 35 km away from El Marques, so people from the community usually buy their food from small CS ("tienditas" or "misceláneas"). Children's information was collected from August 2016 until May 2017.

Children were recruited from the elementary school in the community. Parents were asked to attend a meeting where the study procedures were explained. Those that agreed to participate, signed consent forms and were included in the study. Also, children provided their assent to participate. Children who were under a prescribed physical activity or diet regimen were excluded from the study. This study was conducted according to the guidelines of the Declaration of Helsinki and all procedures involving human subjects were approved by the Bioethics Committee of the Universidad Autónoma de Querétaro (UAQ).

Demographic questionnaire

A demographic questionnaire was answered by the caretaker. The questionnaire included information related to their living conditions (number of rooms in the house, inside running water, home appliances, among others), main mode of transportation, family income and caregiver's level of education. The information in the questionnaire was used to determine the socioeconomic level of the participants' households.

Physical activity

Physical activity was estimated using a validated questionnaire specifically for Mexican populations[23]. According to the compendium of physical activities of Ainsworth[24], the intensities of the physical activities were categorized in three according to the number of the metabolic equivalent of task (METS): light (<3 METS), moderate (3–6 Mets) and vigorous activity (>6 Mets). The resulting hours of each type were divided into days of the week to obtain daily hours practiced of each type of activity.

Anthropometry and body composition

Children were transported with their mothers from the community to the Nutrition Clinic at the UAQ. Weight, height and waist circumference were measured twice with a precision of 0.1 g or 0.1 cm respectively, in all children by trained personnel following the World Health Organization (WHO) procedures [25]. Children were weighed barefoot and wearing light clothes, using a calibrated digital scale (SECA, mod 813 Hamburg, Germany). Height was measured using a stadiometer (SECA, mod 206 Hamburg, Germany). Nutritional status was calculated based on the WHO criteria of BMI-for-age for children aged 5-19 years using the Anthroplus software (Geneva: WHO, 2009). Underweight was defined as two z-scores below the WHO reference median, overweight as one standard deviation above the WHO reference median and obese as two standard deviations above the reference median of the BMI-for-age z-score (BMIz) [26]. Whole body composition was also measured by a certified technician using Dual-energy X-ray absorptiometry (DXA) (Hologic Mod Explorer, 4500 C/W QDR, INC 35 Crosby Drive, Bedford, MA 01730, USA). Body fat percent and body fat content (Kg) were recorded from the values provided by the DXA. Abdominal fat percent and abdominal fat content (Kg) were estimated following procedures described by Hill *et al* [27]. High body fat for girls was considered above 30% and above 25% for boys[28,29].

Geographical data

The geolocation of each participant's household, of all the CS available in the community, and of the school in the community were obtained using ¨Open Data Kit tool¨ that was preinstalled in android OS devices equipped with a Global Positioning System (GPS) chip. We identified through a community audit, two types of stores in the community. The first stores that were identified were the "tienditas" or "misceláneas", typical family owned found in Mexico. The second type of food stores found were "food venues", which are local or ambulant small stalls that usually sell 1 or 2 products, such as "aguas frescas" (sugar sweetened fruit drinks), homemade fried chips, candies, among others. For the purpose of this study, we analyzed only CS, since this is where the inhabitants acquire most of their food [30]. The community audit was done by foot and data collection was obtained from August 2016 until May 2017.

In Store Availability

Using a measuring tape, a two person team measured the shelf-length (m) of Processed Foods (PF) and Non or Minimally Processed Foods (NMPF) to the nearest cm

[31]. The PF were defined as those foods processed to help preserve and enhance nutrients and freshness, foods that combined ingredients (such as flavor, sweeteners, spices and preservatives) for safety and taste, and ready-to-eat foods with minimal or no needed preparation[32]. These PF included foods such as sugar sweetened beverages, salty snacks (chips, popcorn), cookies, pastries, candies (chocolates, hard candy and gum), ice cream, dairy products (except milk), instant soup, doughnuts, box bread, ready-to-eat cereals, ham, sausages, and canned products. The NMPF included fresh fruits and vegetables, unprocessed chicken, beef or pork, eggs, milk, maize tortillas, beans, rice, and water, among others.

Food Store Access

A GIS database was constructed geocoding all the CS and the participants' households using ArcMap 10 (Redlands, CA) (Figure 1). To determine the best density (number of stores/area) proxy for the food environment, four circular buffers of 150 m, 200 m, 250 m and 300 m radius were defined around each household. The WGS1984 coordinate system with a fuller projection was used to geocode addresses and calculate distances and buffers. The number of stores and the shelf length of each type of food (PF and NMPF) within each buffer was quantified. The length of the buffers was determined based on key GIS data collection information and the characteristics of the community, such as the extension, population and number of stores[33]. The proximity was assess using the Euclidean distance (straight-line distance), to evaluate distance between each participant's household and the nearest convenience store.

Statistical analysis

A descriptive analysis of the demographic variables was performed. As a first step, we assessed which density measure best correlated with obesity. For this purpose, a set of linear regression models between the different measurements of obesity (i.e. BMIz, abdominal and total body fat percent) with the number of stores in 150 m, 200 m, 250 m and 300 m buffers were performed. The 250 m buffer was selected to calculate the density of CS because it had the highest coefficient with body fat (b=0.16), abdominal fat (b=0.22) and BMI (b=0.03).

Normality of the independent variables was confirmed by visual inspection and the Shapiro-Wilk test. Linearity of the association was confirmed visually inspecting the data with a LOWESS graph and by plotting the regression residuals. Also, data analysis of all variables where checked for outliers.

We evaluated the relationship between in-store food availability (i.e. total shelf length of PF and NPF) and the different measurements of obesity. We performed a linear model assessing the association between obesity and food environment (i.e. density and proximity of CS), while controlling for the different components of food environment and possible confounders (i.e. sex, age, caregiver's educational level, physical activity and proximity to school). All statistical analyses were performed by SPSS v23.0 (SPSS Chicago, IL, USA).

To evaluate if "other food venues" have an influence on the measurements of obesity, we carried out sensitivity analysis. We calculated the density and proximity, this time including "other food venues" together with the CS in the linear models (i.e. any food venue or convenience store in a 250m buffer or the shortest distance to any "other food venues" or CS).

Results

The general characteristics of the children who participated in the study are shown in Table 1. Of the total population, 55% percent of the studied children were girls, and 52% of the children had an elevated percentage of body fat. The main mode of transportation inside the community in all participants was walking. More than 90% of the households had low SES, more than 29% of the caregivers did not complete elementary school and 91% of the households had access to at least 1 CS within 250 m for their households.

A total of 58 food venues were found in the whole community: 40 CS and 18 other food venues such as two “tortillerías” (stores that only sell tortillas), one pastry shop, two butcheries and one poultry shop, one fast food restaurant and 11 street vendors that sold different kinds of food such as “tamales”, corncob, peanuts, and salty deep-fried “churros”. Sixty-two percent (± 16 SD) of the shelf-space in the CS contains PF, which represents an average of 16.73 m (± 9.3 SD) of the shelf-space (Table 2).

As summarized in Table 3, children with high body fat percent had access to more CS compared to children with normal body fat percent. No differences were observed in proximity to CS in children depending on their body fat percent.

As observed in Table 4, when adjusting for confounding (sex, age, caregiver’s educational level, physical activity and proximity to school), the density of CS was positively associated with all the measurements of obesity (body fat %, abdominal fat % and BMIz). The proximity to CS was negatively associated with all the measurements of obesity, an increase of 100 meters in the proximity to the nearest convenience store was associated with lower body fat -0.9% (95%CI -1.7% and -0.1%) abdominal fat -1.12% (95%CI -2.3% and -0.1%) and BMI-for-age-z-score -0.2 (95%CI -0.4% and -0.1%). Also, the shelf-meters of both PF and NMPF were positively associated with higher BMIz. However, no differences were observed between groups when analyzing the PF/NMPF ratio.

The sensitivity analysis showed no variations in the coefficient or the direction of the associations between density and proximity with the measurements of obesity after including "other food venues".

Discussion

In the present study, the food environment of a rural community of Mexico was evaluated. To the best of our knowledge, the results show for the first time the relationship between obesity and measures of food environment in a rural setting in Mexico, where no supermarkets are available, and where its habitants are compelled to buy their food in small CS. In this community, a high density and low proximity to CS was associated with obesity in children, and they were exposed on average to 11.5 CS within 250 m from their household.

The food environment of this community differs importantly from other studies in different countries. The main reason of these differences is that most of the studies that have evaluated food environment and its relationship with obesity, have been done in high income countries, in both urban and rural communities. There is limited research of this type in rural communities from lower-medium income countries, such as Mexico. This has to be taken into consideration when comparing the results from a rural community in

Mexico to those from other settings in high income countries with different contexts. For instance, in a community in Texas, near the border between Mexico and the United states, three CS could be found within a 1600 m buffer of the participants' households[7]. In Denmark, in metropolitan areas only 54% of the population had one or more CS within a 250 m buffer and in non-metropolitan areas only 22% of the population had one or more CS within a 250 m buffer [34]. In the city of New Orleans in the US, 38% of the studied households had one store within 1600 m buffer and 62% had the nearest store farther than 1600 m buffer[35]. In contrast, in the present study, 91% of the children living in the studied community had access to at least 1 CS in a 250 m buffer. Thus, when comparing with other populations and areas in developed countries, the children of this rural community had access to a higher number of CS in their environment.

Higher density and proximity of food stores was associated with a higher BMI, and with higher body and abdominal fat in 8-10 year children living in a rural setting. Most of the studies that have evaluated the association of food environment and obesity have been done in adults and in urban areas, and only a few studies have been done in rural settings and in children[7,19,36-39]. Results of studies in adults in both urban and rural area are similar to the results of the present study. For instance, in urban settings in the US, proximity, and frequent use of CS, are associated with higher BMI in adults and households[37,40,41]. Food swamps with a higher density of establishments selling high calorie food and lower density of establishments selling healthier food are predictors of adult obesity, particularly in counties with income inequality and low mobility[42].

Similarly, studies in rural communities have found that limited access to healthy foods is one of the main contributors to a poor diet and obesity[43]. Studies that have evaluated the role that the food environment has on childhood obesity have produced inconsistent result [44,45]. In Canada, 58% of children had access to one CS within 800 m walking, and proximity and density was not associated with obesity[46], while children living near a CS in Guam were most likely to have higher BMI z-score compared to those that lived farther away[47]. Similarly, the presence of one or more CS around participants households (a block around or in a 1600 m buffer) in different cities in the US was positively associated with obesity in both children and adolescents[6,7]. In addition, the presence of CS near schools has also been associated with obesity in different countries [19,38,48]. In Mexico, for instance, the number of mobile food venues around both, public and private schools, was positively associated with obesity[19]). Thus, the evidence suggests that the density of CS near children's households and schools is strongly associated with higher BMI.

The association between the density of food venues and obesity in the population studied may be explained by different social and psychological factors. It is more likely that children living close to a higher density of stores can find a store in their way to their destination (i.e. school, family member house, while playing in the street) and therefore have increased access to CS and food products compared with children living far away from CS [49,50]. Also, children sharing a higher density of stores are exposed to visual cues more often, both outside and inside the stores, where advertisement as promotions, free toys, and colorful labels of their food products may be found [51,52].

In the present study, shelf-space dedicated to PF, which tend to be more energy dense, was higher than NMPF, and the shelf-space of both was associated with obesity in children. However, no association was observed of PF/NMPF with any measure of obesity. These results suggest that the density and proximity of CS are better predictors of obesity than the proportion of PF/NMPF. To our knowledge, no studies have evaluated the relationship between shelf-space of specific foods and obesity in Mexico, but there is evidence in developed countries. Studies in both Australia and the United States have shown that shelf-space dedicated to energy dense food and less healthy foods is greater in neighborhoods with low SES[39,53]. Rural stores in Australia had lower shelf space of fruits and vegetables and higher shelf space of soft drinks compared to urban stores, and rural areas in this country have high prevalence of overweight and obesity[54].

Some limitations of the study need to be addressed. The cross-sectional design of the study does not allow to draw conclusions about causality. Even though associations between food environment and obesity were observed, these associations were small. Since obesity is a multifactorial disease, other factors, such as genetics, may be more important. In addition, there may be behaviors that were not measured in the study, such as the routes the children take to visit family members that may influence their exposure to the food environment of the community. Another limitation is the small sample size of the participants. Also, no information of how often children actually shop in the CS is available, or what type of food they actually purchase. Despite adjusting for proximity to the school, children shared similar food environments near their houses and their school, and thus, the assumption of independence of residuals might be violated. Physical activity was measured using self-reported data and this may be subject to recall bias.

The main strength of the study was the assessment of all the CS available to the community, providing better estimates for the associations found. Another strength of the study was using DXA to measure body composition as an indicator of obesity. Also, the present study is one of the few addressing the relationship between “tienditas” and childhood obesity in rural communities, where supermarkets are not available.

Future studies in rural communities should include information regarding how often the children buy food in the CS, what type of food they purchase, and how children move within the community, around their households and their school.

Conclusion

Georeferenced locations provide a useful approach to assess the relationship between food environment and obesity by modelling spatial accessibility (density, proximity to CS and exposure to processed foods). The results show that food environment near participants’ households is associated with obesity in 8-10 year old children living in a rural community in Mexico. In a country where prevalence of childhood obesity is one of the highest in the world, understanding the food environment will contribute to shape the environment to promote and support healthy eating and thus, prevent childhood obesity.

Author Contributions

OPG, MCP and GAZ conceived and designed the study. YTP and GAZ carried out the field work, YTP, JLR, JEEP, CALG, CMD and GAZ analyzed and interpreted data, and OPG, CALG and JLR gave important intellectual advice. OPGO, GAZ and YTP drafted the manuscript. All authors were involved in revising the paper and had final approval of the submitted and published versions.

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Conflict of interest

The Authors declare that there is no conflict of interest.

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Table 1. Main characteristics of the study participants and according to body fat percentage (normal/high).

Characteristics	Total (n=218) Mean ± SD[1]		Normal body fat (n=105) Mean ± SD		High body fat (n=113) Mean ± SD	
Age (months)	100.6 ± 18		97.14 ± 18.07		104 ± 18.34	
Physical activity level						
Moderate physical activity (h/week)	8.57 ± 7.53		8.93 ± 8.06		8.24 ± 7.02	
Intense physical activity (h/week)	3.37 ± 4.15		3.59 ± 5.00		3.15 ± 3.14	
Anthopometry and body						
Weight (kg)	27.07 ± 8		23.36 ± 4.94		30.5 ± 8.4*	
Height (cm)	125.3 ± 10		122.94 ± 9.28		127 ± 9.84*	
Waist circumference (cm)	59.07 ± 9		54.12 ± 5.2		63.7 ± 9.25*	
Height for age (z-score)	-0.72 ± 1		-0.89 ± 1.02		-0.56 ± 0.88	
BMI[2] for age (z-score)	0.33 ± 1		-0.34 ± 1.06		0.96 ± 1.02*	
Body fat (%)	28.77 ± 7		23.42 ± 3.57		33.7 ± 4.78*	
Abdominal fat (%)	27.82 ± 10		20.33 ± 4.32		34.8 ± 7.62*	
	n	%	n	%	n	%
Caregiver's educational level						
No formal education	5	4.4%	14	6.4%	9	8.6%
Incomplete elementary school	28	24.8%	50	22.9%	22	21.0%
Complete elementary school	56	49.6%	114	52.3%	58	55.2%
Middle school or more	24	21.2%	40	18.3%	16	15.2%

[1] SD: Standard Deviation; [2] BMI: Body Mass Index

*Different with t-test or Chi squared-test with Bonferroni correction for multiple comparisons between normal and high body fat (>30% girls and >25% boys).

Table 2. Linear meters of non or minimally and process foods from the convenience stores of the community

	Mean	SD[1]	Median	Minimum	Maximum
Non or Minimally Processed Foods	10.2	10.82	8.90	0	15.32
Processed Foods	16.72	9.32	16.78	0	22.57

[1] SD: Standard Deviation

Table 3. Density and proximity to convenience stores of the study participants according to body fat percentage (normal/high).

	Total (n=218)		Normal body fat (n=105)		High body fat (n=113)	
	Mean (SD)[1]	Median (range)	Mean (SD)	Median (range)	Mean (SD)	Median (range)
Density (n CS[2]/250 m buffer)	11.5 (8.5)	11 (0 - 28)	9.6 (7.8)	10 (0-25)	12.8 (8.7) *	13 (0 - 28)
Proximity to closer store (m)	126.5 (107.2)	86.92 (5.5 - 683.8)	142 (106.7)	100.6 (5.8 - 378.5)	115.6 (107.0)	79.4 (5.6 - 682.8)

[1] SD: Standard Deviation; [2] CS: Convenience stores

*Different with t-test with Bonferroni correction for multiple comparisons between normal and high body fat

Table 4. Association between food environment and measurements of obesity.

	Body fat %			Abdominal fat %			BMIz[3]		
	β[1]	95% CI[2]	*p**	β	95% CI	*p*	β	95% CI	*p*
CS[4] Density (n/250 m buffer)	0.145	(0.048; 0.241)	0.004	0.206	(0.069; 0.343)	0.003	0.028	(0.005; 0.062)	0.005
Proximity (m)	-0.009	(-0.017; -0.001)	0.025	-0.012	(-0.023; -0.001)	0.033	-0.002	(-0.004; -0.001)	0.003
Food Access in CS (250m buffer)									
Shelf-space PF[5] (m)	0.071	(-0.249; 0.392)	0.662	0.047	(-0.409; 0.502)	0.845	0.002	(0.000; 0.003)	0.008
Shelf-space NMPF[6] (m)	0.055	(-0.105; 0.216)	0.497	0.049	(-0.178; 0.277)	0.661	0.072	(0.009; 0.135)	0.025
Ratio PF/NMPF	0.210	(-0.592; 0.479)	0.125	0.266	(-0.121;0.654)	0.174	-0.012	(-0.061; 0.037)	0.662

[1] *β*: beta regression coefficient; [2] BMIz: body mass index z-score; [3]CI: 95% confidence interval; [4]CS: convenience stores;

[5]PF: processed foods; [6]NMPF: non or minimally processed foods

*Adjusted by: sex, age, caretaker's educational level, physical activity and proximity to school