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Chapter 19
Parasitic Infection, Obesity, and Micronutrient Deficiencies in School-Aged Children in Mexico

Olga P. García, Gerardo A. Zavala, Maiza Campos-Ponce, Colleen M. Doak, Katja Polman, and Jorge L. Rosado

19.1 Introduction

Intestinal parasitic infections (PI) are a global health concern, particularly in children. The PI are among the most common infectious diseases in humans worldwide, and combined with obesity and micronutrient deficiencies, account for more than 10% of the global disability-adjusted-life-years (DALY's) (Black et al., 2013; Ng et al., 2014).

Intestinal PI are known to cause micronutrient deficiencies because of their effect on nutrient absorption, dysbiosis, anorexia and nutrient loss (Katona & Katona, 2008). Micronutrient deficiencies are also known to increase the risk of infections, thus, creating a cycle that affects millions of children around the world (Bhaskaram,

O. P. García (✉) · J. L. Rosado
Department of Human Nutrition, School of Natural Sciences, Universidad Autónoma de Querétaro, Querétaro, Mexico
e-mail: olga.garcia@uaq.mx

G. A. Zavala
Department of Health Sciences, University of York, York, UK

M. Campos-Ponce
Section of Infectious Disease, Department of Health Sciences, VU Amsterdam, Amsterdam, the Netherlands
e-mail: m.camposponce@vu.nl

C. M. Doak
Center for Health Sciences Education, St. Ambrose University, Davenport, IA, USA
e-mail: doakcolleenm@sau.edu

K. Polman
Department of Health Sciences, VU Amsterdam, Amsterdam, the Netherlands

Department of Biomedical Sciences, Institute of Tropical Medicine, Antwerp, Belgium
e-mail: kpolman@itg.be

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2002; Katona & Katona, 2008; Stephenson et al., 2000). It is well recognized that PI is strongly related with high rates of undernutrition, particularly in children from low- and middle-income countries with limited access to health services. The most common micronutrients studied in relation to PI have been zinc, iron and vitamin A (de Gier et al., 2014), and little is known of the relationship of PI with other micronutrients, such as vitamins C, D or E that are important to maintain an adequate immune response (Maggini et al., 2007).

There is little information available on the effects of intestinal PI in populations with high prevalence of overweight and obesity. Also, there is limited information regarding the effect of PI in populations that in addition have micronutrient deficiencies. Like many countries in Latin America, Mexico has a high prevalence of micronutrient deficiencies and of PI. In addition, it has one of the highest rates of obesity in the world. Thus, coexistence of these three conditions is not only probable, but also a reality, and its consequences remain to be confirmed.

In this chapter, the epidemiology of PI, micronutrient deficiencies and obesity in rural Mexico is described. The relationship of PI and micronutrients in a population with high rates of obesity is also discussed.

19.2 Epidemiology of PI, Micronutrient Deficiencies and Obesity

Intestinal PI have been among the leading causes of morbidity and mortality in the world, and highly prevalent in populations around the world. They affect mainly children living in low- and middle-income countries, with tropical and subtropical weather. The intestinal PI are caused by soil transmitted helminths (STHs) and intestinal protozoan. The main intestinal parasites that cause infections in humans are shown in Table 19.1.

In Mexico, between 30% and 70% of the children have intestinal PI (Diaz et al., 2003; Morales et al., 2003; Quihui et al., 2006). The highest prevalence has been observed in the southern regions of the country. In Querétaro, a state in the plateau region in Mexico, the overall reported prevalence of PI in school-aged children from rural communities was reported to be 61% (Zavala et al., 2016). In these communities, STHs infection was 19%, and *A. lumbricoides* had the highest prevalence with 16%. A total of 47% had a protozoan infection, and the two most common were *Entamoeba coli* (20%) and *Endolimax nana* (16%). The prevalence of *E. histolytica*

Table 19.1 Main intestinal parasites that cause infections in humans

Soil transmitted helminths	Intestinal protozoan
Ascaris lumbricoides (roundworm)	*Giardia lamblia*
Trichuris trichuria (whipworm)	*Entamoeba histolytica/dispar*
Necator americanus and *Ancycostoma duodenale* (hookworm)	

Source: World Health Organization (WHO, 2013) and *Giardia lamblia* was <6%. Thus, the main protozoan infections among these children were from non-pathogenic protozoans.

In addition to the high prevalence of intestinal PI, the prevalence of micronutrient deficiencies among children in Mexico is still present. The prevalence of anemia in 5–11 years old children is 19%, and among 1–4 years old children is almost 30%. At least one micronutrient deficiency is associated with anemia in approximately 19% and 13% of preschoolers and school-aged children, respectively (De la Cruz-Góngora et al., 2021).

One of the major public health concerns in Mexico, and other countries in Latin America, is the rapid increase in childhood obesity. According to the latest national data, prevalence of overweight among <5-year-old children is 6.8%, and the combined prevalence of overweight and obesity of school-aged children is 35.5% (Shamah-Levy et al., 2020). Obesity is higher among school-aged boys (20.1%) compared to school-aged girls (15%) and are of the highest in the world. In rural areas, the prevalence of obesity among boys and girls has increased in the past years, but the prevalence of overweight has increased more in girls compared to boys (Shamah-Levy et al., 2020). In Queretaro, more than 50% of school-aged children have been reported to have high body fat (Zavala et al., 2018).

The co-existence of obesity, PI and micronutrient deficiencies represent a burden on the health care system in Mexico. It is important to consider that 46% of the Mexican population is living in poverty, which increases the risk of these conditions (CONEVAL, 2020). In addition, living with obesity, micronutrient deficiencies and PI are related with low-grade systemic inflammation, impaired growth and development, and both short- and long-term metabolic consequences (Barrera et al., 2016; Zavala et al., 2013).

19.3 Parasitic Infections, Obesity and Food Intake

The studies of PI have focused on their effects on children's growth and nutrition, mainly due to anorexia, nutrient malabsorption, increased blood loss, nutrient competition and lately, it has also been attributed to the altered composition of the gut microbiota or dysbiosis (Duedu et al., 2015; Nguyen et al., 2012; Oriá et al., 2016; Schaible & Stefan, 2007). For instance, *A. lumbricoides* has consistently been associated with lower BMI z-score (BMIz) and growth impairment (Hall et al., 2008; Papier et al., 2014). There is also evidence of the effect of giardiasis on stunting and impaired psychomotor development in children (Prado et al., 2005; Simsek et al., 2004).

It has been observed that infections with some virus and bacteria may also increase the risk of overweight and obesity (Atkinson, 2008; Yang et al., 2013). Recently, it was found that school-aged children from rural Mexico that had moderate/heavy infection with the "non-pathogenic" *Entamoeba coli* (*E. coli*) had increased body fat (Zavala et al., 2016). There are several mechanisms that may explain this association. As mentioned before, *E. coli*, as other protozoan, may cause alterations in the composition of the gut microbiome, which in turn, cause gut permeability (Oriá et al., 2016). Dysbiosis has been reported to increase energy intake, and thus, increase the risk of obesity (Gangarapu et al., 2014; Sánchez et al., 2014). In addition, gut permeability increases both intestinal and systemic inflammation, which may increase the risk of other non-communicable diseases such as diabetes and hypertension (Cox et al., 2015).

It is well documented that intestinal PI reduce food intake because it may cause reduced appetite and anorexia (Schaible & Stefan, 2007). However, evidence on the effect that PI may cause food intake in populations with a high prevalence of obesity is scarce. In rural Mexico, infection with *E. coli* was associated with higher food intake in children (Zavala et al., 2017). The dysbiosis caused by intestinal PI, specifically *E. coli*, may increase food intake and may even change food preferences, possibly caused by the effect that gut microbiota has on appetite regulation (Byrne et al., 2015; Sánchez et al., 2014). Also, the inflammation observed during PI infections may be another mechanism that increases food intake mainly due to its effect on appetite (Cani et al., 2009). The mechanisms involving the role of *E. coli* in the development of obesity and increased food intake should be studied further.

19.4 Parasitic Infections and Micronutrients

Most of the evidence in Mexico of the relationship between micronutrients and intestinal PI have focused on undernourished populations and only a few micronutrients have been studied, such as iron, zinc, and vitamin A (Rosado et al., 2009; Vazquez-Garibay et al., 2002). For instance, in Mexico, low vitamin A concentrations have been observed in children infected with *G. lamblia* (Quihui-Cota et al., 2008). In both the northwest and the central Pacific coast of Mexico, *T. trichuria* infection has been related to low iron concentrations (Quihui-Cota et al., 2010a, Gutierrez-Rodríguez et al., 2007). Also in the northwest, school-aged children infected with *G. lamblia* were considered at risk of zinc deficiency (Quihui et al., 2010b).

The effect that PI have on vitamins and mineral status is well documented and may be attributed to several mechanisms. Intestinal PI decrease appetite, decrease micronutrient absorption by increasing gut permeability, increase both intestinal and systemic inflammation, and increase blood losses (Hesham et al., 2004; Toro et al., 2019; Zavala et al., 2018). The effect on the human host may vary according to the parasite. For instance, infection with *G. lamblia* or with *A. lumbricoides* have been observed to decrease vitamin A absorption (Astiazaran-García et al., 2010; Strunz et al., 2016). In case of iron, STH and protozoa infections have been observed to interfere with iron metabolism, increase blood loss, decrease iron absorption and increase the risk of iron deficiency anemia in children (Shaw & Friedman, 2011).

It is important to consider that micronutrient deficiencies also increase the risk of intestinal PI (Katona & Katona-Apte, 2008). It is well recognized that malnutrition, including micronutrient deficiencies, impair the immune response and thus, the risk of infection is higher. The PI, in turn, increases the risk of malnutrition and micronutrient deficiencies, causing a vicious cycle that affects growth, cognitive development and overall health outcomes in children.

There is limited information regarding other micronutrients and PI. In a rural population of central Mexico, our research group found higher iron and B12 concentration in school-aged children infected with *E. coli* and *E. nana*, compared to non-infected children, probably due to a higher reported intake of foods, mainly animal food sources (data not published). More research is needed to explore how PI affect the status of other micronutrients.

19.5 Parasitic Infections and Micronutrients, Obesity

Elevated body fat, PI, and micronutrient deficiencies were present in approximately 14% of school-aged children living in rural Mexico. A total of 20% of the children with obesity and 12% of children with micronutrient deficiencies had PI with at least one parasite. In this population, the association between intestinal parasites and micronutrients, specifically zinc and vitamin A, differed between children with normal body weight and obesity, suggesting a complex relationship between these three public health problems.

It is important to consider that all three of these conditions, obesity, intestinal PI and micronutrient deficiency, have a direct effect on local (intestine) and systemic inflammatory processes in the body. Alterations in the immune response and increased concentration of pro-inflammatory markers may induce obesity and as mentioned before, other non-communicable diseases such as type II diabetes and hypertension (Esser et al., 2014). This is true for both pathogenic and non-pathogenic parasites. *E. coli*, for instance, has been associated with gut inflammation in children, even when it is considered a non-pathogenic parasite, and may cause health problems in the future, particularly in populations with a high prevalence of obesity (Zavala et al., 2018). Further research is needed to explore the relationship and possible mechanisms of the coexistence of micronutrient deficiencies, parasites and obesity.

19.6 Policy and Public Health Implications

Approximately 60% of school-aged children in rural areas from central Mexico are infected with IP, and more than 70% have some type of malnutrition (i.e.: micronutrient deficiencies or obesity). According to recent information, some IP may be contributing to the rapid increase in the prevalence of obesity. Thus, policy makers should consider, that not only undernourished but also populations with obesity may be affected by intestinal PI, and the consequences of this infection may vary with specific parasites. The same may be occurring in other countries of Latin America, where intestinal PI, obesity and micronutrient deficiencies are highly prevalent. Public health programs are urgently needed to address these three conditions, not as separate health problems, but as one. In order to address these health problems, a multidisciplinary approach will be needed to reduce the burden of PI, reduce the rates of obesity and decrease the prevalence of micronutrient deficiency in rural Mexico and other low- and middle-income countries.

Also, public health programs and policy makers should consider that the environment is key to the development of these three conditions: PI, obesity and micronutrient deficiency. Nutrition transition in Mexico and other countries because of globalization, has changed food systems and food patterns (Cuevas García-Dorado et al., 2019). The food environment has been related to obesity in rural Mexico due to the increased intake of high energy affordable foods with low nutritional quality (Zavala et al., 2021). Thus, effective public health programs and policies should include improvement in food environments, living conditions (hygiene, access to water), mass anti-parasitic treatment and education (Asaolu & Ofoeri, 2003; Davis et al., 2007).

19.7 Conclusions

In Mexico, as in other parts of Latin America, the prevalence of obesity, intestinal PI and micronutrient deficiencies are high. Some PI, such as infections with *E. coli*, may be increasing the risk of obesity and increased food intake in school-aged children living in rural Mexico. Also, the relationship of micronutrients deficiencies and PI may change depending on body fat content. Coexistence of obesity, PI and micronutrient deficiencies may occur in children living in rural areas with poor hygiene, limited access to health services, and with a diet high in calories and low in micronutrients. More studies are needed to explore the consequences of PI in populations with high prevalence of obesity and micronutrient deficiencies. Also, studies should also evaluate the coexistence of obesity, micronutrient deficiencies and PI in different contexts and different communities in Mexico and other countries in Latin America. The existence of these three conditions should be considered when planning health and community development programs to reduce the burden of PI, obesity and micronutrient deficiencies.

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