

**Examining the multigenerational effects of obesity and stunting in a
Latin American middle income country: The case of Colombia**

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Abstract

The examination of multigenerational effects on health in Latin American populations from grandparents to subsequent generations is a fruitful area for research which has not yet been fully explored. Within this context, understanding the multigenerational effects on obesity—an important health concern both within the US and internationally—merits further consideration. Using comprehensive data collected on households and individuals throughout Colombia in 2010 (**ENDS** and **ENSIN**) we examined the degree to which prevalence of obesity in older generations predicts obesity in subsequent generations. We also examined grandparent and mother height in regards to child stunting. We find strong associations between (1) grandmother-mother and mother-female child in terms of obesity; (2) grandfather and female child obesity; (3) grandparent height and child stunting which is mediated by mother height. While it may be too early for us to fully observe multigenerational effects of obesity, our results suggest the importance of early life conditions. Our examination of multigenerational effects provides a relevant starting point in a field where there are few studies from the LAC region regarding multigenerational effects and health.

Introduction

The examination of multigenerational effects on health in Latin American populations from grandparents to their grandchildren is a fruitful area for research, yet it has not been fully explored. Multigenerational effects on health have been examined using social science survey data (Currie & Moretti, 2007; Davis, McGonagle, Schoeni, & Stafford, 2008). However, the call to examine multigenerational effects within the context of major social and demographic transitions (Mare, 2011)—transitions that have characterized the Latin American and Caribbean (LAC) region in the later part of the 20th century—has largely been unanswered.

Within this context, understanding the multigenerational impact of obesity—an important health concern both within the LAC region and internationally (He, Goodkind, & Kowal, 2016)—merits further consideration. Although individual lifestyle at older ages provides partial explanations for obesity (Kuh & Ben-Shlomo, 2004), poor environmental conditions in early life, such as poor nutrition and infectious diseases in combination with the rapid demographic transitions of the last century, provide relevant explanations for the increasing risk of chronic conditions and obesity (Palloni & Souza, 2013). Rapid improvements in mortality amidst mostly stagnant economic growth produced increasing survivors of poor early life conditions who, at older ages, are at increased risk of chronic conditions and obesity because of their early life environmental conditions (McEniry, 2014; Palloni, McEniry, Wong, & Peláez, 2006). These early life effects, if then transmitted to future generations, could not only influence the nutritional status of future generations but also result in increasing risk of obesity for future generations, even when future generations experience improvement in nutrition.

A large portion of older adults in middle income countries were born or grew up in rural areas which limited access to good nutrition and proper medical care (Flórez, Guataquí, Mendez, & Cote, In press; Flórez & Méndez, 2000; López-Alonso, 2007). Inadequate nutrition *in utero* during critical periods can lead to poor intrauterine and post-birth growth reflected in low birth weight and stunted babies, producing an increased risk of heart disease, diabetes, and obesity at older ages (Barker, 1998). Predictive adaptive responses made *in utero* as a result of cues from a nutritionally resource scarce environment prepare the individual to survive in a similar environment by altering an individual's physiology but a mismatch occurs when exposed to a nutritionally richer environment later in life, leading to disease (Bateson & Gluckman, 2011; Gluckman & Hanson, 2005). Major demographic and epidemiological changes leading to increased urbanization and exposure to non-traditional foods high in saturated fats (Popkin, 2006; Schmidhuber & Shetty, 2005) may compound early life effects by increasing the risk of a mismatch between early life physiological changes and later life environment, thereby increasing the risk of poor health at older ages.

Undoubtedly, there is a complex interplay between environmental, behavioral, genetic, and epigenetic mechanisms explaining differences in the risk of obesity (Gluckman & Hanson, 2005; Somer & Thummel, 2014). However, epigenetic transmission due to poor nutrition provide a compelling explanation for multigenerational effects (Davis et al., 2008; Dijk, Tellam, Morrison, Muhlhausler, & Molloy, 2015; Kelleher et al., 2014; Nielsen, Nielsen, & Holm, 2015) and are very relevant to LAC. Epigenetic factors modify gene expression in one generation and are transmitted as epigenetic inheritance to future generations through phenotypic to phenotype transmission or through direct germ line transmission (Kuzawa & Eisenberg,

2014)¹. The importance of the mother's nutrition cannot be denied in terms on intergenerational and possibly multigenerational transmission (Battista, Hivert, Duval, & Baillargeon, 2011; Currie & Moretti, 2007; Susser et al., 2012). A mother's diet may have a long-lasting influence on the health of upcoming generations, including the propensity to obesity, independently of later diet changes (Cooney, 2006; Cropley, Suter, Beckman, & Martin, 2006; Kuzawa & Eisenberg, 2014).² However, transmission through the germ line of epigenetic information (either male sperm or female egg) can also produce lasting gender-specific effects across generations affecting health (Curley, Mashoodh, & Champagne, 2011; Pembrey et al., 2006; Pembrey, Saffery, Bygren, & Epidemiology, 2014). Thus, male transmission of early life effects is a very relevant consideration and illustrates the importance of examining gender differences to illuminate the presence of possible epigenetic mechanisms at play. Evidence of transgenerational transmission of epigenetic effects occur when gender specific associations are observed between the paternal grandparent and their grandchildren (Kuzawa & Eisenberg, 2014). The culture of care between children and their grandparents may mediate or confound epigenetics effects (Kuzawa & Eisenberg, 2014), particularly for those multigenerational households where children and their mothers and grandparents live together.

¹ Phenotypic to phenotype transmission occurs when poor environmental conditions change the gestational or lactational environments, resulting in poor health for the next generation. Direct germ line transmission occurs when poor environments modify epigenetic factors which are then passed on through sperm or egg, resulting in adverse effects for the next generation.

² Kuzawa & Eisenberg (Kuzawa & Eisenberg, 2014) also point out the importance of understanding the long-term nutritional history of one's ancestors and that there is evidence to show that nutritional supplements during pregnancy are not sufficient to change the long-term nutritional history of the family.

Colombia: A case study

Colombia is an important setting because it is a large, middle income country with a growing population of older adults and an increasing prevalence of obesity and chronic conditions (Cano-Gutierrez, Reyes-Ortiz, Samper-Ternent, Gélvez-Rueda, & Borda, 2015). During the last decades of the 20th century, urban areas in particular benefited from increased modernization, urbanization, and mother's education. However, unlike other LAC countries, the social and political situation had profound effects on population aging. A large percentage of young adults died as a result of the armed conflict and many resources have been devoted to the armed conflict, which has left areas of Colombia with many older adults and affected the country's aging process overall (Gomez, Curcio, & Duque, 2009).

However, patterns of rapid decline in mortality amidst slower economic growth and dramatic improvements in life expectancy in the last century in Colombia fit the pattern described in other LAC countries (Palloni & Souza, 2013). Colombia experienced rapid mortality decline starting at end of the 1930s through the 1980s from improvements in infant mortality due to public health policies and interventions and medical technology (Flórez et al., In press; Flórez & Méndez, 2000). The decline in IMR was most rapid between 1935 and 1979 in contrast to steady and slower economic growth (Figure 1). Because inequality was relatively high (GINI index in the low 50s), the benefit of increased economic growth was not equally distributed in the population. In terms of the impact on generations, by the end of the 20th century, IMR was much lower on average for children born during this period as compared to IMR when their mothers were born and certainly in regards to their grandparents born in the late 1930s

and early 1940s. Accompanying the rapid decrease in IMR was the rapid increase in life expectancy (Flórez et al., In press; Flórez & Méndez, 2000).

Improvements in nutrition dramatically increased in Colombia (Figure 2), resulting in grandparents born in a period of rather low country-level caloric intake (1940s-1950s), mothers born in a period of rapidly increasing caloric intake (1960s-1980s), and children born in period of a steadily increasing and high caloric intake (last decade of the 20th century and early 20th century). Changes occurred particularly during the period from 1965 to 2005 when caloric intake at the country level increased by about 35%. Children born in the last 20 years experienced a period of relatively high caloric intake as compared with their mothers when dramatic changes were occurring and with their grandparents when nutritional supply was more stagnant. Recent consumption data show a remarkable consumption of foods high in saturated fat and sugar especially among young children (Figure 3), exposing them to increased risk of conditions such as obesity.

[Insert Figures 1-3 about here]

The Colombian family dramatically changed in the later portion of the 20th century in terms of living arrangements (Flórez et al., In press; Flórez & Méndez, 2000). Whereas multigenerational households were the predominant household of the early 20th century, by 1993 and 2010, their presence had dropped to about 11% and 8% of households, respectively. Today's grandparent generation was born and raised mostly in the 1950s-1960s in a context where the predominant type of households was two-

parent households while the child generation of the last decade of the 20th century and early 21st century was born in the context of single-parent households and the loss of importance of multigenerational households.

Give the theoretical framework of the social determinants of health, these different social, economic, and demographic contexts in which multi-generations are born and raised have implications for their health conditions (obesity and nutrition). Colombia then is an ideal setting by which to examine the multigenerational effects of obesity in a country which has experienced rapid demographic, nutritional, and social changes. The conditions of rapid improvement in infant mortality in the generation of grandparents of the 1940s-1970s combined with rapid improvement in nutrition in mothers (1970s-1995) and their children (1990s-present) could have produced the type of mismatch resulting in not only a higher prevalence of obesity in older adults but, if we are to believe in epigenetic transmission of effects across generations, also higher risk of obesity in mothers and their children and strong association between poor nutritional status of children and their grandparents.

We start with comprehensive data representative of Colombian households. Even though multigenerational households are now a small portion of all Colombian households and even though living separately undoubtedly impacts interpersonal relationships, if epigenetic transmissions indeed explain multigenerational effects, living arrangements should not make a difference in terms of understanding multigenerational effects that originate through epigenetic inheritance.

Our focus is on maternal grandparent multigenerational households. We examine basic questions regarding health, obesity, and nutritional status in these types of households:

1. What is the overall health profile of Colombian households across generations?
2. What is the pattern of obesity prevalence across generations?
3. Is childhood obesity associated with the mother's or grandparent's obesity? Is there evidence that the nutritional status of children is associated with that of the grandparents?

Data and methods

Data

The data come from two large national surveys of households in Colombia: **ENDS** (National Survey of Demography and Health/Encuesta Nacional de Demografía y Salud; profamilia.org.co/investigaciones/ends/) and **ENSIN** (National Survey of the Nutritional Situation/Encuesta Nacional de la Situación Nutricional; www.icbf.gov.co/portal/page/portal/PortalICBF/bienestar/nutricion/ensin). ENDS is a household survey carried out by ProFamilia in Colombia (ProFamilia, 2011) on a recurring 5-year basis since 1990 and is comparable to other demographic and health surveys from other countries. ENSIN, administered by the Colombian Institute for Family Wellbeing (Instituto Colombiano de Bienestar Familiar, 2011), has extensive information on nutrition on a recurring 5-year basis. ENDS and ENSIN contain a wealth of information on households and individuals. Basic variables such as age, gender, years of education, population concentration of household, and a wealth index are available for all households and individuals. We select 2010 because the selected

sample was the same for both surveys and we can draw upon the comprehensiveness of each survey to obtain in-depth profiles of the health of family members. In addition, the 2010 ENDS survey included an expanded section for older adults. ENDS and ENSIN 2010 sampled 51,447 households and 204,459 individuals.

Measures

We defined **obesity** in adults (ages 18 and older) as a body mass index (BMI) greater than or equal to 30. We used BMI as created in ENDS. For children (18 years and younger), we used obesity as defined by the child growth standards of the World Health Organization (WHO). We used an ENDS created variable (BMI standard deviations, according to WHO) to define obesity in children less than 5 years of age (greater than 3 SD) and children 5-17 years of age (greater than 2 SD). For **stunting** in children, we used an ENDS-created variable (height/age standard deviations, according to WHO) and defined stunting in all children (0-17 years) with standard deviations less than negative two standard deviations from the mean).

We defined **poor self-reported health** (SRH) for those answering either “regular” or “not good” on a 5-point scale using the ENDS variable. Mothers of children less than 5 living in the household answered for themselves and their children. In other instances, the person designated to answer the household questionnaire answered for respondents who could not answer for themselves (e.g., children or adults not present).

We use **age**, **gender**, and **current residence** as controlling variables. To identify biological grandparents, mothers, and their children, we used a variable which asked if the mother/father lived in the household and, if yes, the household line number of the parent. The variable for current residence indicates, to some degree, the socio-

economic context of the household: living in one of the principal cities of Colombia (Bogotá, Medellín, Cali, Barranquilla), all other urban, or rural. The appendix provides more detail in regards to how we created the data files for children with their mothers and grandparents.

Analyses

For our analyses, we first selected households where children (less than 5 years old) living in households had mothers also living in the households and had grandparents who were heads of households. There was more complete information on this group of children and their mothers. We also selected households where children (ages 5-17) had grandparents who were heads of households and where the mother of the child could be either present or not in the household. This older group of children had less information regarding grandparents and mother characteristics. This resulted in a group of 3,020 children less than 5 in 2,467 households and 5,279 children ages 5-17 in 3,749 households.

Our descriptive analyses provide profiles of children, their mothers, and grandparents according to age, gender, poor self-reported health, height, and obesity. We then estimate a series of logistic regression models for each group of children for obesity and stunting controlling for age and gender of child, mother, and grandparent characteristics (when relevant). Providing evidence of epigenetic changes in survey data is difficult due to confounding factors such as behavior (care), especially when multigenerational families live within the same household, noted differences in patterns of gender effects may provide suggestive evidence. Thus, we examine separate logistic regression models for grandmothers and grandfathers with children and then by gender

of children. We estimate nested models of grandparent obesity with child, controlling for mother obesity (height), to determine the degree to which the effects of grandparents are attenuated when adding mother obesity (height). We examine relationships between height of mothers and their parents with ordinary least squares regression models, controlling for mother's age and parent's age and gender.

Missing values or missing information

In most cases, there were few missing values for age, gender, or current residence. Missing values appear for obesity and/or height: *Group of children 5-17* ($n=5729$), biological grandfather (28%), biological grandmother (10%), mother of child 5-17 if living in household (14%), child (9%), household head (female or male) (15%), stunting child (9%). *Group of children less than 5* ($n=3020$), biological grandfather (24%), biological grandmother (9%), mother of child less than 5 (8%), child (5%), household head (female or male) (16%), stunting child (5%)³.

Results

Sample characteristics

Children of both age groups show a slightly higher prevalence of males than females (Table 1) and similar prevalence of poor self-reported health (14-15%). The prevalence of obesity is much smaller in children less than 5 (1%) than in older children (5%). Mothers of children show a higher prevalence of obesity and poor self-reported

³ We examined possible reasons for missing values for grandfather obesity more carefully. In about 2 (6)% of the cases in households of children less than 5 (children 5-17) we found that the grandfather was older than 64 years and was therefore not measured for height or weight. When we excluded these older individuals, there was no difference in age, poor self-reported health or current residence between grandfathers less than 64 with/without missing values for obesity. However, we did find evidence that missing values tended to be higher in wealthier households for households with children less than 5 ($p<0.01$) (but not in households with children 5-17).

health. Height has increased on average by about 2 cm (less than 1 inch) from mother (grandmother) to mother (daughter) in households with children LT 5 years old and by about 4 cm (about 1 ½ inch) in households with older children. There is a higher prevalence of obesity in grandparents and in particular grandmother and a much higher prevalence of poor self-reported health, in particular for grandmothers. There is a high percentage of female household heads (about 50%). For the most part, fathers of the child are not present in the households and in the case of older children, mothers are not always present in the households. Most households are in urban areas and there are instances of multiple children living in the same household with grandparents as heads of households, especially with older children.

[Insert Table 1 about here]

Obesity

For children less than 5 whose mothers are daughters of household heads, we found no direct association between obesity of grandparents and children (Table 2). However, we did find a strong association between obesity of grandparents and mothers, particularly between grandmother and mother [OR 3.47, $p < 0.001$] as compared with grandfathers and mother [OR 1.92, $p < 0.05$]. While there were significant effects of mother obesity and the obesity of their children [OR 3.27, $p < 0.05$ child], particularly their female children [OR 5.69, $p < 0.01$], mother and child models were not significant.

For children 5-17 years old, when we examine only those cases where the mother is living in the household and the mother is the daughter of the head of the household,

we see strong associations between: (1) mother and child obesity [OR 2.63, $p < 0.001$] but particularly with her female children [OR 3.44, $p < 0.001$], (2) grandfather and mother obesity [OR 2.57, $p < 0.001$], (3) grandmother and mother obesity [OR 2.93, $p < 0.001$], and (4) grandfather and child obesity [OR 3.04, $p < 0.001$] which attenuated when adding mother obesity [OR 2.80, $p < 0.01$], (4) stronger associations appear between grandfather obesity and female child obesity [OR 3.93, $p < 0.01$] although these effects attenuate slightly when adding mother obesity [OR 3.39, $p < 0.05$]. Whereas in the grandmother models with children, mother obesity is significant in nested grandmother models ($p < 0.001$), except for models with the male child $p < 0.05$, mother obesity is not significant in nested grandfather models with children. For children 5-17 whose mothers are not living in the household, we find strong associations between the female head of household and child obesity [OR 2.27, $p < 0.01$], in particular with female children [OR 3.81, $p < 0.001$].

[Insert Tables 2-3 about here]

Stunting

For children less than 5 whose mothers are daughters of the household head, we find much stronger and consistent results (most models are significant at $p < 0.001$) (Table 4). Strong associations between mother and grandfather height [OLS 0.46, $p < 0.001$] although slightly stronger between mother and grandmother height [OLS 0.50, $p < 0.001$]. Strong associations between mother height and stunting in their children [OR 0.89, $p < 0.001$], regardless of gender. The effects of grandfather height on child stunting (female or male) are highly significant [OR 0.92, $p < 0.001$] but these effects disappear when adding mother height. The effects of grandmother height on

child stunting are slightly stronger but also highly significant [OR 0.94, $p < 0.001$, OR 0.95, $p < 0.001$] but disappear adding mother height. Mother height in all nested grandparent models is highly statistically significant (results not shown in Table 4).

For children ages 5-17, we find similar results for strong associations between grandfather and mother height [OLS 0.49, $p < 0.001$] and slightly stronger associations between grandmother and mother height [OLS 0.49, $p < 0.001$]. Strong associations appear between mother height and children stunting [OR 0.87, $p < 0.001$], with little difference in gender of child. We observed strong association between grandfather height and child stunting [OR 0.92, $p < 0.001$], although it appears much stronger in male children [OR 0.89, $p < 0.001$]. Adding mother height attenuates these effects and grandfather effects become not significant except for male children [OR 0.94, $p < 0.05$]; mother height is highly significant (later result not shown in table). Similar results appear for grandmothers with the exception of female child where grandmother height is associated with female child stunting [OR 0.92, $p < 0.001$]. When adding mother obesity, significant grandmother effects completely disappear; mother height is highly significant and stronger (results not shown in table). For those children whose mothers are not living in household, we find strong associations between the height of the household head regardless of gender of their grandchildren. There appears to be very small differences between male or female heads of households and their grandchildren.

[Insert Tables 4-5 about here]

Conclusions

Using comprehensive household data from Colombia, we examined multigenerational households where the grandparents were head/spouse of head of the

household and in multigenerational households which have experienced dramatic differences in environmental exposures between child and their mothers and grandparents. Overall, the health profile across generations shows an expected increase in poor self-reported health and obesity as age increases, with mother showing increases in height as compared with their parents. In terms of obesity, we found evidence for strong intergenerational associations in obesity between mothers and their children (grandmother-mother, or mother-female child). For children less than 5, we found nothing very revealing about obesity in younger children but rather in older children (5-17) we do find strong multigenerational associations between grandfather and female child obesity. In terms of stunting, we found strong associations between stunting and maternal grandparents and children of all ages, although mother's height mediates the effects of grandparent height.

Although we cannot identify specific mechanisms of multigenerational transmission of health, our results provide insight as to the relative importance of early life conditions and obesity in Colombia in the context of multigenerational households. The finding of strong associations between the female line (grandmother obesity to mother obesity to female child obesity) regardless of the age of the child is consistent with what other studies have shown (Susser et al., 2012) and point to the importance of understanding the long-term history of maternal nutrition. It is not surprising that we did not find significant associations between grandparents and children under the age of five, as the prevalence of obesity in children less than five was very small and obesity often appears in older children, in particular during the years of rapid growth (Costa-Font, Jofre-Bonet, & Grand, 2016).

The finding of associations between grandfather obesity and granddaughter obesity in households with children 5-17 could point to evidence of paternal epigenetic inheritance and transgenerational transmission (Kuzawa & Eisenberg, 2014). It could also be that there is a unique and special relationship found only between grandfathers and female children in Colombia although this is not a likely explanation. However, missing values for grandfather obesity require caution in making a more definitive interpretation. Although we found no significant differences in age, residence and household wealth for missing/non missing obesity in grandfathers (results not shown), there may be other differences that we cannot adequately capture with our data. The slight attenuation of grandfather effects when adding mother obesity suggests a possible mediation role for mother obesity, although curiously mother obesity was not significant in any of the nested grandfather models (whereas in the nested grandmother models it was). The associations between the obesity of the female head of household (could be biological or not biological grandmother) with female children 5-17, again point to the possible importance of the maternal line of transmission of obesity, although in this group of children we cannot identify the biological relationships because the mother of the child is not present in the household.

In terms of stunting, the direct strong associations between grandparent height and child stunting in children of all ages suggests the importance of multigenerational transmission. The mediating effects of mother height suggests that, in part, nutrition has improved in Colombia for children and that perhaps, if it exists, the chain of multigenerational transmission of stunting has been partially interrupted. It may very well be that the dramatic differences between the environmental exposures between child and grandparents now results in weaker associations between grandparent height

and child stunting. However, a long family history of maternal undernutrition is not easily overcome in one generation of improved nutrition due to phenotypic inertia (Kuzawa & Eisenberg, 2014) and animal models suggests that it takes several generations to eliminate the effects of poor nutrition (Martorell & Zongrone, 2012). International transmission of stunting between mother and child is well established (Martorell & Zongrone, 2012). Without data on multigenerational effects prior to the dramatic changes in Colombia, it is difficult to ascertain the degree to which our findings indeed indicate improvement in breaking a multigenerational cycle of stunting.

Colombia continues to face stunting in children along with increasing prevalence of obesity in older adults. Obesity in older adults is a relatively recent phenomenon, partially due to the rapid demographic transitions of the past (Palloni & Souza, 2013), whereas stunting in children has occurred across several generations. Thus, it may be too early to fully examine the effects of grandparental obesity on children, in particular in aspects of what is occurring in other countries, such as the combination of simultaneous stunting (undernourishment) and obesity (overnourishment) in children (Black et al., 2013). We also do not have information from our data source on obesity in older adults 65 and older—the generation born in the 1930s-1940s when these rapid transitions began—which may help illuminate our multigenerational analysis.

The implications for settings experiencing increased prevalence of obesity in older adults in settings such as Colombia is that if indeed poor early life conditions are transmitted across multiple generations resulting in increased risk of obesity, then our understanding of the determinants of health in future generations will need to reflect this wider perspective into how the past affects future health. Increasingly

understanding the long-term nutritional history may have the potential to help explain current health and point to directions of future research and public policy.

Our study has several limitations. First, we cannot adequately control for the confounding effect of care-mediated effects since our data are multigenerational households, making it more difficult to distinguish epigenetic inheritance from environment and culture. Even though examining gender differences is an important first step, the lack of variables regarding child-grandparent care is an important omitted factor. Second, although we control for mother age, the wide range of mother age reflects a diversity of exposure and we may not be adequately capturing this diversity. Third, the higher number of missing values for grandfather obesity in households with children 5-17 could be problematic, even though for the most part we did not find significant differences between groups of grandfathers along basic characteristics of age, poor self-reported health, residence and wealth of household. Women tended to be more present in the household than men for purposes of measurement. Fourth, models which examine gender differences between children and their grandparents tend to have smaller sample sizes. Fifth, Colombian multigenerational households are a special case of examining multigenerational effects because most of Colombian households are now mostly nuclear and not multigenerational with children and their grandparents living in separate households. While epigenetic inheritance should be independent of living arrangements, it may be that multigenerational households are different in other ways. Sixth, we have yet to fully control for food consumption. Food consumption was obtained on a smaller sample within ENSIN and the next step in our analyses is an imputation of consumption to the larger sample size of children with mothers and grandparents. Seventh, not having information on height and obesity for mothers not

living in the household and fathers in general limits our examination of older children. Both parents being obese is a risk factor for having obese children (Costa-Font et al., 2016). Eight, although in most cases there are not multiple children or mothers within the household, clustering effects due to multiple children or mothers in the households is still a relevant consideration. Nine, child age and parent gender is an important consideration (Thompson, 2012) and while we controlled for these factors, an examination of children by separate age groups according to rapid, slower growth periods may be illustrative. Ten, the focus of our study was on maternal grandparents and thus we cannot reach conclusions about paternal transmission of multigenerational effects.

In spite of these limitations, our examination of multigenerational effects of obesity in a middle income country such as Colombia that has experienced tremendous changes in the last 50-60 years, is a relevant starting point in a field where there are few studies from the LAC region regarding multigenerational effects and health. Increasing prevalence of obesity in older adults raises relevant questions regarding the degree to which future generations may bear the burden of such conditions. In that regard, our study provides insight and suggests that poor early life conditions which explains obesity in one generation may indeed predict obesity in subsequent generations.

Appendix

Mothers living in the household

We used mothers living in the household to determine the biological relationship between grandparents and grandchildren. If mother was not present (children 5-17), we were not able to ascertain biological relationships (about 44% of the grandchildren ages 5-17).

Household heads, ages 65 and higher

We excluded this group of household heads because measurement of height and weight was only obtained in those less than 64 years of age. Spouses who were 65 years and older were not measured for height either.

Maternal versus paternal grandparents

We base our analysis on the mother's relation to the head to determine biological relationships. Thus, we are analyzing maternal grandparents. However, in households with children 5-17 who have no mother living in the household we not only cannot determine biological relationships but we cannot determine if the head of household is the maternal or paternal grandparents. However, given the traditions of Colombian society, many of these households are more probably headed by maternal grandparents.

Fathers of children

We do not examine fathers of children living in households with grandparents as heads of households because, for the most part, there is a small portion of fathers living in the household. Therefore, we cannot examine the obesity of fathers.

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Table 1: Sample characteristics according to age of child

	Children LT 5	Children 5-17
Child age	1.75 (1)	9 (3)
Female (%)	49	48
Poor SRH (%)	14	15
Obesity (%)	1	5
Stunting (%)	11	9
Mother age	24 (5)	30 (5)
Poor SRH (%)	22	27
Obesity (%)	11	15
Height (cm)	156 (6)	156 (6)
Grandfather age	53 (8)	58 (7)
Poor SRH (%)	41	45
Obesity (%)	17	18
Height (cm)	166 (7)	165 (6)
Grandmother age	49 (7)	54 (6)
Poor SRH (%)	51	51
Obesity (%)	32	37
Height (cm)	154 (6)	152 (6)
Context		
Female head of household (%)	50	52
Mother living in household (%)	100	56
Father living in household (%)	21	18
Residence (%)		
Principal urban city	30	25
Other urban	47	48
Rural	23	27
# Children	3020	5729
# Households	2467	3749

Notes: Data are weighted using sample weights. Grandparents are biological grandparents. Households with children LT 5: grandfather (n=1579) and grandmother (n=2855); households with children 5-17: grandfather (n=1225) and grandmother (n=2485).

Table 2: Effects of grandparent and mother obesity on children LT 5 obesity

Obesity	Mother	Child	Female Child	Male Child
Mother		3.27*	5.69**	1.66
Grandfather	1.92*	0.85	1.00	2.36
Grandmother	3.47***	1.71	1.44	2.23

Source: ENDS (ProFamilia, 2011), children LT 5, n=3020. Missing values for obesity result in samples slightly smaller.

Notes: Mother is mother of the child LT 5 years old and daughter to the head and/or spouse. Each cell represents a different model; all models control for child age, gender, mother age, household head age, gender, and residence, where relevant. Models significant at $p < 0.01$ for grandfather and mother and $p < 0.001$ for grandmother and mother. All other models not significant.

Sample sizes:

Mother: child (2684), female child (1345), male child (1339)

Grandfather: mother (1086), child (1150), female child (493), male child (577)

Grandmother: mother (2327), child (2496), female child (1237), male child (1259)

Table 3: Effects of grandparents and mother obesity on children ages 5-17

Obesity	Mother	Child	Female Child	Male Child
<i>Mothers in HH</i>				
Mother		2.63***	3.44***	2.09*
Grandfather	2.57***	3.04***	3.93**	2.59*
Grandfather + mother		2.80**	3.39*	2.45
Grandmother	2.93***	1.62*	1.67	1.58
Grandmother + mother		1.32	1.22	1.42
<i>Mothers not in HH</i>				
HH head female		2.27**	3.81**	1.56
HH head male		2.23*	2.75	1.83

Source: ENDS (ProFamilia, 2011), children 5-17, n=5729. Missing values for obesity result in samples slightly smaller.

Notes: *p<0.05, **p<0.01, ***p<0.001

Household head is female or male and possibly not biological parent and grandparent. Only about 50% of mothers of children were living in household to determine whether the household head was related to the mother. Mother is the mother of the child 5-18 years old and daughter to the head and/or spouse. Each cell represents a different model; all models control for child age, gender, mother age, grandparent age, grandparent gender, and residence, where relevant.

Sample sizes with significance of estimated model:

Mother: child (2178***), female child (1057***), male child (1121)

Grandfather: mother (792***), child (768**), female child (378**), male child (390)

(Grandfather + mother): child (768*), female child (378**), male child (390)

Grandmother: mother (1961***), child (1906), female child (916), male child (990*)

(Grandmother + mother): child (1906***), female child (916***), male child (990**)

Household head female: child (1157*), female child (552*), male child (605*)

Household head male: child (1022), female child (491), male child (531)

Note that mother obesity was significant in nested grandmother models (p<0.001), except for with male child model (p<0.05). In contrast, mother obesity was not significant in any of the grandfather models with children.

Table 4: Effects of grandparent and mother height on stunting in children LT 5

Height (cm)	Mother height (OLS coeff)	Child (OR)	Child Stunting	
			Female Child (OR)	Male Child (OR)
Mother		0.89***	0.90***	0.88***
Grandfather	0.46***	0.92***	0.92***	0.92***
Grandfather + mother hgt		0.96*	0.96	0.96
Grandmother	0.50***	0.94***	0.94***	0.95***
Grandmother + mother hgt		0.99	0.98	1.01

Source: ENDS (ProFamilia, 2011), children LT 5, n=3020. Missing values for height result in samples slightly smaller.

Notes: *p<0.05, **p<0.01, ***p<0.001

Mother height models based on ordinary least squares (OLS); all other models based on logistic regression and show odds ratios (OR).

Mother is mother of the child LT 5 years old and daughter to the head and/or spouse. Each cell represents a different model; all models control for child age, gender, mother age, grandparent age, grandparent gender, and residence, where relevant.

Sample sizes, significance of which are all at p<0.001 except where noted:

Mother: child (2473), female child (1236), male child (1237)

Grandfather: mother (1023), child (997), female child (498*), male child (499)

Grandfather + mother: child (997), female child (498), male child (499)

Grandmother: mother (2194), child (2140), female child (1058), male child (1082)

Grandmother + mother: child (2140), female child (1058), male child (1082)

Note that mother height is significant in all cases for both grandfather and grandmother models when adding mother height (results not shown in table).

Table 5: Effects of grandparent and mother height on stunting in children 5-17

Height (cm)	Mother height (OLS coeff)	Child Stunting		
		Child (OR)	Female Child (OR)	Male Child (OR)
<i>Mother in HH</i>				
Mother		0.87***	0.86***	0.88***
Grandfather	0.44***	0.92***	0.96	0.89***
Grandfather + mother hgt		0.97	1.00	0.94*
Grandmother	0.49***	0.94***	0.92***	0.95**
Grandmother + mother hgt		0.99	0.98	1.00
<i>Mother not in HH</i>				
HH head female		0.92***	0.92***	0.92**
HH head male		0.93***	0.94**	0.93***

Source: ENDS (ProFamilia, 2011), children 5-17, n=5729. Missing values for height result in samples slightly smaller.

Notes: *p<0.05, **p<0.01, ***p<0.001

Mother height models based on ordinary least square linear regression (OLS); all other models based on logistic regression and show odds ratios (OR).

Household head is female or male and possibly not biological parent and grandparent. Only about 50% of mothers of children were living in the household to determine whether the household head was related to mother. Mother is mother of the child 5-18 years old and daughter to the head and/or spouse. Each cell represents a different model; all models control for child age, gender, mother age, grandparent age, grandparent gender, and residence, where relevant.

Sample sizes, significance of which are all at p<0.001 except where noted:

Mother: child (2179), female child (1057), male child (1122)

Grandfather: mother (793), child (769), female child (378), male child (391)

Grandfather + mother height: child (769), female child (378), male child (391)

Grandmother: mother (1962), child (1908), female child (917), male child (991)

Grandmother + mother height: child (1908), female child (917), male child (991)

HH head female: child (1159), female child (605), male child (554**)

HH head male: child (1023), female child (464**), male child (532)

Note that in all nested models for grandparents, mother height is highly significantly (p<0.001) and stronger (results not shown in table).

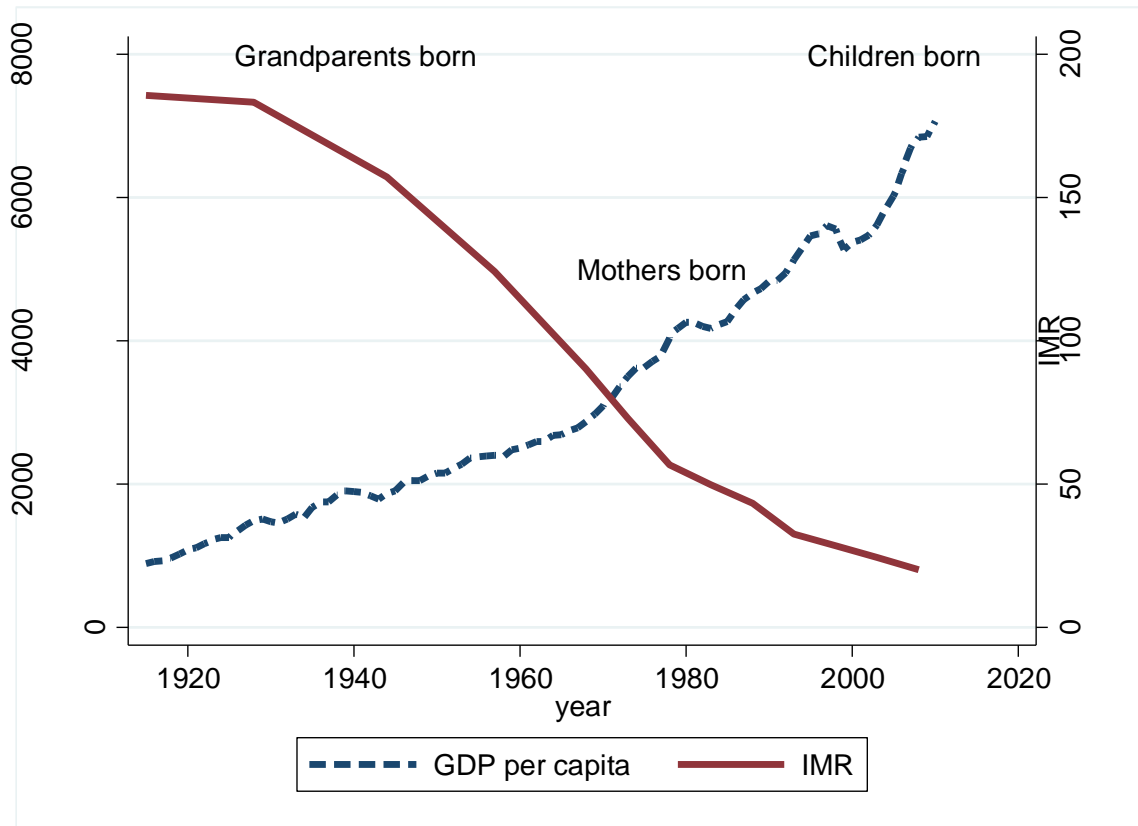


Figure 1: GDP per capita and IMR in Colombia: 1915-2007

Sources: (Flórez et al., *In press*; *The Maddison Project*, 2013); in 1990 international Geary-Khamis dollars

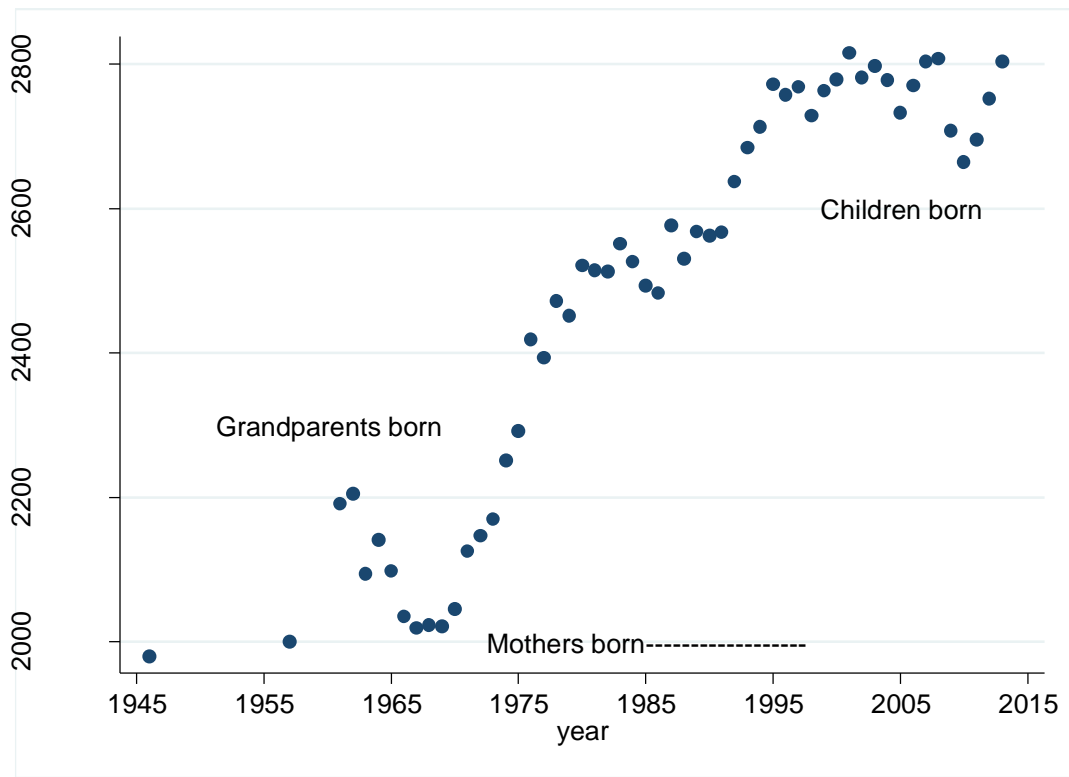


Figure 2: Net daily caloric intake per capita over time in relation to birth dates of grandparents, mothers and their children

Source: (Food and Agriculture Organization of the United Nations, 1946; The Food Security Portal, 2012; United Nations Statistical Office & the Department of Economic and Social Affairs, 1958)

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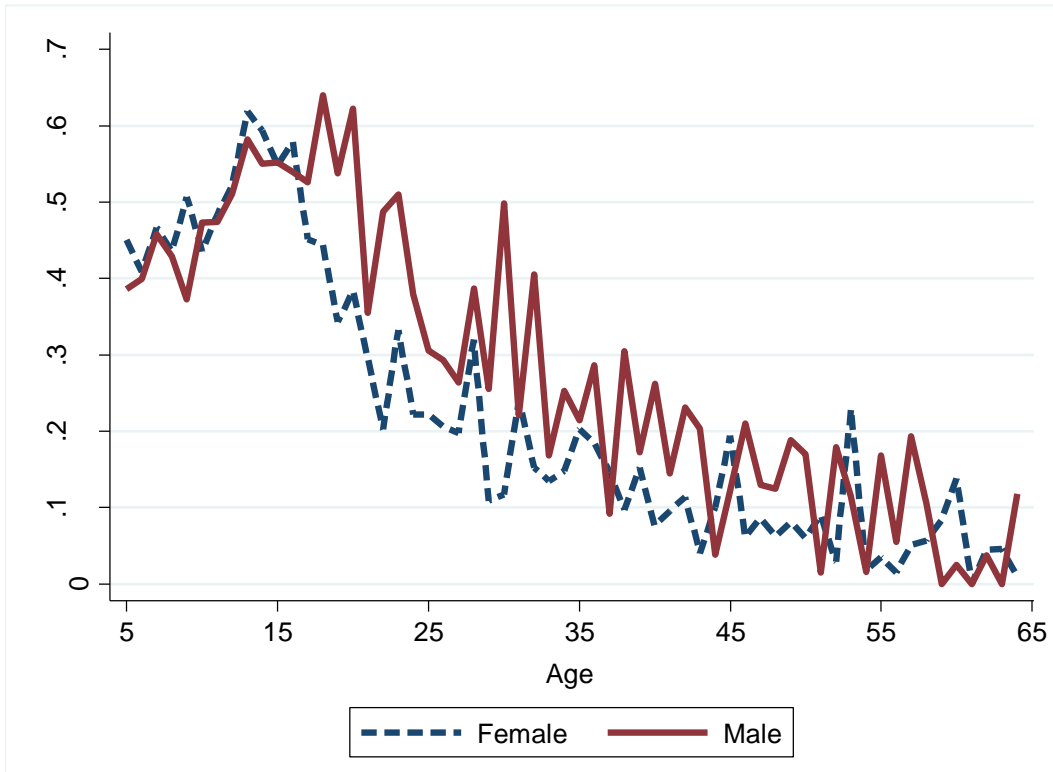


Figure 3: Percent eating junk food at least 3 times daily according to age
Source: (Instituto Colombiano de Bienestar Familiar, 2011)