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From Birth to Adulthood: Anthropometric Trajectories and their Implications for Chronic Diseases

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SUMMARY

There is not much research on nutritional status transitions over the life course because of the dearth of longitudinal studies that cover a long period of time, and such studies are even rarer in countries that are not high-income. Not much is known about the relationship between childhood anthropometrics, adulthood anthropometrics, and chronic diseases over the life course in the developing context. The objective of this paper was to study nutritional status and growth, as measured by height and weight, over the life course and their connection with chronic diseases in Guatemala – a country with high levels of both childhood under-nutrition and adulthood over-nutrition. With a birth cohort consisting of 1570 individuals from Guatemala and several decades of data, nutritional transitions from childhood to adulthood were analysed. The association of childhood and adulthood anthropometrics was investigated, and both of these were linked with chronic disease indicators using multiple regressions and structural equation modeling. Moving upwards in nutritional status from childhood to adulthood happened frequently in this population. Unlike sex and place of residence, early anthropometrics were generally not associated with adulthood body mass index (BMI). However, there were direct relationships between childhood nutritional status and growth with high-density lipoprotein (HDL) cholesterol, triglycerides, and fasting blood glucose. Furthermore, these relationships were not mediated by BMI. These conclusions were not sensitive to the metric of childhood anthropometrics, as the use of length-for-age, weight-for-age, and weight-for-length all resulted in similar conclusions. Such relationships demonstrated the importance of early childhood conditions for later-in-life outcomes. The lack of such relationships for blood pressure would suggest that the biological links between childhood anthropometrics and various chronic diseases might vary.

INTRODUCTION

Nutritional circumstances from childhood could manifest themselves later on in the form of morbidity or mortality. It is important to study the impacts that these early childhood conditions could have on adult health and well-being. However, such life course transitions cannot be analysed properly without longitudinal data, preferably starting from birth and

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continuing on through adult years. Much of the existing research analysing anthropometrics over the life course were conducted using longitudinal studies in higher-income countries (Braddon et al. 1986; Power et al. 1997; Van Abeleen et al. 2012), leaving much to be desired in contexts where studies are arguably the most needed. Although there are birth cohort studies in less-developed contexts (one of which was used in this analysis), they often do not cover a long enough period for the participants to reach adult ages. The few papers that did use such cohort studies have results that are somewhat inconclusive and worthy of further research.

To study anthropometric transitions in a less-studied context, a birth cohort from Guatemala with several decades of data was used. Guatemala was an appropriate country for this investigation due to the anthropometric status of its constituents. Despite gradual improvements in reducing under-nutrition, the prevalence of stunting under five years of age was 46.5% in 2014 – 2015; to put this value into perspective, this is considered to be very high by standards for public health significance, as set by the World Health Organization (WHO) (FANTA 2017). Meanwhile, on the other end of the nutritional spectrum, more than 50% of Guatemalan women were overweight in 2016, and more than 20% were obese (WHO 2016a).

While this might seem contradictory, human biology could explain why under-nutrition as a child might in fact place a person at higher risk of becoming overweight as an adult. The fetal origins hypothesis states that if a child lacks nutrients, either in utero through the mother's body or in early post-natal care, the child's natural biological reaction is to conserve energy. With this survival mechanism in place, such a child then develops "a thrifty phenotype in which the metabolic and endocrine control systems are tuned to expect a meager substrate supply and are ill-adapted for later nutritional excess" (Adair and Prentice 2004). As a result, any improvement in nutrition later in life could actually be detrimental in the long run, as it could result in excess accumulation of energy and body fat (Barker 2004; Caballero 2005). "Because intrauterine growth retardation and low birth weight are common in developing countries, this mechanism may result in the establishment of a population in which many adults are particularly susceptible to becoming obese" (Caballero 2005). While this refers specifically to fetal growth, the concept also extends to early life environments (Barker 2004).

With rich Guatemalan longitudinal data, transitions between under-nutrition and over-nutrition over the life cycle were studied in this paper. Additionally, which characteristics were associated with adult body mass index (BMI)? Childhood nutritional status and growth were considered, alongside other adulthood characteristics. The Young Lives cohort study had found that early-life stunting of Peruvian children was not associated with increased BMI when they became older. However, the children were only around 12 years of age at the end of this study (Andersen et al. 2016). Another study used the Consortium of Health-Orientated Research in Transitioning Societies (COHORTS), which consisted of birth cohorts from five low- and middle-income countries. This study showed that adult BMI appeared to be strongly and positively associated with weight indices in childhood. This finding seems to contradict the fetal origins hypothesis and the above-mentioned result. However, body mass consists of both lean and fat masses, and since these masses result from

distinct biological processes, the implications of having high BMI might be different depending on the kind of body mass (Victora et al. 2008).

The potential implications of early life nutritional experiences could be more far reaching than just anthropometric status. Under-nutrition is commonly linked with infectious diseases, and over-nutrition with chronic diseases (Belahsen 2014). Yet even if under-nourished individuals survive their childhood years, they might still have a higher risk of chronic diseases as adults (Barker 1997; Roseboom 2012; Shrimpton and Rokx 2012). However, was this because under-nourished children transition into overweight as an adult? Or was over-nutrition in the middle of the pathway a sufficient, but not necessary condition?

Due to irreversible changes through programming of organs and biological systems earlier in life, those who face poor nutritional circumstances early in life could be at a higher propensity of not only obesity, but also chronic conditions later in life (Barker 1997). Permanent alterations to the programming of the body that can result from early under-nutrition include “change[s] in the distribution of cell types, hormonal feedback, metabolic activity, and organ structure” (Barker 1997). A previous study conducted on Finnish data demonstrated that lower birth weight was associated with higher risk of coronary heart disease and that rapid weight gain during childhood increased such risk for those who were thin at birth, as measured by the ponderal index (Eriksson et al. 2001). Many chronic conditions have been discussed in relation to the fetal origins hypothesis, including diabetes, hypertension, and cardiovascular diseases (Delisle 2002).

Weight gain in childhood, in addition to under nourishment, has been implicated in chronic disease risk. In the COHORTS countries, rapid weight gain after infancy for under-nourished children was shown to be linked with various adult outcomes, though the authors stressed that policies should be designed to take into account the age range in which that gain had occurred as well as the chronic disease indicators of interest (Victora et al. 2008). This is not surprising, since complicated biological mechanisms that vary by early size, age of exposure to weight gain, and impacted organs are at play (Calkins and Devaskar 2011). With this Guatemalan birth cohort, the relationships of various chronic disease indicators, used as proxies for chronic disease risk, with childhood size and growth trajectories at various childhood age intervals were analysed, with an eye to understanding potential associations and policy implications.

METHODS

COHORTS is a collaboration consisting of five birth cohort studies spanning a large geographical area (Brazil, Guatemala, India, the Philippines, and South Africa) (Richter et al. 2012). For this study, the Institute of Nutrition of Central America and Panama (INCAP) Nutrition Trial Cohort Study data for Guatemala was used. It has one of the longest time spans among the five studies, an important consideration in a study of nutritional outcomes during childhood and their association with chronic diseases at older ages.

The cohort used consisted of children under seven years of age in 1969 and children born between then and 1977 in four Guatemalan villages (Stein et al. 2008). The original size of

the birth cohort was 2392, though the sample size in subsequent waves decreased for reasons including death, migration, and inability to trace the respondents; in the 2002 – 2004 follow-up, 1570 individuals were available for data collection. Their characteristics could be found in the Stein et al. paper profiling these cohort members (Stein et al. 2008). Many analyses had been conducted using these data (Maluccio et al. 2009; Hoddinott et al. 2013; Ford et al. 2016), though usually not with an end goal of studying chronic diseases.

Recumbent length and weight were measured at several age points throughout childhood. From these data, length-for-age, weight-for-age, and weight-for-length z-scores were calculated at these ages using software from the World Health Organization (WHO) (WHO 2011). Results reported in this paper were based on length-for-age z-scores, though these analyses were also run using weight-for-age z-scores and weight-for-length z-scores to test whether results were sensitive to the choice of anthropometric measure. However, there were often missing data and there was a lack of consistency as to which age points contained information. To take advantage as much as possible of the available information, z-score means over age intervals were used to ascertain nutritional status, and slopes of the best fitting lines among the z-scores were used to measure growth trajectory. For nutritional status at adulthood, BMI calculated from height and weight measurements in the year 2004 was used, though height and weight from 1998 were also used for sensitivity checks.

In the first year of a child's life, measurements had been taken once a month. In the second and third years, measurements had been taken once every three months. In the fourth and fifth years, measurements had been taken once every six months. Between ages zero and five, the data were split into three segments according to the frequency of measurement – under age one, between ages one and under three, and between ages three and five. Doing so in the regression studies allowed for investigating how various dependent variables were associated with nutritional status and growth at different ages.

The slopes, measured as the change in z-scores per month, were classified into downward, stagnant, and upward categories. In most cases, there were no significant differences between models with continuous slopes versus models with categorical slopes (as determined by Vuong's closeness test). From boxplots, it appeared that the outliers were usually below 0.1 and above 0.1. If different growth patterns might lead to different consequences, it would be important to distinguish such outliers. Therefore, decreases in slope of more than 0.1 and increases in slope of more than 0.1 were used as the downward and upward categories, respectively, though different thresholds were also tested.

Ordinary least squares regressions were run with two sets of models. The general forms of these models are shown in (1) and (2) below. The first looked at how these childhood anthropometrics and growth trajectories, as well as other characteristics, were associated with adult BMI in 2004. It should be noted that adult BMI was not measured for pregnant women or women under six months post-partum (Stein et al. 2008). The second looked at how all of these same variables, along with adult BMI, were associated with various chronic disease indicators, namely blood pressure (systolic and diastolic), cholesterol (high-density lipoprotein (HDL), low-density lipoprotein (LDL), and triglycerides), and fasting blood glucose. These data, measured using fasting samples in 2004, served as proxies for the

propensity of becoming afflicted by a range of chronic diseases. High levels of blood pressure and cholesterol (except HDL, or “good cholesterol,” which has the opposite relationship) are usually considered to be associated with an increased risk of heart disease and stroke (NIH 2005; NIH 2015). High levels of fasting blood glucose are linked with type two diabetes (NIH 2012).

$$\begin{aligned} \text{Adult BMI} = & \gamma_0 + \gamma_1 * \text{sex} + \gamma_2 * \text{mean 0 to under 1} + \gamma_3 * \text{mean 1 to under 3} \\ & + \gamma_4 * \text{mean 3 to 5} + \gamma_5 * \text{slope 0 to under 1} + \gamma_6 * \text{slope 1 to under 3} \\ & + \gamma_7 * \text{slope 3 to 5} + \gamma_8 * \text{educational attainment} + \gamma_9 * \text{socioeconomic status} \\ & + \gamma_{10} * \text{place of residence} + \gamma_{11} * \text{ever smoked} + \text{error} . \end{aligned} \quad (1)$$

$$\begin{aligned} \text{Chronic disease indicator} = & \delta_0 + \delta_1 * \text{sex} + \delta_2 * \text{mean 0 to under 1} + \delta_3 * \text{mean 1 to under 3} \\ & + \delta_4 * \text{mean 3 to 5} + \delta_5 * \text{slope 0 to under 1} + \delta_6 * \text{slope 1 to under 3} \\ & + \delta_7 * \text{slope 3 to 5} + \delta_8 * \text{educational attainment} + \delta_9 * \text{socioeconomic status} \\ & + \delta_{10} * \text{place of residence} + \delta_{11} * \text{ever smoked} + \delta_{12} * \text{adult BMI} + \text{error} . \end{aligned}$$

(2)

In these regression models, the independent variables sex (reference group – male), slope (reference group – downward trajectory), place of residence (reference group – rural), and smoking status (reference group – never smoked) were categorical. All the other variables were continuous. Educational attainment was in grades completed, socioeconomic status was a combination of a wealth index and durable goods/household characteristics, blood pressure was in mmHg, and the other chronic disease indicators were in mg/dL. It should be noted that while age was significant as a covariate for adult BMI, it was not significant as a covariate for chronic disease indicators; in fact, the adjusted R^2 values usually decreased with the addition of age. This might be because most of these observations were in the same birth cohort and there was not enough variation in age. As a result, age was not included.

The two sets of regressions above, while certainly useful, did not consider certain indirect effects on the chronic disease indicators. While sex, childhood anthropometrics, childhood growth, adulthood characteristics, and adult BMI were included as independent variables in (2), the first four were also embedded in adult BMI. As a result, if adult BMI was indeed significant for chronic disease indicators, part of the association might be the direct effect of BMI, and part of it the indirect effect of sex, childhood anthropometrics, childhood growth, and adulthood characteristics working through BMI. Structural equation modeling (SEM) was used to parse out the direct and indirect effects of each variable. Specifically of interest here were the direct and indirect effects of the childhood z-scores and growth.

All analyses were run using the statistical software R (version 3.3.2) (R Core Team 2017). The R package lavaan was used for SEM (Rosseel 2012). Models were run after listwise

deletion for missing data. When discussing results, the term “significant” meant significant at the level of five percent.

RESULTS

Distribution of nutritional states and transitions

First, it would be important to characterize the distribution of nutritional states at childhood and adulthood, and the transitions that these individuals made. Figure 1 depicts the most common transitions of study participants with data in all the three childhood periods and adulthood. The childhood categories were determined using mean length-for-age z-score, with child under-nutrition defined as having a length-for-age z-score under -2 , over-nutrition as having a z-score over 2, and the normal range in between (WHO 2016b). The adulthood categories were determined using BMI in the year 2004, with adult under-nutrition defined as having a BMI under 18.5 kg/m^2 , over-nutrition as having a BMI of 25 kg/m^2 or above, and the normal range in between (WHO 2006). By 2004, the study participants were between 25 and 42 years of age.

The colors in each horizontal bar represent different sequences that a person could take from childhood to adulthood. The height of each horizontal bar is the relative frequency of children with such a sequence. For example, the lowest horizontal bar shows that almost 20% of children were under in the age interval $[0, 1)$, under in the age interval $[1, 3)$, under in the age interval $[3, 5)$, and normal as adult. It should be noted that the width of the rectangles does not represent a scale of duration.

These ten sequences depict the pathways of 96.2% of study participants. In none of these sequences does over appear in any of the childhood age intervals. In fact, none of the study participants was considered over-nourished as a child based on length-for-age z-scores. The most common sequence is being under throughout childhood and then transitioning to normal as adults, followed by being under throughout childhood and then transitioning to over. These sequences show that upward trajectories in nutritional status were common in this Guatemalan birth cohort, though much of the growth occurred after the age of five.

Adult BMI

Table 1 shows which childhood length-for-age z-score means and slopes, and adulthood characteristics were significantly associated with adult BMI measured in the year 2004. The numbers in the table are coefficient estimates and the asterisks represent the level of significance.

In this regression, with length-for-age as the anthropometric measure, females and urban dwellers had a significantly higher average adult BMI than males and rural dwellers. Means and slopes did not appear to be significant; this would suggest that childhood nutritional status and growth trajectory using length-for-age as the anthropometric measure were not very influential for adult BMI.

Table 1 shows the regression results when length-for-age z-scores were used. The significance was similar for models based on weight-for-age and length-for-weight z-scores.

Figure 2 displays the significant variables and their coefficient estimates in the same model, using length-for-age, weight-for-age, and weight-for-length measures. A caveat – although the vertical bars of the same independent variable give a visual representation of the magnitudes of the coefficient estimates across the three measures, the vertical bars of different independent variables are not comparable, because different independent variables have different scales of measurement.

The significant variables had the same directions and similar coefficient magnitudes across measures. For weight-for-age and weight-for-length, z-score mean in [3, 5] was positively associated with adult BMI. That is, nutritional status at a young age (though not too young) was significant for nutritional status as an adult. If the three age-segment weight-for-age z-score means were replaced with the overall weight-for-age z-score mean, the z-score mean was significant, indicating that significance was driven by childhood anthropometrics between ages three and five. Slope was not at all significant, suggesting that there was no evidence pointing to an association of childhood growth trajectories with adult BMI.

In all of these models, sex and place of residence were consistently significant. However, adulthood characteristics such as educational attainment, socioeconomic status, and having ever smoked (current or former smoker) were never significant at the five-percent level. Neither their inclusion nor their exclusion from the models had much of an impact on the significance levels of the other variables or signs and magnitudes of their coefficient estimates.

Chronic disease indicators

Finally, the association of chronic disease indicators with childhood anthropometrics, childhood growth trajectories, adulthood characteristics, and adulthood BMI was investigated. Table 2 shows these results. The continuous dependent variables of interest were systolic blood pressure, diastolic blood pressure, HDL cholesterol, triglycerides, and fasting blood glucose. Regressions with LDL cholesterol, or “bad cholesterol,” did not inform much, as the models were extremely weak, so they were not displayed below.

Sex and adult BMI were significant for systolic and diastolic blood pressure. Both kinds of blood pressure tended to be higher for males than for females, and adult BMI was positively associated with blood pressure. However, early anthropometrics and early growth did not seem to be associated with either blood pressure variable. The model for systolic blood pressure was noticeably stronger than the one for diastolic blood pressure.

With HDL cholesterol, or “good cholesterol,” as the dependent variable, adult BMI was a significantly negative variable. Females had a significantly higher HDL cholesterol level. With downward as the reference category, both stagnant and upward growth trajectories on [0, 1) were significant and negative. This result would suggest an association of growth in the first year of life with lower levels of good cholesterol as an adult. Furthermore, upward was more negative, signifying that more growth might have greater adverse consequences.

Females had a significantly lower triglycerides level. Nutritional status on [0, 1) was significantly negatively associated with triglycerides, i.e., having a higher mean z-score in

the first year of life was associated with a lower level of triglycerides. And as with the other chronic disease indicators discussed up to now, adult BMI was significantly associated with triglycerides, the association being positive here.

Upward slopes on [0, 1) (relative to downward) as well as on [3, 5] (relative to stagnant) were significantly positively associated with fasting blood glucose, though it was more positive and more significant for slope between ages three and five. Having an upward slope between ages zero and one or between ages three and five increased the level of fasting blood glucose. Adult BMI was not a significant variable for fasting blood glucose, though it was for all the other models with chronic disease indicators as dependent variables.

Figure 3 shows the results by different anthropometric measures.

Sex and BMI were consistently significant for all dependent variables (except fasting blood glucose) regardless of the anthropometric measure used. Nutritional status at [0, 1) registered as significant and negative on a couple occasions – diastolic blood pressure using weight-for-length and triglycerides using length-for-age (reported in Table 2) and weight-for-age. However, using weight-for-length, nutritional status at [1, 3) registered as significant and positive for diastolic blood pressure. While the adjusted R^2 values for the fasting blood glucose models were not as high, there was a clear pattern across measures. Upward slope at [3, 5] was significant using length-for-age and weight-for-age (marginally insignificant for weight-for-length) and the coefficient estimates were always positive.

Interactions between childhood and adulthood nutritional statuses were not reported in the tables due to their insignificance. Various specifications of interactions were tested between the three childhood means and adult BMI, both as continuous variables, one as a continuous variable and the other as a categorical variable, and both as categorical variables. However, none of these interactions ever registered as significant. This would suggest that, in this cohort, childhood z-scores and adulthood BMI made their impacts additively and did not interact. However, this lack of interaction significance could simply be due to the relatively small size of the sample.

Structural equation modeling

BMI was a significant variable for almost all chronic disease indicators. However, was adult BMI truly a significant variable, or was it just a mediating factor through which sex, adulthood characteristics, or childhood nutritional status and growth affected the development of chronic diseases? In the former case, policies with adult BMI as a goal could have a significant effect on chronic diseases. However, if adult BMI only acted as an intermediary between a component of sex, adulthood characteristics, or childhood nutrition and chronic diseases, then the focus should be on such a component. As a result, it would be important to study both the direct effects of these variables on chronic disease indicators and the indirect effects of these variables on chronic disease indicators that worked through BMI. SEM could help evaluate the full role, which might have been partially hidden in the regression models, that these variables played. Table 3 shows the coefficient estimates of the direct effects and indirect effects (through adult BMI) of sex, adulthood characteristics, and

childhood nutrition variables in the model. It should be noted that the coefficient estimates for the direct effects were the same as those that had been reported in Table 2.

Being female was directly associated with significantly lower blood pressure and triglycerides compared to males. However, sex had indirect effects on blood pressure and triglycerides in the opposite way. These opposite indirect associations were expected, as being female was associated with having a higher BMI, which was positively associated with blood pressure and triglycerides. This general pattern was reversed for HDL cholesterol. In addition, direct effects were generally stronger than indirect effects. Although place of residence usually did not have a direct association with chronic diseases, it had significant indirect association. Living in an urban area was indirectly positively associated with both kinds of blood pressure and triglycerides, and indirectly negatively associated with HDL cholesterol. Again, these might be due to the strong association of urban dwellers with having a higher BMI.

Childhood nutritional status and growth were not significant (directly or indirectly) for systolic blood pressure or diastolic blood pressure. For HDL cholesterol, triglycerides, and fasting blood glucose, there were some significant direct effects for the z-score means and slopes, but none of the indirect effects was significant. The z-score means and slopes that were significant work directly with the chronic disease indicators themselves, and did not manifest themselves through adult BMI. This was not too surprising, since these variables were almost always insignificant when used as independent variables for adult BMI. These results would indicate the importance of the direct relationship between adult BMI and chronic diseases, as well as the direct relationship between childhood nutrition and chronic diseases.

DISCUSSION

Transitioning out of under as a child to either normal or over as an adult was a common trajectory within this Guatemala sample, though it did not appear that under-nourished children were at significantly different risk from those who begin in the normal category. What was associated with adulthood anthropometrics? Being female and living in an urban area were associated with higher adult BMI, which had been found before in other contexts (Mascie-Taylor and Goto 2007; Wang et al. 2009; Ramachandran 2011).

Using an earlier iteration of these Guatemalan data, researchers found that while risk factors of cardiovascular disease were related to adult adiposity, they were not associated with birth weight for young adult women (and only weakly inversely associated for men) (Stein et al. 2002). As expected, adult BMI was important in models for chronic disease indicators in this analysis. Additionally, it was demonstrated in this analysis that childhood nutritional status and growth trajectories did not consistently register as significant across anthropometric measures. The only cases in which a result showed up for more than one measure were for triglycerides and fasting blood glucose levels. Nutritional status in the first year was negatively associated with triglycerides using length-for-age and weight-for-age as anthropometric measures, and having an upward growth trajectory between the ages of three and five was positively associated with higher levels of fasting blood glucose using these

same two measures. These results would suggest that childhood under-nutrition and growth might have consequences for adult health, corroborating the work that had been done on more developed countries (Barker 2004). Furthermore, these were direct effects, and did not work through BMI as a mediating factor.

The above showed that those who were under-nourished as children or those who experienced above-average growth in certain windows within the first five years might be at a disadvantage later in life. This was the case for triglycerides and fasting blood glucose as dependent variables. However, none of these childhood status or growth variables was significant for blood pressure. A similar result had previously been obtained by Stein et al. – using an aggregation of the COHORTS data, they found that being born preterm or small was not related to blood pressure as an adult. However, they found that these were also not related to fasting blood glucose (Stein et al. 2013). Such a relationship between anthropometrics and fasting blood glucose was found in this study, but the significance came from the childhood growth variables. Further research on biological processes linking childhood growth with various chronic diseases would be illuminating.

A notable insignificant result was that interactions between childhood and adulthood nutritional statuses were not significant. Nutritional status and growth trajectory in specific windows between ages zero and five were sometimes individually significant for various chronic disease indicators, but childhood z-scores and adulthood BMI did not interact multiplicatively in their association with chronic disease indicators. The fetal origins hypothesis posits that those who are under-nourished as children and experience growth later in life could be at a disadvantage as adults, in terms of both adulthood BMI and chronic disease outcomes, and it was thus important to study the interaction model that included an interaction between early and later size (Lucas et al. 1999; Delisle 2002). However, the lack of significant interactions between childhood under-nutrition and adulthood over-nutrition for chronic disease indicators would seem to counter this hypothesis. While this could be just a statistical artifact stemming from the sample size, perhaps either starting nutritional status or growth within a certain window in childhood, as opposed to the combination of the two, is what matters.

There were other potentially interesting results here as well, specifically for nutritional status between ages zero and under one, nutritional status between ages one and under three, and growth trajectory between ages zero and under one. However, the significance of these variables often differed depending on which anthropometric measure was used. It was not surprising that length-for-age, weight-for-age, and weight-for-length produced different results, as these three measures were all calculated using different components. While having a low value for any of these measures is not desirable, different measures reflect different conditions. For example, having a low length-for-age (stunting) reflects chronic under-nutrition, whereas having a low weight-for-height (wasting) reflects acute under-nutrition (FANTA 2011). Similar substantive conclusions were generally obtained in this study, independent of the measure used. However, there were certain instances where the significance results did not all line up. These measures should not be used interchangeably, and researchers should understand the nuances of these anthropometric measures before choosing an appropriate one for analysis.

There might be some concern that the adjusted R^2 values for the models presented were not high. However, the objective of creating these models was not to get the highest R^2 , but to ascertain which variables were associated with various outcomes. However, there were likely other variables also associated with these outcomes of interest, but had not been taken into account. There might also be concern about potential multicollinearity between the mean and slope variables, but variance inflation factors (VIFs) were calculated for each model, and these were never at worrisome levels.

Sensitivity checks were performed, especially on the mean and slope variables, to test the robustness of the results. The way in which mean and slope variables were separated into various age segments did not make much of a difference. Three segments were used since that would make the most sense given the frequency of measurements. Two-segment models with ages zero to under one and one to five, as well as zero to under two and two to five were tried. The results remained relatively consistent between models. Regressions using only the three means, but without the slopes, were also run. The models with the additional slope variables were stronger, and they also revealed the significance of some of the slope variables. Other thresholds to classify slopes, such as 0.05, were also used to test the sensitivity of the models to the data-driven choice of 0.1. Similar conclusions were obtained.

To further validate the chronic disease models, BMI measured in 1998 instead of in 2004 was used, as there could have been some lag between nutritional status as measured by BMI and chronic disease incidence. The conclusions were very similar, though the models using BMI in 2004 were stronger, perhaps due to larger sample sizes and typically higher correlations between BMI and chronic disease indicators in the same year. Different variables for smoking status were also tested. Regardless, smoking status never registered as significant in these models.

What do these results mean for policy? Assistance from higher-income countries and international organizations often goes to children who are under-nourished. This analysis showed that those with a lower mean z-score in the first year of life, on average, had a higher level of triglycerides as adults, already placing them at a disadvantage. Consequently, it would seem natural to try to help children with lower nutritional status to avoid further detriment from under-nourishment. However, policy implementation might be precarious here, as promoting catch-up growth might also not be the best form of assistance for other long-term outcomes (Ong 2007; Thureen 2007; Nobili et al. 2008). Here, it was shown that upward growth between ages three and five was associated with higher levels of fasting blood glucose. The fetal origins hypothesis conjectures that quick growth in childhood could actually have undesirable consequences later in life, and these analyses suggested that both nutritional status and growth at young ages might be associated with at least some chronic diseases.

While the results of this analysis were not definitively causal, policy-makers should take into account the timing (age of children) and allocation (variations in the amount of aid throughout childhood) of nutritional assistance. The concept of “healthy catch-up growth” is critical, but additional exploration is necessary to further flesh it out. This has been cited as an important “goal of future research” (Ong 2007). The important link between mother and

child suggests that it might also be worthwhile to consider interventions directed toward the previous generation. Education and nutritional supplementation for mothers could have important intergenerational impacts that could end up being crucial for their children (Bhutta et al. 2013).

CONCLUSION

These analyses on a Guatemalan birth cohort demonstrated how demographic characteristics and nutritional processes were associated with later health outcomes. Since the data came from only one country, any generalization should be cautious. Nevertheless, the context in which this was being studied is novel, as analyses from birth to adulthood are rare in the developing context. This study would provide a good first step in the analysis of nutritional transitions over the life course and chronic disease risk in developing countries, as well as a discussion on the implementation of assistance.

More research is still needed to study the underlying biological processes and to determine how strong these associations are, with a view to optimally implement the timing and allocation of assistance to prevent exacerbating the harm to those who might already have been handed a disadvantage at birth.

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Figure 1.

Frequencies of nutritional status sequences from birth to adulthood

Figure 2.
Significant variables for adult BMI by anthropometric measure

Figure 3.
Significant variables for chronic disease indicators by anthropometric measure

Table 1

Regression of adult BMI on sex, length-for-age childhood anthropometrics, growth trajectories, and adulthood characteristics

	Adult BMI
Intercept	27.665 ***
Female	2.191 ***
Mean [0, 1)	0.324
Mean [1, 3)	-0.145
Mean [3, 5]	0.389
Slope [0, 1) (stagnant)	-0.027
Slope [0, 1) (upward)	-0.598
Slope [1, 3) (stagnant)	-0.765
Slope [1, 3) (upward)	-1.137
Slope [3, 5] (stagnant)	-4.976
Slope [3, 5] (upward)	-4.24
Educational attainment	-0.105
Socioeconomic status	-0.481
Urban	2.224 ***
Ever smoked	-0.262
Adjusted R ²	0.119

In this table and all tables hereinafter,

* denotes significance at the 0.05 level,

** at the 0.01 level, and

*** at the 0.001 level.

Regressions of chronic disease indicators on sex, length-for-age childhood anthropometrics, growth trajectories, adulthood characteristics, and adulthood anthropometrics

Table 2

	Systolic blood pressure	Diastolic blood pressure	HDL cholesterol	Triglycerides	Fasting blood glucose
Intercept	83.952 ***	43.945 ***	55.093 ***	80.444	88.193 ***
Female	-13.403 ***	-5.766 ***	8.499 ***	-35.354 *	-3.881
Mean [0, 1]	-0.021	1.217	-1.563	-21.723 *	-1.123
Mean [1, 3]	1.636	0.405	-0.130	5.380	1.478
Mean [3, 5]	0.001	-1.002	2.099	13.253	-1.687
Slope [0, 1] (stagnant)	-0.898	0.382	-3.614 *	-12.231	-3.189
Slope [0, 1] (upward)	-1.115	2.104	-5.943 *	-4.037	10.033 *
Slope [1, 3] (stagnant)	1.879	2.579	-1.486	-50.024	-0.978
Slope [1, 3] (upward)	-4.888	-2.665	-5.673	110.270	1.544
Slope [3, 5] (stagnant)	17.265	10.139	ref level	ref level	ref level
Slope [3, 5] (upward)	13.308	4.394	-5.553	53.930	38.401 ***
Educational attainment	-0.264	-0.221	0.208	1.571	0.278
Socioeconomic status	-0.972	-0.661	0.579	1.892	-1.299
Urban	2.095	0.364	0.919	-20.595	-2.365
Ever smoked	-0.688	-0.421	2.232	-16.271	-1.548
Adult BMI	1.277 ***	0.888 ***	-0.991 ***	8.686 ***	0.171
Adjusted R ²	0.358	0.174	0.170	0.133	0.083

The baseline category for slope between ages three and five switched from downward to stagnant. There were no observations in the downward category for slope between ages three and five that also have information on HDL cholesterol, triglycerides, and fasting blood glucose, so the baseline category changed.

Table 3

Direct and indirect effects using SEM

	Systolic blood pressure		Diastolic blood pressure		HDL cholesterol		Triglycerides		Fasting blood glucose	
	Direct	Indirect	Direct	Indirect	Direct	Indirect	Direct	Indirect	Direct	Indirect
Female	-13.403 ***	2.776 ***	-5.766 ***	1.930 ***	8.499 ***	-2.219 **	-35.354 *	19.459 **	-3.881	0.384
Mean [0, 1)	-0.021	0.513	1.217	0.356	-1.563	-0.205	-21.723 *	1.794	-1.123	0.035
Mean [1, 3)	1.636	-0.207	0.405	-0.144	-0.129	0.096	5.380	-0.845	1.478	-0.017
Mean [3, 5]	0.001	0.435	-1.002	0.303	2.099	-0.335	13.253	2.937	-1.687	0.058
Slope [0, 1) (stagnant)	-0.898	0.055	0.382	0.038	-3.614 **	-0.137	-12.231	1.200	-3.189	0.024
Slope [0, 1) (upward)	-1.115	-0.690	2.104	-0.480	-5.943 *	0.683	-4.037	-5.991	10.033 *	-0.118
Slope [1, 3) (stagnant)	1.879	-1.079	2.579	-0.750	-1.486	0.814	-50.024	-7.137	-0.978	-0.141
Slope [1, 3) (upward)	-4.888	-1.561	-2.665	-1.085	-5.673	2.228	110.270	-19.541	1.544	-0.385
Slope [3, 5] (stagnant)	17.265	-6.254	10.139	-4.347	ref level	ref level	ref level	ref level	ref level	ref level
Slope [3, 5] (upward)	13.308	-5.309	4.394	-3.690	-5.553	-1.102	53.930	9.663	38.401 ***	0.191
Educational attainment	-0.264	-0.138	-0.221	-0.096	0.208	0.132	1.571	-1.161	0.277	-0.023
Socioeconomic status	-0.972	-0.585	-0.661	-0.407	0.579	0.338	1.892	-2.967	-1.299	-0.058
Urban	2.095	2.827 ***	0.364	1.965 ***	0.919	-2.377 ***	-20.595	20.841 ***	-2.364	0.411
Ever smoked	-0.688	-0.444	-0.421	-0.309	2.232	0.138	-16.721	-1.206	-1.548	-0.024