Height-weight-mortality patterns among older adults in middle- and high-income settings: evidence of disparate pathways to high life expectancy

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Introduction

Adults in low and middle-income countries born in the 1930s-1960s benefitted from rapid infant and childhood mortality decline under improvements in standards of living nowhere near the magnitude and reach that characterized the secular mortality decline in Western Europe and North America (Preston, 1976, 1980; Palloni &Wyrick, 1984; Palloni & Pinto,2010). These historical circumstances generated cohorts of older adults who may survive to older ages even after experiencing adverse early life conditions, including in utero, infant and childhood malnutrition, as well as systemic exposure to infectious and parasitic illnesses. We conjecture that these cohorts are characterized by patterns of mortality and physical growth in sharp contrast with those typical of older adults in Western Europe and North America. Two forces will combine to produce this result. First, a mortality decline primarily sustained by the diffusion first of antibiotics and then of vaccines, rather than by wholesale improvements in standards of living and public health, biases the composition of cohorts to one distinguished by relatively high life expectancy but with only marginal or moderate gains in height (i.e, moderate nutritional improvements). Second, the rapid nutritional transition of the 20th century (NCD Risk Factor Collaboration, 2017; Popkin, 2006; Schmidhuber & Shetty, 2005) exposes adult survivors who experienced adverse nutritional status (in utero, as infants, or as young children) to increased likelihood of mismatches between their pre-birth, infancy and early childhood environments and those they face during late childhood, early adolescence and adult life. As a consequence, surges in life expectancy may occur in the midst of an expansion of physiological dysregulation including metabolic disorders, such as obesity, T2D and associated chronic illnesses (Barker, 1998; Bateson & Gluckman, 2011; Gluckman & Hanson, 2005)

The mortality trajectory followed by Western Europe and North America (Canada and the US) was one where increases in standard of living, accompanied by massive improvements in public health, drove the bulk of mortality decline. This route to mortality decline resulted in increases in height as an added outcome of better nutritional status and, at least initially, was accompanied by increases in weight within a normal range expected by increases in height. In contrast, when mortality decline is largely driven by diffusion of antibiotics and is only weakly sustained by rapidly changing standards of living and public health, nutritional status and stature will increase more slowly even though life expectancy rises sharply. If, in addition, these populations swiftly adopt Western lifestyles (high-caloric diet, sedentarism), there will be ample room for predictive adaptive responses (PAR) to operate (Gluckman & Hanson, 2005). According to conjectures put forward by DOHaD theories, one of the

implications of this should be the increase in the population level propensity of obesity and metabolic diseases (and associated expansion of morbidity and disability) even though life expectancy could attain levels comparable to those in high income countries. Furthermore, because improvements in nutritional status have been slow and uneven within each population, we may encounter the simultaneous coexistence of expanding obesity and T2D, significant prevalence of stunting or moderate malnutrition, and high life expectancy, an unprecedented combination of phenotypes that may now characterize the majority of human populations (Lancet on double burden, 2020)

Through the use of height-weight-mortality surfaces estimated from data of a high income population (Waaler, 1984), Fogel argued that moderately stunted individuals must be heavier to reach a minimum risk mortality line on Waaler surfaces but do so at the cost of higher mortality than taller individuals (Fogel, 2004). In this paper we argue that cohorts of low to middle-income countries will be heavier (leaning to obesity) while simultaneously experiencing levels of life expectancy comparable to those of adults in high-income countries. As a consequence, and in contrast to Fogel's argument about moderately stunted individuals in high income countries, populations in low to middle income countries pay a cost for improved life expectancy in the form of increased expansion of morbidity at older ages and persistent secondary effect of substandard nutritional status. This may be particularly pronounced in the very large poorer and most deprived segments of these populations where adverse conditions continue to prevail.

The key issues we address in this paper is about the joint patterns of improvements in survival and human physical growth in older adults under the following conditions:

(a) mortality declines rapidly but accompanied by only moderate improvements in well-being in general and nutritional status in particular;

(b) as a result of (a) the representation at older ages of individuals who experienced adverse early conditions, including chronic moderate or severe malnutrition, is augmented and

(c) these same cohorts are exposed to an enriched food environment with high levels of consumption of simple carbohydrates and poor levels of physical activity? [1]

To investigate this question we estimate Waaler height-weight-mortality surfaces using Latin American and Caribbean (LAC) data and contrast them with Waaler surfaces for the US older adult populations. These contrasts show that Waaler surfaces for LAC are "distorted" variants of those in the US (and likely those in Western Europe) for they are characterized by the following singularities:

a. A significant representation of partially stunted and more obese subpopulations;
b. High levels of life expectancy coupled with significant underachievement in height
c. High levels of life expectancy coupled with overachievement in body weight

Our results support the existence of optimal height-weight-life expectancy curves that are "displaced" relative to those in the US. We claim that this is (partial) empirical

[1] We hasten to add that ours is a first pass at the key question since the investigation can be extended to include patterns of chronic morbidity and disability rather than being confined to mortality levels

evidence of an alternative evolutionary path for human physical growth, disease, and mortality.

Methods

Data

Data to construct mortality surfaces for older adults came from population-based surveys representative of older adults 60 years and old: the Mexican Health and Aging Study (**MHAS**, 2001, n=7171), the Puerto Rican Elderly: Health Conditions (**PREHCO**, 2003-04, n =4291) project, the Costa Rican Longevity and Healthy Aging study (**CRELES**, 2003, n=2827) and the Health and Retirement Study (**HRS**, 2000, n=12,527). Mortality data were available through 2015 (MHAS), 2013 (CRELES), 2017 (PREHCO) and 2014 (HRS).

Measures

Height (cm)—We adjusted height for shrinkage at older ages by gender based on equations developed n the The Tucson Epidemiological Study (Cline MG, 1989). We then developed height categories (140-149, 150-159, 160-169, etc).

Weight (kg)—Similarly we developed weight categories (40-49, 50-59, etc).
Country dummy variables—For pooled models we developed dummy variables for country/setting.

Analysis

For each country data set, we selected the 60-74 years old (born 1926-1940s) and computed mortality rate overall by gender and then by gender for each height and weight category using number of dead and person years lived. We dropped cells with very small cells size. We then computed relative mortality risk (RR) for each height and weight category (relative to overall mortality). Using these computed RR per height and weight category we then estimated linear regression models for the ln of RR as a function of the mid-point of height and weight categories using quadratic equations and then plotted the resulting surfaces by gender using the ln of life expectancy. Regression equations produced a higher R-squared for US older adults (about 0.68 males) than for the pooled LAC older adults (about 0.41 males). Surfaces indicate several BMI lines and then a "minimum risk" line (optimal line)—the height and weight where mortality risk is minimized. We converted RR to life expectancy using the relationship between risk and life expectancy (LE) from male and female Coale-Demeny Model West life tables. We pooled country data for Mexico, Costa Rica and Puerto Rico and then estimated the ln LE using height, weight and country dummies. The surfaces depict ln LE curves for mortality in addition to curves showing varying values of BMI (body mass index).

We use the following key metrics to compare surfaces:

1. location of optimal lines in relation to obesity line (BMI=30). We would expect to observe that taller in LAC increases risk of being obese for moderately stunted individuals in contrast to the US where taller means a tilt toward being overweight but not obese. More severely stunted LAC males show opposite pattern.
2. slope of "minimum risk"-optimal lines. We would expect to observe that increasing weight results in higher height in the US as compared with LAC

(alternatively, increasing height results in higher weight in LAC as compared with the US).

3. keep height constant and predict weight using both optimal lines and estimate life expectancy at age 60 (Table 2). We would expect to observe a lower life expectancy at a given height using US surface than we actually do if you experience the same weight as in LAC.

Alternatively, we predict height using both optimal lines and estimate LE 60 (the complement of Table 2—results not shown). We would expect to observe a lower life expectancy at a given weight using US surface than you actually do if you experience the same height as in LAC (fixing the weight).

4. keep height and weight at some level (average male LAC height=165 cm and weight=80 kg) and estimate corresponding life expectancy at age 60. Then hold life expectancy at age 60 constant and increase weight, by 10 kg intervals and assess the effect on height in both surfaces (US and LAC). We expect to observe that if there is an increase in weight due to Western diet, you need a smaller change in height to preserve the same level of mortality than if you were in the US.

Selected results

Descriptives

We begin by showing empirical evidence of dislocations between LAC time trends of life expectancy, calorie intake and GDP per capita spanning the period 1930-2015. Life expectancy gains were large and took place during a very contracted period of time, with gains of about .80 years per year. This trend is completely dissociated from trends in economic growth, as indexed by GDP as countries that rank low and high in the GDP hierarchy attain similar levels of life expectancy by 2015. Further, and more importantly, we show that increases in calorie intake, though significant throughout the period, do not take place at the same pace as increases in GDP or, least of all, life expectancy. Information on time trends in stunting and moderate malnutrition reveals levels that in Western Europe and North America were prevalent but at much lower levels of life expectancy.

Table 1 (Panel A) describes stunted populations of older adults (males average 164-167 cm) born in the early to mid- 20th century in Mexico, Costa Rica and Puerto Rico who nevertheless are, on average, heavier and overweight than comparable male adults in the developed world of France or Britain several decades earlier. Older adults in the US in contrast are taller (177 cm males) but also are, on average, overweight.

[Insert Table 1 about here]

Waaler height-weight-life expectancy surfaces

Figure 1 depicts Waaler surfaces for LAC and US males 60-74 years of age. Each curve on the surfaces represents a level of life expectancy (expressed as the natural LN of life expectancy) corresponding to a particular height and weight. Higher numbers reflect higher life expectancy at 60-74 years of age. Appearing on the graphs are so-called optimal lines in red which indicate the height-weight combination with the

highest life expectancy. Also appearing are lines indicating several levels of BMIs (18.5, 25, 30, and 35) corresponding to different levels of height and weight. In both surfaces the average heights and weights of individuals 60-74 years of age (from Table 1) lie in the area of BMI [25 to 30], suggesting an overweight population regardless of setting. Immediately apparent is the shape of the LAC surface which tilts farther to the right and a "minimum risk" (optimal) line with a shallower slope, suggesting heavier individuals. The slopes of the optimal line across surfaces in relation to weight are 0.67 (LAC) and 1.26 (US), indicating that a one kg increase in weight results in a 1.26 cm increase in height for US but only 0.67 cm increase for LAC. Alternatively, a one cm increase in height results in a 1.49 kg increase in weight for LAC but only 0.79 kg increase for US.

Along this line in the LAC surface very severely stunted individuals (height < 160) are overweight where more moderately stunted (height > 160) and taller individuals are increasingly obese. Tracing the average LAC male height of 165 cm (moderate stunting) horizontally to the minimal risk line shows that the average LAC male is slightly heavier using the LAC surface (85.4 kg) than using the US surface (82.7 kg).

Life expectancies along the optimal lines show, as expected, higher life expectancy using the LAC surface across all heights (Table 2). At the average male LAC height of 165 cm, life expectancy using the LAC surface is 18.0 and 17.5 using the US surface. Differences in life expectancy between taller and shorter are not that evident as life expectancy is similar across all heights with the exception at severely stunted individuals where life expectancy is 16.4 (16.7) on the US surface. Average heights-weights using the LAC surfaces also show similar life expectancies across Costa Rica, Mexico and Puerto Rico (17.6-1.76) with the US slightly higher (18.0). In contrast, in the HRS surface, life expectancy is slightly lower for Costa Rica, Mexico and Puerto (16.8-17.2) and the US (17.5).

[Insert Figure 1 and Table 2 about here]

Discussion

Preliminary analyses of male data show that the LAC older population (1) is heavier (obese) when attaining optimum levels of life expectancy and (2) reached modern levels of life expectancy in the absence of significant increases in height and the persistence of non-trivial levels of stunting and moderate malnutrition. In our final paper we augment these analyses by considering jointly males and females and, importantly, by drawing unique implications of these results for the controversy over expansion/compression of morbidity and disability for older adults in LAC settings.

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Table 1: Key items of notice in selected population surveys

Panel A: Average height, weight and BMI for male respondents 60-74 years old

	Height (cm)	Weight (kg)	BMI	LE 60+	Mortality
Costa Rica	164 (6.2)	71 (13.1)	26 (4.2)	19.3	0.032
Mexico	165 (11.8)	73 (14.3)	26 (4.4)	19.7	0.036
Puerto Rico	167 (7.0)	76 (14.1)	27 (4.5)	19.6	0.036
US	177 (7.3)	87 (15.5)	28 (4.3)	19.6	0.036

Panel B: Changes in life expectancy, caloric intake and GDP per capita

	LE Birth 1930 (2000)	Caloric Intake 1930 (2000)	GDP per capita 1930 (2000)
Costa Rica	42 (76)	2014 (2804)	1626 (6174)
Mexico	34 (73)	1909 (3172)	1618 (7218)
Puerto Rico	40 (78)	2219 (--)	815 (14,106)
US	60 (76)	3249 (3732)	6231 (28,129)

Notes: Standard deviation shown in parentheses for average height, weight and body mass index (BMI). BMI is underweight (LT 18.5), normal (18.5-25), overweight (25-30) and obese (over 30). LE=life expectancy. Caloric intake is daily caloric intake per capita. GDP per capita expressed in 1990 international dollars. Puerto Rico GDP per capita for 1930 is estimated through linear extrapolation.
Sources: Panel A is based on respondents born mid 1920s-1940s. Panel B draws from McEniry (2013), CRELES, MHAS, PREHCO, HRS population surveys

Table 2: Comparison of life expectancy at age 60-74 using US and LAC height-weight-mortality surfaces: Males

Panel A: Using optimal line US for wgt					Panel B: Optimal line LAC for wgt			
Height (cm)	**Predicted Weight US (kg)**	**LE LAC (A)**	**LE US (B)**	**A-B**	**Predicted Weight LAC (kg)**	**LE LAC (C)**	**LE US (D)**	**C-D**
Males								
150	70.9	18.0	16.7	1.3	63.1	18.1	16.4	1.8
155	74.8	17.9	17.0	0.9	70.5	18.0	16.9	1.0
160	78.8	17.9	17.3	0.6	78.0	17.9	17.3	0.6
165	82.7	18.0	17.5	0.5	85.4	18.0	17.5	0.5
170	86.7	18.1	17.6	0.4	92.8	18.2	17.4	0.7
175	90.6	18.2	17.7	0.5	100.2	18.5	17.2	1.3
180	94.6	18.5	17.7	0.8	107.6	18.9	16.7	2.1

Notes: Differences may be slightly off due to rounding. Life expectancy for average heights and weights from Table 1 on graph using the LAC surface is 17.6 (Costa Rica), 17.6 (Mexico), 17.7 (Puerto Rico), and US (18.0). Life expectancy using US surface is 16.8 (Costa Rica), 17.0 (Mexico), 17.2 (Puerto Rico) and 17.5 (US).

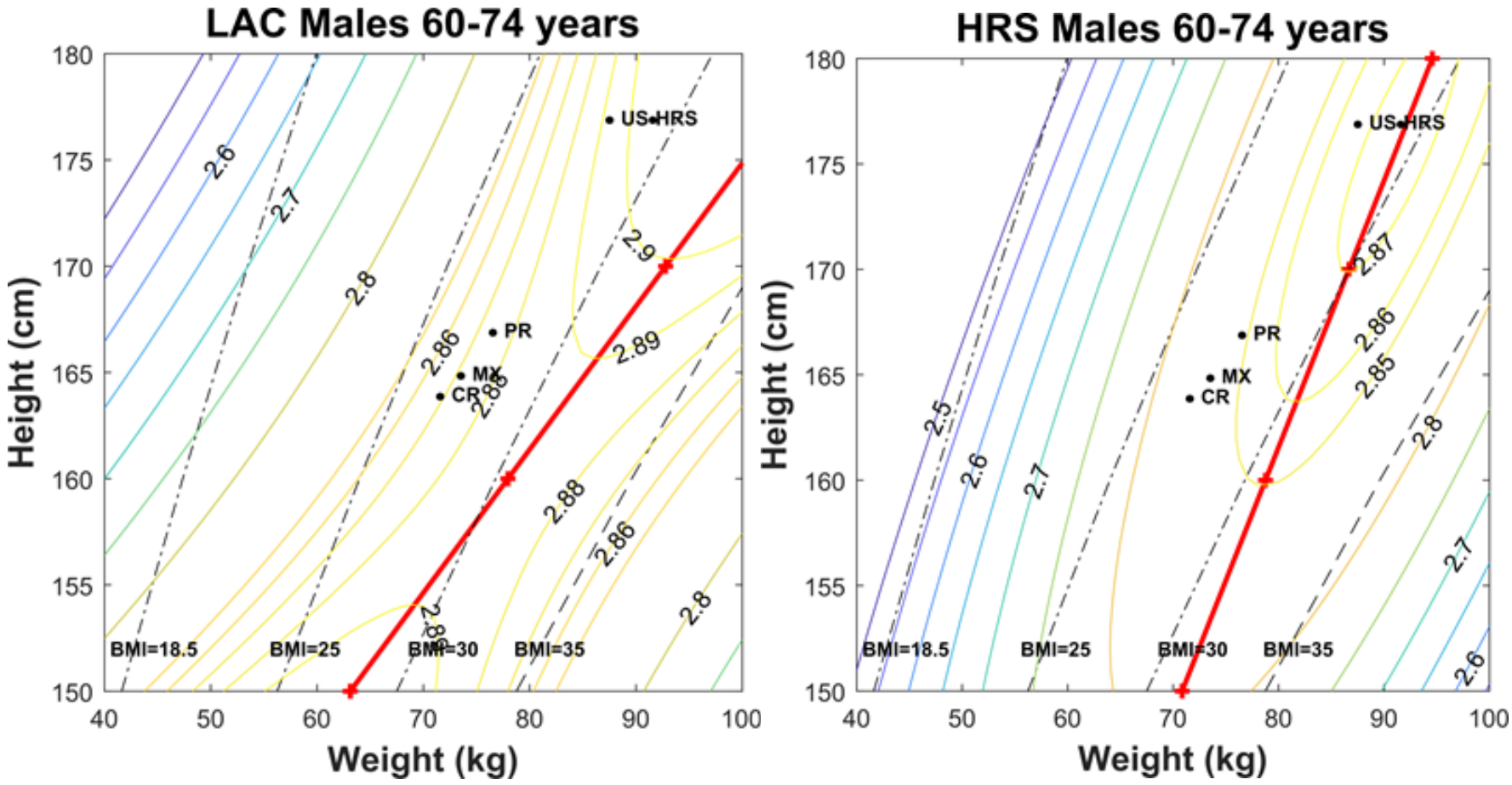


Figure 1: Comparison of Waaler surfaces—males