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Inequalities in adiposity trends between 1979 and 1999 in Guatemalan children

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Abstract

Background: Guatemala suffered from civil war and high levels of inequality and childhood stunting in the second half of the 20th century, but little is known about inequalities in secular trends in adiposity.

Objectives: To investigate differences in childhood body mass index (BMI) and skinfold thickness trajectories from 1979 to 1999 between three groups of children: High socioeconomic position (SEP) Ladino, Low SEP Ladino, and Low SEP Indigenous Maya.

Methods: The sample comprised 19 346 children aged 7–17 years with 54 638 observations. The outcomes were height, BMI, triceps skinfold thickness (TST), and subscapular skinfold thickness (SST) Z-scores according to the Centers for Disease Control and Prevention (CDC) references. Sex-specific multilevel models were used to estimate and compare mean trajectories from 1979 to 1999 between the three groups.

Results: Mean Z-scores were always highest for High SEP Ladino children and lowest for Low SEP Maya children. Despite their very short stature, the Low SEP groups had SST trajectories that were above the 50th centile. The BMI trajectories were relatively flat and within one major centile band of the CDC median, with differences between the three groups that were small (0.2–0.3 Z-scores) and did not attenuate over time. Conversely, the TST Z-score trajectories demonstrated larger positive secular trends (e.g., from −1.25 in 1979 to −0.06 in 1999 for Low SEP Maya boys), with differences between the three groups that were large (0.5–1.2 Z-scores) and did attenuate over time (in boys). Secular trends and between-group difference in the SST Z-score trajectories were less pronounced, but again we found stronger evidence in boys that the estimated inequalities attenuated over time.

Conclusions: Secular trends and inequalities in skinfolds differ from those for BMI in Guatemalan children. Differences between groups in skinfolds attenuated over time, at least in boys, but whether this is good news is questionable

given the very short stature yet relatively large subscapular skinfolds of the Low SEP groups.

1 | INTRODUCTION

Childhood malnutrition is a leading cause of morbidity and mortality globally (Black et al., 2013; GBD Risk Factors Collaborators, 2020). In 2019, 21.3% (144 million) of all children under five were stunted and 5.6% were overweight (or obese) (*2021 Global Nutrition Report: The state of global nutrition*, 2021). Among older children aged 5–19 years, 10.4% (192 million) were underweight and another 6.7% were obese in 2016 (NCD Risk Factor Collaboration, 2017). Many low- and middle-income countries are currently facing issues related to both undernutrition and overnutrition. As reported in the 2019 Lancet series, severe levels of this double burden of malnutrition have shifted to the countries in the poorest income quartile (Popkin et al., 2020). Within such countries, and indeed arguably within all countries, there are also inextricable inequalities in malnutrition between groups of children of different socioeconomic positions (SEPs) (*2021 Global Nutrition Report: The state of global nutrition*, 2021; Seferidi et al., 2022). Investigations of inequalities in secular trends (and secular trends in inequalities) are important because changes over time in rates of childhood malnutrition might be driven or masked by different or changing levels of inequality.

While childhood stunting is relatively easy to ascertain, obesity (defined according to the World Health Organization as "abnormal or excessive fat accumulation that presents a risk to health") is not. Most secular trend and/or inequality work in the field of obesity has been based on body mass index (BMI). The BMI is not, however, a measure of adiposity. It is a weight-for-height index that is known to suffer from being positively correlated with height in much of childhood and adolescence and not account for differences (e.g., in the weight-height association or the average amount of fat at any given BMI) between sexes and ethnic groups (Bogin, 2021; Bogin & Varela Silva, 2012; Johnson et al., 2020 and Prentice & Jebb, 2001). In children, BMI is not always highly correlated with total body fat, and changes in BMI (within an individual) over age do not accurately reflect changes in adiposity (Demerath et al., 2006; Freedman et al., 2005). It is, therefore, reasonable to question whether secular trends and/or inequalities in childhood BMI are comparable to those observed when using skinfold thicknesses or other body fat measurements. A 2017 paper by Freedman et al used adulthood National Health and Nutrition Examination Survey (NHANES) data from 1988 to 1994 through 2009–2010 to demonstrate that secular trends in skinfold thicknesses were meaningfully different to those in BMI in women, but data from many other countries are lacking (Freedman et al., 2017). Existing research has also demonstrated how inequalities in body fat (e.g., from bioelectrical impedance or dual-energy x-ray absorptiometry) differ to those observed for BMI, but again a lot of this work has been focused on high-income country settings (Davillas & Benzeval, 2016).

Guatemalans are one of the shortest populations in the world, with up to approximately 70% of Indigenous Maya under-five children being stunted in 1995 compared against 40% of non-Indigenous (predominately Ladino) children (Gatica-Dominguez et al., 2019). Guatemala also suffers from very high levels of inequality, such that the prevalence of stunting varied in 1995 from 15% in the highest wealth quintile to 70% in the lowest (Gatica-Dominguez et al., 2019). Childhood obesity rates are much lower than those for stunting but, at least at the household level, the double burden of malnutrition (i.e., stunting + obesity) in Guatemala is high (Popkin et al., 2020). There are no national data on childhood malnutrition prior to 1995, but we have previously used data from the Universidad del Valle de Guatemala (UVG) Longitudinal Study of Child and Adolescent Development to describe secular trends (across birth years 1955–1993) and inequalities (between five socioeconomically distinct school groups) in childhood height and BMI growth curves (between 3 and 19 years) (Mansukoski et al., 2020). In brief, that paper reported large inequalities in height that attenuated over time, due to a stronger positive secular trend in the lower SEP groups, but much smaller inequalities and secular trends in BMI. Data from the Institute of Nutrition of Central America and Panama Study have similarly shown that BMI in children less than 6 years old remained relatively stable between 1968 and 2007 (Stein et al., 2009), but inequalities in secular trends (and secular trends in inequalities) in measures of adiposity have not been well-documented in any large Guatemalan study.

The aim of this study was to investigate differences in childhood BMI and skinfold thickness CDC Z-score trajectories from 1979 to 1999 between three groups of Guatemalan children: High SEP Ladino, Low SEP Ladino, and Low SEP Indigenous Maya. For completeness and to help interpret our results, we also perform the same analysis on height CDC Z-scores. The 1979–

1999 time period includes the last 17 years of the Guatemalan Civil War (1960–1996), including the most brutal years of that war during the 1980s, and the first few years after the signing of peace accords in 1996, which offered some hope for better living conditions in Guatemala (Bogin, 2022). Documenting inequalities in adiposity trends is particularly important in this context as the results will demonstrate the impact of war on child nutritional status.

2 | METHODS

2.1 | Study sample

The sample comprised 11 192 boys and 8154 girls, aged 7–17 years, born between 1963 and 1992, who participated in the UVG Longitudinal Study of Child and Adolescent Development (Bogin et al., 2018). The study ran between 1953 and 1999, with the target population being all children attending seven schools in and around Guatemala City. Previous publications have treated the data as being from five school groups (herein just called schools or groups), which are strongly indicative of SEP.

- School 1 was a private institution charging high fees and was attended by some individuals of North American and European (mostly Spanish) heritage, but primarily by individuals of mixed heritage (self-identified ethnically as Ladinos).
- School 2 was comprised of two single-sex private Catholic schools (one for boys and one for girls) with moderate fees and attended by individuals of Ladino ethnicity.
- School 3 comprised two coeducational Catholic private institutions with low fee or no fee and attended by individuals of Ladino ethnicity.
- School 4 was a coeducational, state-run, nonsectarian institution with no fees, and attended by individuals of mostly Ladino ethnicity.
- School 5 comprised two coeducational, semi-urban, state-run, nonsectarian schools with no fee, and attended by individuals of Indigenous Maya ethnicity.

Ladino or mixed heritage in the Guatemalan context refers to individuals of mixed Spanish and Indigenous Maya heritage but identify with Spanish/European culture in terms of language (Spanish), social values, and religion. Maya people identify with traditional Indigenous language, behaviors, social values, and religion.

The present study uses data from Schools 2, 4, and 5, thereby allowing comparisons of (1) “Low SEP Ladino” to “High SEP Ladino” and (2) “Low SEP Maya” to “High SEP Ladino”. The difference between the “Low SEP Ladino” and “Low SEP Maya” groups is also of interest. We do not use data from School 1 (because the ethnic mix hinders comparisons) or School 3 (because skinfold thickness measurements ended in 1987 in this group).

The UVG Longitudinal Study was approved by the Guatemalan Ministry of Education and the secondary analysis of these data has been approved by UVG and Loughborough University Human Participants Sub-Committee (Ref No: G13-P2).

2.2 | Measurements

For the present study, we used four outcomes: height, BMI, triceps skinfold thickness (TST), and subscapular skinfold thickness (SST). The UVG data set does not include waist circumference, hip circumference, or any other measurements recommended as proxies of body fatness. Anthropometric measurements were taken by a trained research team from the UVG following the guidelines of the International Biological Program; detailed protocols have been described previously (Bogin et al., 2018; Bogin & MacVean, 1978). Briefly, skinfolds were measured to the nearest millimeter using Lange skinfold caliper (Beta Technology, Santa Cruz, CA). Differences in skinfold measurements within and between observers were small, and indicative of good reliability (Bogin & MacVean, 1981). All anthropometric measurements were taken on all pupils between 1979 and 1999. The 19 346 children included in the present paper yielded a total of 54 638 complete observations (Tables 1 and 2). Table S1 shows the number of measurements by calendar year, stratified by sex, and group. Table S2 shows the number of measurements by chronological age, stratified by sex and group.

2.3 | Statistical analysis

All analyses were performed for boys and girls separately.

Height and BMI Z-scores according to the CDC 2000 Growth Charts were calculated (Kuczmarski et al., 2000). Z-scores for TST and SST were calculated using the charts published by Addo and Himes (2010), which are based on the same samples as those included in the CDC 2000 BMI Charts. Descriptive statistics were produced stratified by group. Because the data are longitudinal, we chose to show descriptive statistics for the first observation of each child and, separately, for the last observation of each child.

A multilevel model (measurement occasion at level one and children at level two) was developed for each CDC Z-score outcome (i.e., height, BMI, TST, and SST).

TABLE 1 Description of study sample: boys.

		Boys ($N = 11\,192$)		
		High SEP Ladino ($N = 5877$)	**Low SEP Ladino ($N = 2839$)**	**Low SEP Maya ($N = 2476$)**
Date of birth	Median (IQR)	1978 (1972, 1984)	1976 (1970, 1984)	1980 (1974, 1985)
Number of observations				
1	*N* (%)	963 (16.4)	1152 (40.6)	728 (29.4)
2	*N* (%)	1307 (22.2)	752 (26.5)	602 (24.3)
3	*N* (%)	1079 (18.4)	524 (18.5)	403 (16.3)
4	*N* (%)	845 (14.4)	335 (11.8)	381 (15.4)
5	*N* (%)	866 (14.7)	66 (2.3)	222 (9.0)
6	*N* (%)	755 (12.9)	9 (0.3)	20 (0.8)
7	*N* (%)	62 (1.1)	1 (0.04)	1 (0.04)
Total	*N*	19 488	5959	6637
First observation				
Age	Median (IQR)	7.9 (7.5, 11.8)	8.4 (7.6, 11.4)	8.4 (7.6, 11.5)
Date	Median (IQR)	1987 (1981, 1993)	1983 (1980, 1993)	1989 (1982, 1995)
BMI (kg/m^2)	Median (IQR)	17.2 (15.8, 19.5)	16.5 (15.5, 17.8)	16.4 (15.6, 17.7)
Height (cm)	Mean (SD)	133.5 (15.6)	125.0 (13.2)	124.1 (14.4)
TST (mm)	Median (IQR)	10.0 (7.0, 13.5)	7.5 (6.0, 10.0)	7.5 (6.0, 9.0)
SST (mm)	Median (IQR)	7.0 (5.0, 11.0)	6.0 (5.0, 7.5)	5.5 (4.5, 7.0)
BMI CDC Z-score	Mean (SD)	0.38 (1.01)	0.02 (0.85)	−0.02 (0.73)
Height CDC Z-score	Mean (SD)	−0.41 (0.95)	−1.77 (0.98)	−2.09 (0.91)
TST CDC Z-score	Mean (SD)	0.29 (1.15)	−0.37 (1.06)	−0.48 (0.98)
SST CDC Z-score	Mean (SD)	0.71 (1.07)	0.33 (0.90)	0.03 (1.04)
Last observation				
Age	Median (IQR)	14.3 (11.3, 15.6)	11.9 (9.7, 13.0)	13.0 (10.6, 14.8)
Date	Median (IQR)	1992 (1986, 1989)	1986 (1982, 1996)	1993 (1986, 1998)
BMI (kg/m^2)	Median (IQR)	19.8 (17.6, 22.4)	17.4 (16.2, 18.9)	17.9 (16.5, 19.54)
Height (cm)	Mean (SD)	155.3 (16.8)	135.1 (13.1)	139.2 (14.8)
TST (mm)	Median (IQR)	11.0 (7.5, 15.5)	8.5 (6.5, 11.0)	8.0 (6.5, 10.5)
SST (mm)	Median (IQR)	9.5 (6.5, 15.0)	7.0 (5.0, 9.0)	7.0 (5.5, 9.5)
BMI CDC Z-score	Mean (SD)	0.28 (1.04)	−0.08 (0.88)	−0.15 (0.77)
Height CDC Z-score	Mean (SD)	−0.45 (0.93)	−1.70 (0.97)	−2.00 (0.89)
TST CDC Z-score	Mean (SD)	0.39 (1.01)	−0.19 (0.95)	−0.21 (0.86)
SST CDC Z-score	Mean (SD)	0.74 (0.90)	0.39 (0.84)	0.26 (0.83)

Abbreviations: BMI, body mass index; SEP, socioeconomic position; SST, subscapular skinfold thickness; and TST, triceps skinfold thickness.

Chronological age (centered at 11 years) was fitted as a restricted cubic spline, with four knots at default locations based on Harrell's recommended quantiles (Harrell, 2001). The model constant and the three age spline terms were allowed to have random effects at level two, with an unstructured variance–covariance matrix, thereby allowing each child to essentially have their own growth curve. Building on this basic structure, decimal date of measurement (centered at 1979) was added, also as a restricted cubic spline with four knots at default locations. Binary dummy terms for the low SEP Ladino and low SEP Maya groups (i.e., setting high SEP Ladino as the referent) were included and interacted with the date of measurement spline terms to allow the mean trajectory to differ flexibly between groups. These dummy variables were also interacted with the age spline terms because we know that at least height and BMI-for-age curves differ between schools (Mansukoski et al., 2020).

TABLE 2 Description of study sample: girls.

		Girls (N = 8154)		
		High SEP Ladino (N = 3936)	**Low SEP Ladino (N = 2293)**	**Low SEP Maya (N = 1925)**
Date of birth	Median (IQR)	1977 (1972, 1984)	1975 (1970, 1984)	1980 (1975, 1985)
Number of observations				
1	N (%)	849 (21.6)	978 (42.7)	509 (26.4)
2	N (%)	740 (18.8)	589 (25.7)	534 (27.7)
3	N (%)	636 (16.2)	410 (17.9)	394 (20.5)
4	N (%)	504 (12.8)	275 (12.0)	315 (16.4)
5	N (%)	609 (15.5)	35 (1.5)	132 (6.9)
6	N (%)	554 (14.1)	6 (0.3)	39 (2.0)
7	N (%)	44 (1.1)	0	2 (0.1)
Total	N	12 930	4697	4927
First observation				
Age	Median (IQR)	7.9 (7.5, 12.4)	8.5 (7.6, 11.4)	8.3 (7.6, 10.2)
Date	Median (IQR)	1987 (1981, 1993)	1983 (1980, 1992)	1989 (1983, 1994)
BMI (kg/m^2)	Median (IQR)	17.6 (15.8, 20.3)	16.5 (15.4, 18.2)	16.4 (15.5, 17.6)
Height (cm)	Mean (SD)	133.1 (15.3)	125.1 (13.3)	121.0 (11.9)
TST (mm)	Median (IQR)	13.0 (9.5, 17.0)	10.0 (7.5, 12.5)	9.0 (7.0, 11.5)
SST (mm)	Median (IQR)	9.5 (6.5, 15.5)	7.5 (5.5, 10.5)	6.5 (5.0, 9.0)
BMI CDC Z-score	Mean (SD)	0.37 (0.93)	0.03 (0.81)	0.05 (0.69)
Height CDC Z-score	Mean (SD)	−0.59 (0.92)	−1.81 (1.03)	−2.21 (0.93)
TST CDC Z-score	Mean (SD)	0.21 (1.06)	−0.43 (1.01)	−0.64 (0.96)
SST CDC Z-score	Mean (SD)	0.73 (0.93)	0.33 (0.83)	0.10 (0.88)
Last observation				
Age	Median (IQR)	15.0 (12.3, 15.8)	11.9 (9.5, 13.1)	12.0 (9.9, 13.7)
Date	Median (IQR)	1992 (1986, 1988)	1986 (1982, 1995)	1992 (1986, 1998)
BMI (kg/m^2)	Median (IQR)	20.5 (18.4, 22.8)	17.9 (16.2, 19.9)	18.0 (16.4, 20.3)
Height (cm)	Mean (SD)	149.9 (12.4)	135.0 (12.9)	133.9 (12.2)
TST (mm)	Median (IQR)	16.5 (13.0, 21.0)	11.5 (9.0, 15.0)	11.0 (8.5, 14.5)
SST (mm)	Median (IQR)	14.5 (10.0, 20.5)	9.5 (7.0, 13.0)	9.5 (6.5, 14.0)
BMI CDC Z-score	Mean (SD)	0.35 (0.87)	0.07 (0.83)	0.09 (0.74)
Height CDC Z-score	Mean (SD)	−0.74 (0.91)	−1.72 (1.01)	−2.12 (0.90)
TST CDC Z-score	Mean (SD)	0.33 (0.87)	−0.25 (0.93)	−0.38 (0.90)
SST CDC Z-score	Mean (SD)	0.75 (0.77)	0.41 (0.79)	0.37 (0.81)

Abbreviations: BMI, body mass index; SEP, socioeconomic position; SST, subscapular skinfold thickness; and TST, triceps skinfold thickness.

Models were rerun setting Low SEP Ladino children as the referent to obtain estimates comparing this group to the Low SEP Maya group. We also re-ran the TST and SST Z-score models adding in an adjustment for CDC height Z-scores (grand mean centered).

For each outcome, we used the multilevel model to produce a figure showing the mean Z-score trajectory between 1979 and 1999 for each group. We also used to the models to obtain estimates (mean values for each group and differences between groups) of (1) Z-scores in 1979 and 1999 and (2) Z-score changes between 1979 and 1999. Finally, to help understand secular trends and inequalities in central versus peripheral fat storage, we used the models to produce a figure showing the difference between the TST and SST Z-score trajectories for each group.

All analyses were performed in Stata SE 15.1. The command runmlwin was used for the multilevel models (Leckie & Charlton, 2012).

2.4 | Code availability

Available from the first author upon request.

3 | RESULTS

Descriptive statistics are shown in Table 1 for boys and Table 2 for girls.

Investigation of external Z-scores confirmed the known inequality in height. For example, for both sexes and using either the first or last observation data, the mean CDC height Z-score was −2.0 or lower (i.e., the 2nd centile and cutoff for stunting) in Low SEP Maya children, between −1.8 and −1.7 in Low SEP Ladino children, and between −0.7 and −0.4 in High SEP Ladino children. The same ranking of groups was observed for BMI, TST, and SST Z-scores. Despite their short stature, mean BMI Z-scores of Low SEP Maya and Low SEP Ladino children approximated zero (i.e., the 50th centile). Further, in all groups, mean SST Z-score values were consistently higher than mean BMI and TST Z-score values.

3.1 | Height

Figure 1 shows the estimated trajectories between 1979 and 1999 for height Z-scores. The inequalities between groups were stark but did attenuate over time. For example, in 1979, Low SEP Maya boys were 1.82 (−1.73, −1.90) Z-scores shorter than High SEP Ladino boys, but in 1999 this difference was 1.50 (1.42, 1.57) (Table 3). This narrowing inequality is also reflected in height Z-score change over time. Between 1979 and 1999, mean height Z-score increased by 0.22 (0.15, 0.29) units in high SEP Ladino boys but by 0.54 (0.43 and 0.64) units in Low SEP Maya boys, with the difference of 0.32 (0.20, 0.44) being significant at alpha 5%.

Estimates comparing the two Low SEP groups are shown in Tables S3 and S4. Low SEP Maya children were shorter than Low SEP Ladino children, but this inequality did attenuate between 1979 and 1999.

3.2 | BMI, TST, and SST

Figure 2 shows the estimated trajectories for BMI, TST, and SST Z-scores.

The mean BMI Z-score trajectories were relatively flat, with the strongest visual evidence of a positive secular trend seen in boys post approximately 1994. Across the full 20-year period, mean BMI increased by only between 0.2 and 0.3 Z-scores for each sex and SEP group (Tables 3 and 4). While Low SEP Ladino and Low SEP Maya children consistently had lower mean BMI Z-scores than high SEP Ladino children, there was no strong evidence that this inequality attenuated over time.

Opposite to the findings for BMI, all the TST trajectories showed a positive secular trend, which was most pronounced at least up until 1989. Across the full 20-year period, mean TST increased between 0.7 and 1.2 Z-scores for each sex and SEP group (Tables 3 and 4). Low SEP Ladino and Low SEP Maya children consistently had lower mean TST Z-scores than high SEP Ladino children, and the magnitude of these inequalities was always larger than that found for BMI. For example, in 1979, Low SEP Maya boys had a mean TST that was 1.16 (1.06, 1.27) Z-scores lower than that for High SEP Ladino boys, but the equivalent estimate for BMI was only 0.52 (0.43, 0.61) Z-scores (Table 3). In addition, unlike the findings for BMI Z-scores, there was evidence (for boys but not girls) that the inequality in TST Z-scores attenuated over time.

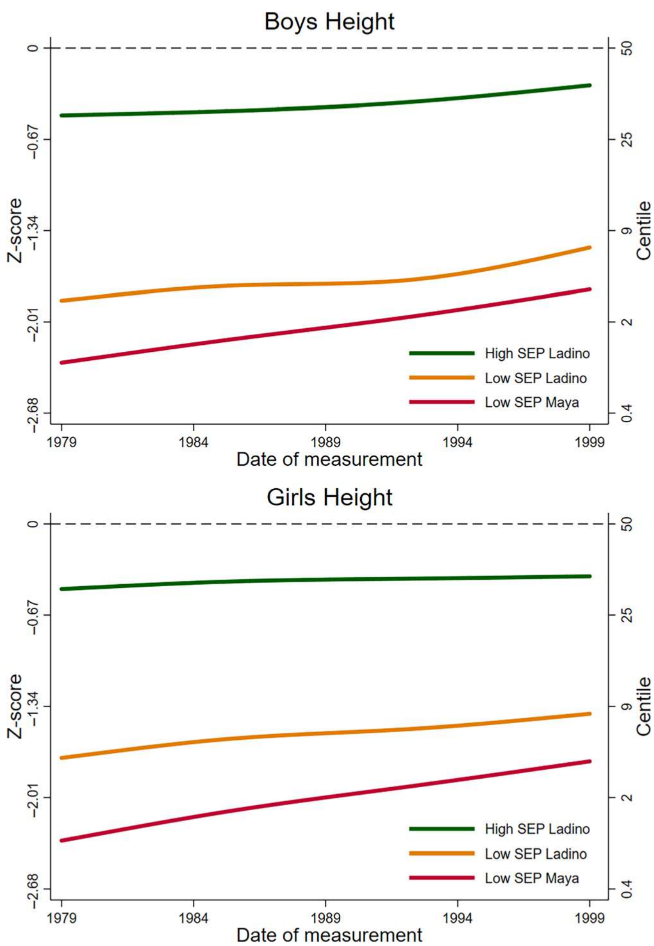

FIGURE 1 Trajectories for height CDC Z-scores between 1979 and 1999, estimated from the multilevel growth curve models. SEP, socioeconomic position.

TABLE 3 Differences between groups in mean height, BMI, TST, and SST Z-scores (in 1979 and 1999) and Z-score changes (from 1979 to 1999), estimated from the multilevel growth curve models: boys.

	Height CDC Z-score		BMI CDC Z-score		TST CDC Z-score		SST CDC Z-score	
	Mean	Difference	Mean	Difference	Mean	Difference	Mean	Difference
	B (95% CI)	B (95% CI)	B (95% CI)	B (95% CI)	B (95% CI)	B (95% CI)	B (95% CI)	B (95% CI)
1979								
High SEP Ladino	−0.49 (−0.54, −0.45)	–	0.29 (0.25, 0.34)	–	−0.08 (−0.14, −0.03)	–	0.63 (0.58, 0.68)	–
Low SEP Ladino	−1.85 (−1.91, −1.79)	−1.36 (−1.44, −1.29)	−0.06 (−0.12, 0.004)	−0.35 (−0.43, −0.27)	−0.89 (−0.96, −0.81)	−0.80 (−0.89, −0.71)	0.18 (0.11, 0.25)	−0.45 (−0.53, −0.36)
Low SEP Maya	−2.31 (−2.39, −2.23)	−1.82 (−1.90, −1.73)	−0.23 (−0.31, −0.15)	−0.52 (−0.61, −0.43)	−1.25 (−1.34, −1.16)	−1.16 (−1.27, −1.06)	−0.21 (−0.3, −0.13)	−0.84 (−0.94, −0.75)
1999								
High SEP Ladino	−0.27 (−0.31, −0.23)	–	0.60 (0.56, 0.64)	–	0.65 (0.61, 0.70)	–	0.66 (0.62, 0.71)	–
Low SEP Ladino	−1.46 (−1.53, −1.40)	−1.19 (−1.27, −1.11)	0.12 (0.05, 0.19)	−0.48 (−0.56, −0.40)	0.17 (0.09, 0.25)	−0.48 (−0.57, −0.39)	0.48 (0.40, 0.55)	−0.19 (−0.27, −0.10)
Low SEP Maya	−1.77 (−1.83, −1.71)	−1.50 (−1.57, −1.42)	0.04 (−0.02, 0.11)	−0.56 (−0.64, −0.48)	−0.06 (−0.13, 0.005)	−0.72 (−0.80, −0.63)	0.09 (0.03, 0.16)	−0.57 (−0.65, −0.50)
1979 to 1999								
High SEP Ladino	0.22 (0.15, 0.29)	–	0.31 (0.24, 0.37)	–	0.74 (0.66, 0.81)	–	0.03 (−0.03, 0.10)	–
Low SEP Ladino	0.39 (0.30, 0.48)	0.17 (0.06, 0.28)	0.17 (0.08, 0.27)	−0.13 (−0.25, −0.02)	1.06 (0.95, 1.16)	0.32 (0.19, 0.45)	0.30 (0.20, 0.39)	0.26 (0.14, 0.38)
Low SEP Maya	0.54 (0.43, 0.64)	0.32 (0.20, 0.44)	0.27 (0.17, 0.37)	−0.04 (−0.16, 0.09)	1.18 (1.07, 1.30)	0.45 (0.31, 0.58)	0.30 (0.20, 0.41)	0.27 (0.14, 0.40)

Abbreviations: BMI, body mass index; SEP, socioeconomic position; SST, subscapular skinfold thickness; and TST, triceps skinfold thickness.

Between 1979 and 1999, mean TST Z-score increased by 0.74 (0.66, 0.81) units in high SEP Ladino boys but by 1.18 (1.07, 1.30) units in Low SEP Maya boys, with the difference of 0.45 (0.31, 0.58) being significant at alpha 5% (Table 3).

The general pattern of findings for SST was that all trajectories increased to a peak in approximately 1994 before decreasing and being indicative of a slight negative secular trend. As a result, across the full 20-year period, mean SST increased by ≤0.4 Z-scores for each sex and SEP group (Tables 3 and 4). The magnitude of the inequalities was not as large as those for TST. For example, in 1999, Low SEP Ladino girls had a mean SST that was 0.33 (0.24, 0.41) Z-scores lower than that for High SEP Ladino girls, but the equivalent estimate for TST was 0.67 (0.57, 0.77) Z-scores (Table 4). However, similar to the findings for TST Z-scores, there was stronger evidence for boys than girls that the inequality in SST Z-scores attenuated over time.

Estimates comparing the two Low SEP groups are shown in Tables S3 and S4. TST and SST, but not BMI, Z-scores were lower in the Low SEP Maya group than the Low SEP Ladino children in both 1979 and 1999. Only for TST Z-scores in girls was there evidence that this inequality attenuated over time.

Adjustment of the TST and SST models for height CDC Z-scores had minimal impact on the pattern of results we observed (Figure S1; Tables S5 and S6).

3.3 | SST minus TST Z-score trajectories

Figure 3 shows the difference between the TST and SST Z-score trajectories. Values above zero occur when SST Z-score was greater than TST Z-score and are indicative of greater central than peripheral adiposity. None of the values were ever below zero. Despite the Low SEP Ladino and Low SEP Maya groups consistently having higher trajectories than the High SEP Ladino group, all three groups showed a negative secular trend toward a more balanced (i.e., less centrally dominant) pattern of fat distribution.

4 | DISCUSSION

Our paper is the largest study of skinfold thickness measurements in Guatemalan children to date, with approximately 55 000 observations on 19 000 children. We know from previous UVG study publications that the lower SEP schools (e.g., 4 and 5) are shorter, lighter, and with lower BMI than the higher SEP schools (e.g., 1 and 2) (Mansukoski et al., 2020). But we extend that knowledge

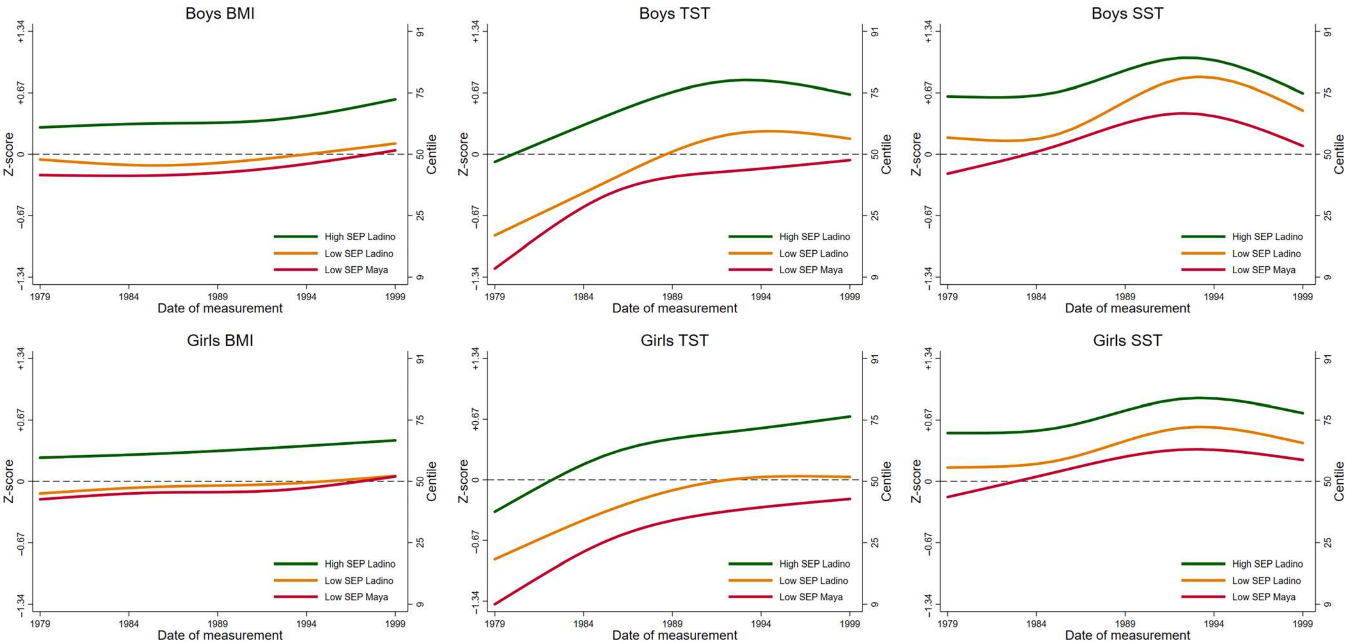

FIGURE 2 Trajectories for body mass index (BMI), triceps skinfold thickness (TST), and subscapular skinfold thickness (SST) CDC Z-scores between 1979 and 1999, estimated from the multilevel growth curve models. SEP, socioeconomic position.

by showing secular trends over a 20-year period of measurement, and by presenting largely unpublished data on skinfold thickness measurements. Indeed, previous UVG study publications including the TST and SST measurements have only focused on subsamples of approximately 1000 to 5000 children and from only the first few years of data collection (Bogin & MacVean, 1981; Bogin & Sullivan, 1986).

It is well known that Guatemalans are one the shortest populations in the world. In the 2020 NCD Risk Factor Collaboration Lancet paper, it was estimated that, in 2019 and at 19 years of age, Guatemalan women were shorter (on average) than girls from any of the other 199 countries and territories studied (NCD Risk Factor Collaboration, 2020). Guatemalan 19-year-old men were the sixth shortest. While clearly important, such population level statistics do not capture variation within a country (e.g., between socioeconomic groups) and average over any inequalities that exist. This is particularly important in the context of our setting because Guatemala is one of the most income unequal countries in the world (Marini & Gragnolati, 2003). Approximately 50% of the population is Maya, an Indigenous group that has suffered extreme violence, oppression, and injustice particularly during the civil war between 1960 and 1996 (Bogin, 2022). The majority of the other 50% of the population identified as Ladino and are descendants of predominantly Spanish, Spanish-Maya, and other ethnic groups. In addition to there being inequality in childhood height between the Maya and Ladinos, our results show the inequality between Ladino SEP groups. The deficit in height of Low SEP Ladino children was almost as large as the deficit in height of Low SEP Maya children. This finding provides further evidence that the short stature of the Maya is not just genetic, as claimed by some (Bogin, 2022). Despite the civil war, our results provide some evidence that the height inequality narrowed slightly between 1979 and 1999. This is positive, but the magnitude of change is very small compared to the known gains in height (e.g., in studies comparing Maya born in Guatemala to their siblings born in the United States of America (USA)) that can be achieved by changing the environment in which children grow and develop (Bogin et al., 2002). At the end of our study, in 1999, Low SEP Ladino and Low SEP Maya children were still more than 1 Z-score shorter than High SEP Ladino children.

While some high-income countries like the USA started to experience an increase in pediatric BMI and obesity as early as the 1960's and 1970's (Komlos et al., 2009; Troiano et al., 1995), our results show that mean BMI Z-score trajectories were relatively flat. The strongest evidence of a positive secular trends was seen in boys post approximately1994. This makes sense given the nutritional insecurity that occurred as a result of the civil war, the worst years of which may have been in the early 1980's during the military dictatorship of José Efrain Ríos Montt (Bogin, 2022). The observed inequalities (i.e., between-school differences) in BMI were smaller than those in height. Across the time-period of our

TABLE 4 Differences between groups in mean height, BMI, TST, and SST Z-scores (in 1979 and 1999) and Z-score changes (from 1979 to 1999), estimated from the multilevel growth curve models: girls.

	Height CDC Z-score		BMI CDC Z-score		TST CDC Z-score		SST CDC Z-score	
	Mean	Difference	Mean	Difference	Mean	Difference	Mean	Difference
	B (95% CI)	B (95% CI)	B (95% CI)	B (95% CI)	B (95% CI)	B (95% CI)	B (95% CI)	B (95% CI)
1979								
High SEP Ladino	−0.48 (−0.54, −0.42)	–	0.26 (0.21, 0.31)	–	−0.35 (−0.41, −0.29)	–	0.53 (0.47, 0.58)	–
Low SEP Ladino	−1.72 (−1.78, −1.65)	−1.24 (−1.33, −1.15)	−0.13 (−0.20, −0.07)	−0.39 (−0.47, −0.31)	−0.88 (−0.95, −0.81)	−0.53 (−0.62, −0.43)	0.15 (0.09, 0.22)	−0.38 (−0.46, −0.29)
Low SEP Maya	−2.33 (−2.42, −2.23)	−1.85 (−1.96, −1.74)	−0.20 (−0.29, −0.11)	−0.45 (−0.56, −0.35)	−1.37 (−1.48, −1.27)	−1.02 (−1.14, −0.90)	−0.17 (−0.27, −0.08)	−0.70 (−0.81, −0.59)
1999								
High SEP Ladino	−0.38 (−0.44, −0.33)	–	0.45 (0.40, 0.50)	–	0.70 (0.65, 0.75)	–	0.75 (0.70, 0.79)	–
Low SEP Ladino	−1.39 (−1.47, −1.32)	−1.01 (−1.10, −0.92)	0.06 (−0.01, 0.13)	−0.39 (−0.48, −0.30)	0.03 (−0.05, 0.11)	−0.67 (−0.77, −0.57)	0.42 (0.35, 0.49)	−0.33 (−0.41, −0.24)
Low SEP Maya	−1.74 (−1.81, −1.67)	−1.36 (−1.45, −1.27)	0.05 (−0.01, 0.12)	−0.40 (−0.48, −0.31)	−0.21 (−0.29, −0.14)	−0.91 (−1.00, −0.82)	0.23 (0.17, 0.30)	−0.51 (−0.59, −0.43)
1979 to 1999								
High SEP Ladino	0.09 (0.01, 0.18)	–	0.19 (0.11, 0.26)	–	1.05 (0.97, 1.13)	–	0.22 (0.14, 0.29)	–
Low SEP Ladino	0.32 (0.22, 0.43)	0.23 (0.10, 0.36)	0.19 (0.09, 0.29)	0.004 (−0.12, 0.13)	0.91 (0.80, 1.02)	−0.14 (−0.28, −0.01)	0.27 (0.17, 0.37)	0.05 (−0.07, 0.17)
Low SEP Maya	0.58 (0.46, 0.71)	0.49 (0.34, 0.64)	0.25 (0.13, 0.37)	0.06 (−0.08, 0.20)	1.16 (1.03, 1.29)	0.11 (−0.04, 0.26)	0.41 (0.29, 0.52)	0.19 (0.05, 0.33)

Abbreviations: BMI, body mass index; SEP, socioeconomic position; SST, subscapular skinfold thickness; and TST, triceps skinfold thickness.

study, the Low SEP Ladino and Low SEP Maya children had body weights that were roughly appropriate for their heights, as shown by mean BMI Z-scores according to the CDC approximating zero. While these children were chronically stunted, there were no widespread issues with underweight or overweight according to BMI. The children were from a largely urban population and their access to foods may not have suffered as much as children in rural areas during the war. It has only been more recently that pediatric obesity has become a public health concern in Guatemala. We know, for example, that childhood obesity rates in the country approximately tripled (from 4% to 12%) between 2000 and 2019 (*2022 Global Nutrition Report: Stronger commitments for greater action*, 2022).

The observed secular trends in skinfold measurements did not match those for BMI. During time periods when there was no clear secular change in BMI, both TST and SST were increasing. Conversely, between 1990 and 1999, BMI was increasing while SST was decreasing. This is another demonstration of the well-known limitations of BMI as a proxy of adiposity in children, even at the population level (Demerath et al., 2006; Prentice & Jebb, 2001). In both children and adults, other studies (e.g., NHANES from 1988 to 1994 through 2009–2010) have shown that secular trends for skinfolds differ from those for BMI (Freedman et al., 2017). Skinfold thickness measurements are a particularly good indicator of adiposity in children, because at younger versus older ages a greater proportion of total body fat is subcutaneous (Kuk et al., 2009). TST, more so than SST, is known to be a sensitive measure of food insecurity (Kapoor et al., 2012) and, in our population, it is not surprising that CDC Z-scores for TST were lower than those for SST. The increasing TST Z-scores of Low SEP Ladino and Low SEP Maya children across the study period, and the narrowing inequality observed in boys, could be viewed as positive signs of better food security. The same is probably also true for the positive secular trends seen in High SEP Ladino children given evidence of the protective effects of peripheral adiposity. For example, even in modern day high-income country settings, higher TST in adults is associated with lower all-cause and cardiovascular mortality (Li et al., 2022). The evidence for SST is more mixed (Liu et al., 2020) but, at least in children, higher SST values indicate greater central adiposity (Ketel et al., 2007), which is associated with increased risk for negative effects on cardiovascular, metabolic, and renal systems (Jayedi et al., 2020). It is therefore worrying that (after 1984) all groups had higher mean SST values than the 50th centile of the CDC references. The finding that deficits in SST Z-scores (relative to High SEP Ladino children) attenuated between 1979 and 1999 for Low SEP

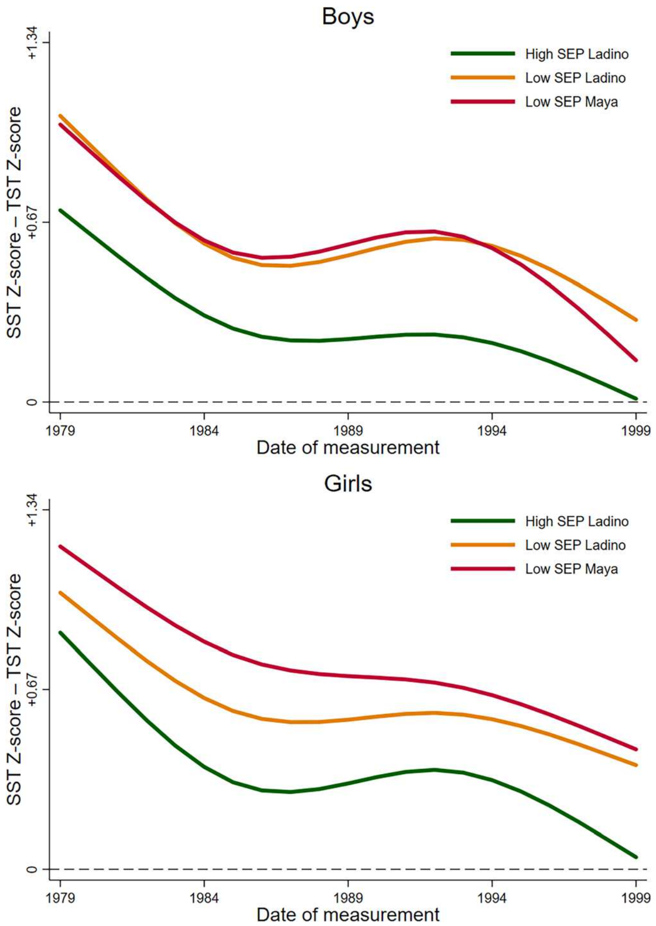

FIGURE 3 Differences between the subscapular skinfold thickness (SST) and triceps skinfold thickness (TST) internal Z-score trajectories (in Figure 2). SEP, socioeconomic position.

Ladino boys, Low SEP Maya boys, and Low SEP Maya girls is perhaps also a cause for concern.

Our results also show how all groups had relatively greater central than peripheral adiposity (i.e., SST Z-scores > TST Z-scores) across the period studied. This pattern of fat distribution was most pronounced in Low SEP Ladino and Low SEP Maya children. Studies in various pediatric populations have also demonstrated greater central fat and lower peripheral fat in groups with lower SEP (Jimenez-Mora et al., 2020; Ribeiro et al., 2020; Silva, 2013). More novel is the evidence we provide showing that all groups showed a trend toward a more balanced (i.e., less centrally dominant) pattern of fat distribution over the 20-year period studied. Indeed, by 1999, high SEP Ladino children had mean Z-scores for TST and SST that were essentially the same. We are not certain of the reasons for this trend in fat distribution, but it is predominantly driven by an increase over time in average TST Z-scores, suggesting that levels of food insecurity (although high in the Low SEP groups) did improve between 1979 and 1999 in Guatemala (Messer & Cohen, 2007; Thomas, 2006). Because we know that a higher centripetal fat ratio is related to poorer health outcomes (Baumgartner et al., 1987; Foster et al., 1987), the observed secular trend toward a more balanced body fat distribution would suggest better health outcomes (of children aged 7–17 years) in 1999 than in 1979.

The main strength of our paper is the thorough analysis of 54 638 observations, between 1979 and 1999, on 19 346 children attending three very socioeconomically different schools in and around Guatemala City. SEP was based solely on which school children attended, but we know that this grouping is strongly indicative of SEP according to family-level measures. For example, in a random sample of 672 families, Bogin and MacVean (1983) showed that a composite score (range 4–15 points) for parental occupation, parental education, and residential zone differed substantially between School 1 (mean = 12.2 points), School 2 (10.2 points), and School 4 (5.8 points). While many studies are restricted to investigations of BMI (and weight and height), which is a very limited indicator of adiposity in children (Demerath et al., 2006; Prentice & Jebb, 2001), we also had skinfold thickness measurements of subcutaneous fat. Such measurements in children are, unsurprisingly, more strongly related than BMI to concurrent and future total body fat as measured from dual-energy x-ray absorptiometry (Bedogni et al., 2003; Nooyens et al., 2007). Our results may be added to the scientific literature we cite critical of pediatric BMI as a proxy for fatness and recommending more direct biological measures of child and adolescent body composition (Bogin, 2021; Bogin & Varela Silva, 2012; Demerath et al., 2006; Freedman et al., 2005; Johnson et al., 2020; Prentice & Jebb, 2001). Skinfold thickness measurements are clearly useful for monitoring secular trends and inequalities in body fatness.

One limitation is that, while our models were robustly adjusted for chronological age, we did not have the numbers sufficient to investigate secular trends stratified by age group (e.g., 7–9, 10–13, and 14–17 years). Indeed, the Low SEP groups had fewer data at the oldest ages, presumably because economic constraints drive many of these students to join the labour market after the end of compulsory schooling at age 13 years. Because our multilevel models robustly adjust for chronological age and efficiently handle missing data, it is unlikely that our results are biased by small differences between the three schools in the age distributions (Table S2). Greater morbidity and mortality of children in the Low SEP Ladino and Low SEP Maya groups might have also caused different levels of attrition, leaving the healthier and, therefore, taller, heavier, and fatter children in the sample. If this were the case, our estimates of differences between groups might be too small. We do not, however, have any direct evidence of such bias in the results. It is also worth mentioning that the UVG study does not include any data on pubertal development. Observed differences between the groups might therefore be partly due to systematic differences between groups in the maturational status of each child at each observation. Finally, our trajectories show differences in means levels of BMI, TST, and SST, and it might be possible that inequalities and trends are different at other parts of the distributions (e.g., at the 90th quantile) (Bann et al., 2018; Bann et al., 2020). Future work might consider investigating multiple forms of malnutrition based on low, medium, and high categories of BMI, TST, SST, and height.

5 | CONCLUSION

Secular trends and inequalities in skinfold thickness measurements differ from those for BMI in Guatemalan children. Because skinfolds increased over time while BMI was stable and differences between Low and High SEP groups in skinfolds were larger than those for BMI, pediatric obesity research that only uses BMI may underestimate or fail to capture secular trends and inequalities in adiposity. We found some evidence that inequalities in height and adiposity in Guatemalan children attenuated over time and that there was a shift in all groups toward a more balanced (i.e., less centrally dominant) pattern of fat distribution. Nonetheless at the end of our study, in 1999, Low SEP Ladino and Low SEP Maya children were still much shorter than the CDC 50th percentile but had SST skinfold values that were above the CDC 50th percentile. Follow-up of these children now that they are adults would provide novel epidemiological evidence on the health consequences associated with being short but with relatively higher levels of central fat.

AUTHOR CONTRIBUTIONS

William Johnson, Liina Mansukoski, J. Andres Galvez-Sobral, Luis Furlán, and Barry Bogin designed research. William Johnson performed statistical analysis; William Johnson wrote the first draft of the paper; William Johnson had primary responsibility for final content. All authors have read, edited, and approved the final manuscript.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

Data described in the manuscript, code book, and analytic code will be made available upon request pending application and approval.

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REFERENCES

Addo, O. Y., & Himes, J. H. (2010). Reference curves for triceps and subscapular skinfold thicknesses in US children and adolescents. *The American Journal of Clinical Nutrition*, *91*(3), 635–642. https://doi.org/10.3945/ajcn.2009.28385

Bann, D., Fitzsimons, E., & Johnson, W. (2020). Determinants of the population health distribution: An illustration examining body mass index. *International Journal of Epidemiology*, *49*(3), 731–737. https://doi.org/10.1093/ije/dyz245

Bann, D., Johnson, W., Li, L., Kuh, D., & Hardy, R. (2018). Socioeconomic inequalities in childhood and adolescent body-mass index, weight, and height from 1953 to 2015: An analysis of four longitudinal, observational, British birth cohort studies. *The Lancet Public Health*, *3*(4), e194–e203. https://doi.org/10.1016/S2468-2667(18)30045-8

Baumgartner, R. N., Roche, A. F., Chumlea, W. C., Siervogel, R. M., & Glueck, C. J. (1987). Fatness and fat patterns: Associations with plasma lipids and blood pressures in adults, 18 to 57 years of age. *American Journal of Epidemiology*, *126*(4), 614–628. https://doi.org/10.1093/oxfordjournals.aje.a114701

Bedogni, G., Iughetti, L., Ferrari, M., Malavolti, M., Poli, M., Bernasconi, S., & Battistini, N. (2003). Sensitivity and specificity of body mass index and skinfold thicknesses in detecting excess adiposity in children aged 8-12 years. *Annals of Human Biology*, *30*(2), 132–139. https://doi.org/10.1080/0301446021000033409

Black, R. E., Victora, C. G., Walker, S. P., Bhutta, Z. A., Christian, P., de Onis, M., Ezzati, M., Grantham-McGregor, S., Katz, J., Martorell, R., Uauy, R., & Maternal, & Child Nutrition Study, G. (2013). Maternal and child undernutrition and overweight in low-income and middle-income countries. *Lancet*, *382*(9890), 427–451. https://doi.org/10.1016/S0140-6736(13)60937-X

Bogin, B. (2021). *Patterns of human growth* (3rd ed.). Cambridge University Press.

Bogin, B. (2022). Fear, violence, inequality, and stunting in Guatemala. *American Journal of Human Biology*, *34*(2), e23627. https://doi.org/10.1002/ajhb.23627

Bogin, B., Camacho de Paz, R., & MacVean, R. B. (2018). *The Universidad del Valle de Guatemala longitudinal study of child and adolescent development: History, description, and research prospectus*. U. d. V. d.

Bogin, B., & MacVean, R. B. (1981). Body composition and nutritional status of urban Guatemalan children of high and low socioeconomic class. *American Journal of Physical Anthropology*, *55*(4), 543–551. https://doi.org/10.1002/ajpa.1330550415

Bogin, B., & MacVean, R. B. (1983). The relationship of socioeconomic status and sex to body size, skeletal maturation, and cognitive status of Guatemala City schoolchildren. *Child Development*, *54*(1), 115–128. https://www.ncbi.nlm.nih.gov/pubmed/6831980

Bogin, B., Smith, P., Orden, A. B., Varela Silva, M. I., & Loucky, J. (2002). Rapid change in height and body proportions of Maya American children. *American Journal of Human Biology*, *14*(6), 753–761. https://doi.org/10.1002/ajhb.10092

Bogin, B., & Sullivan, T. (1986). Socioeconomic status, sex, age, and ethnicity as determinants of body fat distribution for Guatemalan children. *American Journal of Physical Anthropology*, *69*(4), 527–535. https://doi.org/10.1002/ajpa.1330690413

Bogin, B., & Varela Silva, M. I. (2012). The body mass index: The good, the bad, and the horrid. *Bulletin de la Société Suisse d'Anthropologie*, *18*(2), 5–11.

Bogin, B. A., & MacVean, R. B. (1978). Growth in height and weight of urban Guatemalan primary school children of low and high socioeconomic class. *Human Biology*, *50*(4), 477–487. https://www.ncbi.nlm.nih.gov/pubmed/744589

Davillas, A., & Benzeval, M. (2016). Alternative measures to BMI: Exploring income-related inequalities in adiposity in Great Britain. *Social Science & Medicine*, *166*, 223–232. https://doi.org/10.1016/j.socscimed.2016.08.032

Demerath, E. W., Schubert, C. M., Maynard, L. M., Sun, S. S., Chumlea, W. C., Pickoff, A., Czerwinski, S. A., Towne, B., & Siervogel, R. M. (2006). Do changes in body mass index percentile reflect changes in body composition in children? Data from the Fels longitudinal study. *Pediatrics*, *117*(3), e487–e495. https://doi.org/10.1542/peds.2005-0572

Foster, C. J., Weinsier, R. L., Birch, R., Norris, D. J., Bernstein, R. S., Wang, J., Pierson, R. N., & Van Itallie, T. B. (1987). Obesity and serum lipids: An evaluation of the relative contribution of body fat and fat distribution to lipid levels. *International Journal of Obesity*, *11*(2), 151–161. https://www.ncbi.nlm.nih.gov/pubmed/3610468

Freedman, D. S., Wang, J., Maynard, L. M., Thornton, J. C., Mei, Z., Pierson, R. N., Dietz, W. H., & Horlick, M. (2005). Relation of BMI to fat and fat-free mass among children and adolescents. *International Journal of Obesity*, *29*(1), 1–8. https://doi.org/10.1038/sj.ijo.0802735

Freedman, D. S., Zemel, B. S., & Ogden, C. L. (2017). Secular trends for skinfolds differ from those for BMI and waist circumference among adults examined in NHANES from 1988-1994 through 2009-2010. *The American Journal of Clinical Nutrition*, *105*(1), 169–176. https://doi.org/10.3945/ajcn.116.135574

Gatica-Dominguez, G., Victora, C., & Barros, A. J. D. (2019). Ethnic inequalities and trends in stunting prevalence among Guatemalan children: An analysis using national health surveys 1995-2014. *International Journal for Equity in Health*, *18*(1), 110. https://doi.org/10.1186/s12939-019-1016-0

GBD Risk Factors Collaborators. (2020). Global burden of 87 risk factors in 204 countries and territories, 1990-2019: A systematic analysis for the global burden of disease study 2019. *Lancet*, *396*(10258), 1223–1249. https://doi.org/10.1016/S0140-6736(20)30752-2

Global Nutrition Report. (2021). *The state of global nutrition*. Development Initiatives.

Global Nutrition Report. (2022). *Stronger commitments for greater action*. Development Initiatives.

Harrell, F. J. (2001). *Regression modeling strategies*. Springer Publishing Company.

Jayedi, A., Soltani, S., Zargar, M. S., Khan, T. A., & Shab-Bidar, S. (2020). Central fatness and risk of all cause mortality: Systematic review and dose-response meta-analysis of 72 prospective cohort studies. *BMJ*, *370*, m3324. https://doi.org/10.1136/bmj.m3324

Jimenez-Mora, M. A., Nieves-Barreto, L. D., Montano-Rodriguez, A., Betancourt-Villamizar, E. C., & Mendivil, C. O. (2020). Association of Overweight, obesity and abdominal obesity with socioeconomic status and educational level in Colombia. *Diabetes, Metabolic Syndrome and Obesity*, *13*, 1887–1898. https://doi.org/10.2147/DMSO.S244761

Johnson, W., Norris, T., Bann, D., Cameron, N., Wells, J. K., Cole, T. J., & Hardy, R. (2020). Differences in the relationship of weight to height, and thus the meaning of BMI, according to age, sex, and birth year cohort. *Annals of Human Biology*, *47*(2), 199–207. https://doi.org/10.1080/03014460.2020.1737731

Kapoor, S., Verma, D., Bhasin, P., Dhall, M., & Bhardwaj, S. (2012). Skinfolds as prognosticators of nutritional status among adult undernourished males of India. *International Journal of Sociology and Anthropology*, *4*(9), 257–265.

Ketel, I. J., Volman, M. N., Seidell, J. C., Stehouwer, C. D., Twisk, J. W., & Lambalk, C. B. (2007). Superiority of skinfold measurements and waist over waist-to-hip ratio for determination of body fat distribution in a population-based cohort of Caucasian Dutch adults. *European Journal of Endocrinology*, *156*(6), 655–661. https://doi.org/10.1530/EJE-06-0730

Komlos, J., Breitfelder, A., & Sunder, M. (2009). The transition to post-industrial BMI values among US children. *American Journal of Human Biology*, *21*(2), 151–160. https://doi.org/10.1002/ajhb.20806

Kuczmarski, R. J., Ogden, C. L., Grummer-Strawn, L. M., Flegal, K. M., Guo, S. S., Wei, R., Mei, Z., Curtin, L. R., Roche, A. F., & Johnson, C. L. (2000). CDC growth charts: United States. *Advance Data*, *Data(314)*, 1–27. https://www.ncbi.nlm.nih.gov/pubmed/11183293

Kuk, J. L., Saunders, T. J., Davidson, L. E., & Ross, R. (2009). Age-related changes in total and regional fat distribution. *Ageing Research Reviews*, *8*(4), 339–348. https://doi.org/10.1016/j.arr.2009.06.001

Leckie, G., & Charlton, C. (2012). Runmlwin: A program to run the MLwiN multilevel modeling software from within Stata. *Journal of statistical software*, *52*(11), 1–40.

Li, W., Yin, H., Chen, Y., Liu, Q., Wang, Y., Qiu, D., Ma, H., & Geng, Q. (2022). Associations between adult triceps skinfold thickness and all-cause, cardiovascular and cerebrovascular mortality in NHANES 1999-2010: A retrospective National Study. *Frontiers in Cardiovascular Medicine*, *9*, 858994. https://doi.org/10.3389/fcvm.2022.858994

Liu, X. C., Liu, L., Yu, Y. L., Huang, J. Y., Chen, C. L., Lo, K., Huang, Y. Q., & Feng, Y. Q. (2020). The Association of Subscapular Skinfold with all-cause, cardiovascular and cerebrovascular mortality. *Risk Management and Healthcare Policy*, *13*, 955–963. https://doi.org/10.2147/RMHP.S262300

Mansukoski, L., Johnson, W., Brooke-Wavell, K., Galvez-Sobral, J. A., Furlan, L., Cole, T. J., & Bogin, B. (2020). Four decades of socio-economic inequality and secular change in the physical growth of Guatemalans. *Public Health Nutrition*, *23*(8), 1381–1391. https://doi.org/10.1017/S1368980019003239

Marini, A., & Gragnolati, M. (2003). Malnutrition and poverty in Guatemala. *The World Bank*. https://documents1.worldbank.org/curated/pt/432431468774666300/pdf/multi0page.pdf

Messer, M., & Cohen, M. J. (2007). Conflict, food insecurity and globalization. *Food, Culture & Society*, *10*(2), 297–315.

NCD Risk Factor Collaboration. (2017). Worldwide trends in body-mass index, underweight, overweight, and obesity from 1975 to 2016: A pooled analysis of 2416 population-based measurement studies in 128.9 million children, adolescents, and adults. *Lancet*, *390*(10113), 2627–2642. https://doi.org/10.1016/S0140-6736(17)32129-3

NCD Risk Factor Collaboration. (2020). Height and body-mass index trajectories of school-aged children and adolescents from 1985 to 2019 in 200 countries and territories: A pooled analysis of 2181 population-based studies with 65 million participants. *Lancet*, *396*(10261), 1511–1524. https://doi.org/10.1016/S0140-6736(20)31859-6

Nooyens, A. C., Koppes, L. L., Visscher, T. L., Twisk, J. W., Kemper, H. C., Schuit, A. J., van Mechelen, W., & Seidell, J. C. (2007). Adolescent skinfold thickness is a better predictor of high body fatness in adults than is body mass index: The Amsterdam growth and health longitudinal study. *The American Journal of Clinical Nutrition*, *85*(6), 1533–1539. https://doi.org/10.1093/ajcn/85.6.1533

Popkin, B. M., Corvalan, C., & Grummer-Strawn, L. M. (2020). Dynamics of the double burden of malnutrition and the changing nutrition reality. *Lancet*, *395*(10217), 65–74. https://doi.org/10.1016/S0140-6736(19)32497-3

Prentice, A. M., & Jebb, S. A. (2001). Beyond body mass index. *Obesity Reviews*, *2*(3), 141–147. https://doi.org/10.1046/j.1467-789x.2001.00031.x

Ribeiro, A. I., Fraga, S., Correia-Costa, L., McCrory, C., & Barros, H. (2020). Socioeconomic disadvantage and health in early childhood: A population-based birth cohort study from Portugal. *Pediatric Research*, *88*(3), 503–511. https://doi.org/10.1038/s41390-020-0786-9

Seferidi, P., Hone, T., Duran, A. C., Bernabe-Ortiz, A., & Millett, C. (2022). Global inequalities in the double burden of malnutrition and associations with globalisation: A multilevel analysis of demographic and health surveys from 55 low-income and middle-income countries, 1992-2018. *The Lancet Global Health*, *10*(4), e482–e490. https://doi.org/10.1016/S2214-109X(21)00594-5

Silva, D. A. (2013). Socioeconomic inequalities in abdominal obesity in Brazilian female adolescents: A national-based study. *European Journal of Pediatrics*, *172*(12), 1665–1670. https://doi.org/10.1007/s00431-013-2106-4

Stein, A. D., Wang, M., Digirolamo, A., Hoddinott, J., Martorell, R., Ramirez-Zea, M., & Yount, K. (2009). Height for age increased while body mass index for age remained stable between 1968 and 2007 among Guatemalan children. *The Journal of Nutrition*, *139*(2), 365–369. https://doi.org/10.3945/jn.108.098343

Thomas, H. (2006). Trade reforms and food security: Country case studies and synthesis. https://www.fao.org/3/a0581e/a0581e.pdf

Troiano, R. P., Flegal, K. M., Kuczmarski, R. J., Campbell, S. M., & Johnson, C. L. (1995). Overweight prevalence and trends for children and adolescents. The National Health and nutrition examination surveys, 1963 to 1991. *Archives of Pediatrics & Adolescent Medicine*, *149*(10), 1085–1091. https://doi.org/10.1001/archpedi.1995.02170230039005

SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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