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ORIGINAL ARTICLE

Obesity, underweight and BMI distribution characteristics of children by gross national income and income inequality: results from an international survey

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Summary

BACKGROUND

Economic wealth and income inequality may impact on childhood BMI distribution by affecting overconsumption of food and sedentary forms of transportation and entertainment across the whole or some of the population.

OBJECTIVES

To determine whether BMI distribution of children differs by gross national income (GNI) per capita and Gini index derived from World Bank data.

METHODS

Secondary analysis of largely self-reported height and weight data from a multi-country, cross-sectional study (ISAAC), of 77,963 children aged 6–7 (from 19 countries) and 205,388 adolescents aged 13–14 (from 36 countries), were used to examine underweight vs obesity prevalence and BMI distribution skewness, median and dispersion.

RESULTS

Children and adolescents from ‘lower’ GNI countries had higher prevalence of underweight than those from ‘higher’ GNI countries (6% vs 3%, p = 0.03; 2% vs 1%, p = 0.05 respectively), but the prevalence of obesity was not different (2% vs 5%, p = 0.29; 2% vs 2%, p = 0.66). BMI distribution of participants from ‘higher’ GNI countries had higher median, without significant difference in skewness or dispersion compared to ‘lower’ GNI countries (higher medians +1.1 kg/m^2 for 6–7 year olds, and + 0.7 kg/m^2, +1.2 kg/m^2 for 13–14 year old girls and boys respectively). Gini index was not associated with underweight or obesity prevalence in either children or adolescents, nor with any BMI distribution characteristics with one exception. Adolescent girls from higher income inequality countries had a greater median BMI (+0.7 kg/m^2) and a less skewed BMI distribution.

CONCLUSIONS

It appears that the obesogenic impact of economic prosperity affects all children similarly. Income inequality may have a gender specific effect affecting BMI distribution in adolescent girls.

Keywords: Gross national income, ISAAC study, obesity, underweight.

Introduction

While childhood obesity is recognized as a global health problem (1), childhood underweight also remains a major public health concern (2). Both are linked with increased morbidity and mortality (3,4). However, these two categorical outcomes are derived from continuous measures of BMI. Differences in the entire BMI distribution of populations from different countries may have biological and environmental explanations, which are important to examine in the context of the economic wealth of the nation and income inequality. A common way of achieving wealthier nations is through increasing sales of products including food and energy saving devices such as cars and electronic entertainment such as television and video games. Increasing sales, is associated with overconsumption of food and increased sedentary behaviour, which could promote increases in BMI. of the population. Income inequality of a nation also could influence this relationship.

Various obesogenic risk factors have been identified as being associated with a small increase in mean BMI among children (5–8). These risk factors may have variable effects on the proportion classified as underweight, overweight or obese. If all individuals in a single population were both equally exposed and susceptible to obesogenic risk factors, then the mean BMI would be higher, as the entire population BMI distribution curve would move upwards, leading to less underweight and more obesity, while dispersion and skewness would remain unchanged. However, if only some individuals within a population were exposed or susceptible to these obesogenic risk factors (eg: a gene–environment interaction, or large socioeconomic gradients), then the BMI distribution would be skewed on the upper part, with little shift of the remaining distribution curve, including those in the underweight category, thereby producing greater dispersion. Increasing dispersion of the BMI distribution in the adult population of the US has recently been described (9), however, whether the BMI distribution of children and adolescents may be even more susceptible to national economic factors is not well characterized.

At the macro-environmental level, obesity is believed to be largely due to the increased availability of calorie-dense foods and decreased necessity for physical activity, which are both likely more prevalent in higher income countries (10,11). In contrast, childhood underweight is likely more prevalent in lower income countries predominantly due to nutritional scarcity. High economic development and income inequality of a nation has been associated with increases in mean BMI and proportions of obesity in adults (11–15) and children (16). National income and income inequality may also be associated with the dispersion of childhood BMI distributions. National income inequality may influence individual inequalities in total caloric intake and physical activity patterns through factors such as access to education, food availability, transportation, and psychosocial stress (17), potentially resulting in greater BMI dispersion reflected by the standard deviation (SD) of the BMI. Both the prevalence of environmental risk factors for either underweight or obesity and the populations' biological response, may differ among countries according to their gross national income per capita (GNI) and income inequality, leading to distinct BMI distributions encompassing underweight and obese.

Potential associations of the macro-economic environment with the dispersion in childhood BMI distribution may be an important consideration for policy development aimed at reducing inequalities in health and for determining whether interventions need to be aimed at those in the upper and/or lower tails of the BMI distribution or to the population as a whole (18). Greater dispersion in BMI may result in greater consequences of obesity such as social stigma, discrimination and depression in environments where there is greater BMI inequality (19).

This study investigated whether among female and male children and adolescents from different countries (a) the prevalence of underweight and obesity (b) the skewness, median, and dispersion of the BMI distribution curves, differed by gross national index (GNI) or the Gini index (to estimate national wealth and income inequality), using data from 6 to 7 year old and 13–14 year old boys and girls collected between 2000 and 2003 in the International Study of Asthma and Allergies in Childhood (ISAAC) (20). This study also investigated how these BMI distribution curve characteristics from the ISAAC study participants differed from those derived from nationally representative datasets from Brazil, United Kingdom (UK), Hong Kong, Netherlands, Singapore and the United States of America (USA) between 1963 and 1993 (21). The study hypothesis was that children and adolescent BMI distributions (including proportions underweight and obese), would differ by national income and income inequality.

Methods

ISAAC is a multi-centre, multi-country, multi-phase cross sectional study originally designed to measure time trends in the prevalence and severity of asthma, rhinoconjunctivitis and eczema and their risk factors (20). ISAAC Phase Three was undertaken between 2000 and 2003 and involved 6–7 year old children and 13–14 year old adolescents from a random sample of schools, representative of the centres they were selected from, as described in the published protocol (22). Height and weight were reported by the parents of the 6–7 year old children and were self-reported by adolescents. In some centres, each participant's height and weight were measured, although there were no standardized instructions for doing this. BMI was calculated (weight (kg)/height (m)^2). Each individual was classified as underweight, normal weight, overweight or obese using the absolute age and sex specific thresholds that are designed to pass through BMI thresholds at 18 years of below 16 kg/m^2 for thinness (23), above 25 kg/m^2 for overweight and above 30 kg/m^2 for obese, as recommended by the International Obesity Task Force (IOTF) (21). These were derived from six nationally representative datasets of BMI with ages ranging from 6 to 18 years in: Brazil (1989, n = 31,806), UK (1978–93, n = 32,222), Hong Kong (1993, n = 23,965), Netherlands (1980, n = 41,766), Singapore (1993, n = 33,972) and USA (1963–80, n = 28,996) (21).

BMI distribution shapes for boys and girls aged either 6–7 years or 13–14 years at each centre were described using statistics describing curves: L (lambda) for skewness, M (mu) for median, S (sigma) for dispersion or coefficient of variation, calculated from the equation described previously (21), based on the Box-Cox family of transformations using non-linear regression (SAS 9.3), and were also compared to this international reference population (21). Skewness indicates whether the data distribution is symmetric or has a more pronounced tail in one direction than the other. An L value of 0 means that the BMI distribution is lognormal, while an L value of 1 indicates a normal distribution. Going from 0 to 1 indicates reducing skew. Median refers to the midpoint of the distribution.

To be included in the analysis, centres had to assess at least 1,000 subjects and have a response rate of $>$70% to the height, and weight questions. Individuals without complete data on sex, age, height, weight, were also excluded. To preserve as much remaining data as possible, but also to eliminate likely erroneous data, those in the top and bottom 0.5% of weights and heights in each centre were excluded. On the basis of empirical biological implausibility criteria, children in each centre with heights less than 1.0 metre, or BMIs outside of the range between 9 kg/m^2 and 40 kg/m^2, and adolescents in each centre who had heights less than 1.25 m or BMIs outside the range between 10 kg/m^2 and 45 kg/m^2, were excluded.

Countries were designated as high or low income according to World Bank data on GNI. Those in the World Bank categories of "high"-, plus "high-middle"-income countries were designated as "high income", and those in the World Bank categories of "low" plus "low-middle" were designated as "low income". Data on country-level income inequality came from Gini index listed on www.quandl.com/collections/demography/gini-index-worldbank-by-country, ascertained from surveys between 1998 and 2012, and accessed in November 2015. Gini index ranges from 0 to 100%, with lower values ($<$40), indicating greater income equality, and higher values ($>$ = 40), representing greater income inequality. To assess whether the Centre BMI distribution curves differed by country GNI or GINI category the overall effect was assessed in a general linear mixed model (GLMM) by comparing the difference in parameter estimates for GNI for each of the three measures (3 df) simultaneously and then again for each of the 3 statistics separately. This was repeated using GINI instead of GNI in the model. The correlations between the M, L and S statistics were incorporated using this GLMM.

Results

There were 214,706 children from 73 centres in 32 countries and 362,019 adolescents from 122 centres in 53 countries who provided data. After excluding centres with less than 70% complete BMI data and applying the other exclusion criteria there were 77 963 children from 31 centres in 18 countries (Supplementary Figure **1**a) and 205,388 adolescents from 75 centres in 36 countries (Supplementary Figure **1**b). The proportions of children and adolescents who were classified as underweight, normal, overweight or obese by gender and participating country are shown in Table 1. Overall, the mean BMI in adolescents was positively associated with mean BMI in children (r = 0.83, supplementary Figure 2).

Prevalence of underweight or obesity among ISAAC children and adolescents according to GNI or Gini index

Children from low GNI countries had significantly higher proportions of underweight compared to children from high GNI countries (6% vs 3%, p = 0.03), but not significantly different proportions of obesity (2% vs 5%, p = 0.29) due to greater variances in the latter. There was a tendency for low GNI countries to have higher proportions of underweight adolescents than high GNI countries (2% vs 1%, p = 0.05), but not significantly different proportions of obesity (2% vs 2%, p = 0.66). There was no correlation between Gini index and prevalence of underweight in male and female children (r = 0.17, p = 0.52 and r = 0.00, p = 0.99 respectively), or in male and female adolescents (r = 0.19, p = 0.28 and r = −0.02, p = 0.91 respectively). There was also no correlation between Gini index and the prevalence of obesity

Table 1 Proportions of (a) 6–7 year old (b) 13–14 year old girls and boys classified as underweight, normal, overweight or obese in each participating country

			Sex							
			6–7 year Girls				6–7 year Boys			
			Underweight	Normal	Over weight	Obese	Under weight	Normal	Over weight	Obese
Country	GNI	GINI	3.4	82.7	11.0	2.9	3.0	84.5	9.2	3.3
Belgium	high	low								
Estonia	high	low	2.1	83.5	12.4	2.0	1.0	83.1	13.5	2.4
Hungary	high	low	3.2	76.6	14.9	5.2	1.9	80.0	13.8	4.3
India	low	low	16.7	83.0	0.3	0.0	15.8	83.7	0.5	0.0
Indonesia	low	low	23.6	67.1	6.6	2.8	25.6	66.4	6.0	1.9
Japan	high	low	1.1	89.8	7.2	1.9	0.5	87.2	9.4	2.9
Lithuania	high	low	3.3	84.9	10.3	1.5	1.9	85.6	11.4	1.2
Mexico	high	high	2.2	71.7	17.6	8.5	2.5	71.1	16.4	10.0
Nigeria	low	high	6.5	84.2	8.1	1.3	5.3	85.7	7.3	1.7
Poland	high	low	3.9	79.3	13.6	3.1	2.8	78.9	14.5	3.8
Portugal	high	low	3.1	72.9	14.5	9.5	3.0	73.0	15.2	8.7
South Korea	high	low	1.6	79.7	15.0	3.7	0.7	75.6	17.7	5.9
Spain	high	low	1.2	68.1	22.1	8.5	1.3	70.5	19.2	9.0
Sultanate of Oman (Oman)	high		11.1	84.4	3.1	1.4	10.7	86.7	2.1	0.4
Syrian Arab Republic	low	low	3.9	81.0	12.0	3.1	3.7	80.7	12.6	3.0
Taiwan	high	low	1.4	78.3	14.5	5.9	1.0	73.3	16.8	8.9
Thailand	low	low	3.1	76.4	13.0	7.5	2.8	70.2	14.5	12.5
Uruguay	high	high	4.2	67.5	18.9	9.3	4.7	66.7	17.5	11.1

			Sex							
			13–14 years Girls				13–14 year Boys			
			Under weight	Normal	Overweight	Obese	Under weight	Normal	Over weight	Obese
Country	GNI	GINI	1.5	89.3	8.3	0.9	1.1	84.9	12.7	1.4
Argentina	high	high								
Belgium	high	low	1.4	92.4	5.8	0.4	0.6	91.6	7.5	0.3
Bolivia	high	high	0.6	76.1	20.0	3.4	0.8	78.7	16.5	4.0
Brazil	low	high	1.4	85.8	11.3	1.6	1.1	84.8	11.7	2.4
Canada	high	low	0.9	87.8	9.1	2.3	0.6	76.8	17.8	4.8
Chile	high	high	0.3	79.1	18.5	2.1	0.5	76.8	20.0	2.7
China	low	low	2.0	89.5	7.1	1.4	1.2	83.2	12.0	3.6
Colombia	low	high	5.3	86.8	7.1	0.8	2.6	82.3	13.8	1.3
Cote d'Ivoire	low	high	0.0	72.8	26.7	0.5	0.1	70.7	28.0	1.1
Ecuador	low	high	0.3	77.1	19.3	3.3	0.1	72.3	22.1	5.5
Estonia	high	low	0.5	93.6	5.2	0.7	0.4	89.5	9.2	0.9
Fiji	low	high	3.0	74.1	19.4	3.6	1.8	80.9	14.3	2.9
Finland	high	low	0.2	88.5	9.3	2.0	0.1	82.0	16.0	1.9
Hungary	high	low	0.9	88.0	9.7	1.3	0.5	84.5	12.9	2.1
India	low	low	8.4	76.0	12.5	3.1	12.6	74.3	11.1	2.0
Indonesia	low	low	6.1	90.0	3.4	0.5	6.5	87.1	5.5	0.8
Iran	low	low	4.5	79.4	12.8	3.2	4.4	80.2	13.5	1.9
Japan	high	low	1.2	94.9	3.5	0.4	0.2	92.3	6.5	1.1
Lithuania	high	low	1.6	93.9	4.2	0.3	0.6	92.1	7.0	0.3
Mexico	high	high	0.7	77.4	19.2	2.7	0.8	68.8	26.1	4.3
Morocco	low	high	1.8	86.1	10.7	1.3	2.4	91.2	5.6	0.8
New Zealand	high	low	0.9	78.8	16.8	3.5	0.2	70.7	22.9	6.2
Nigeria	low	high	2.2	92.6	5.0	0.2	3.6	93.1	3.2	0.1

Continues

Table 1. *Continued*

			Sex							
			6–7 year Girls				6–7 year Boys			
			Underweight	Normal	Over weight	Obese	Under weight	Normal	Over weight	Obese
Peru	**high**	**high**	0.7	87.7	11.3	0.3	0.6	81.6	16.8	1.0
Poland	**high**	**low**	1.0	95.2	3.6	0.2	0.9	88.1	10.2	0.9
Portugal	**high**	**low**	0.6	84.4	13.3	1.7	0.6	77.5	19.0	2.8
Republic of Macedonia	**low**	**high**	0.4	90.4	8.7	0.5	0.4	77.8	19.6	2.2
Singapore	**high**	**high**	2.0	87.1	8.8	2.1	2.2	80.1	14.7	2.9
South Africa	**high**	**high**	0.9	80.1	16.0	3.0	0.7	87.3	10.1	1.9
South Korea	**high**	**low**	0.6	92.6	6.5	0.4	0.3	81.6	16.0	2.2
Spain	**high**	**low**	0.4	89.3	9.5	0.8	0.3	79.1	18.8	1.8
Sultanate of Oman (Oman)	**high**		3.3	77.0	15.0	4.6	3.4	83.2	9.6	3.7
Syrian Arab Republic	**low**	**low**	1.1	84.9	12.5	1.4	0.4	84.7	12.8	2.2
Taiwan	**high**	**low**	0.6	85.8	11.1	2.5	0.4	74.8	19.1	5.7
USA	**high**	**high**	0.2	84.1	12.2	3.5	0.0	74.6	20.1	5.3
Uruguay	**high**	**high**	0.5	86.0	12.6	1.0	0.3	81.0	16.4	2.3

in male and female children (r = 0.22, p = 0.39 and r = 0.19, p = 0.47 respectively), or in male and female adolescents (r = 0.15, p = 0.39 and r = −0.02, p = 0.91 respectively).

BMI distribution curve characteristics of ISAAC children and adolescents according to GNI or Gini index

BMI distribution curves were significantly different among high vs low GNI countries for 6–7 year old males (p = 0.001) and females (p = 0.001). This was mostly due to the difference in medians of +1.1 kg/m^2 for both genders from high GNI countries. The differences in both skewness (−0.16 and − 0.21 in males and females respectively) and dispersion (−0.006 and − 0.001 in males and females respectively) were small and not statistically significant between high vs low GNI countries.

BMI distribution curves for adolescent males ($p < 0.0001$) and females (p = 0.0001) were also significantly different among high vs low GNI countries. Again this was mostly from the M statistic, which was 1.2 and 0.7 kg/m^2 higher for males and females respectively from high GNI countries. The differences in skewness (−0.08 and − 0.21) and dispersion (−0.002 and − 0.006) in adolescent males and females respectively, were also small and not statistically significant.

Populations grouped by high or low Gini index countries differed significantly in their BMI distribution curves for adolescent females (p = 0.003), which was mostly related to both the skewness (p = 0.007), and median (p = 0.002), but not the dispersion (p = 0.31). There was less skewness and higher BMI medians (−0.53 vs −0.83 and 19.7 vs 19.0 respectively) among adolescent females from high Gini index countries (with higher income inequality). However, there was no difference between high and low Gini index groups seen in the BMI distribution curve characteristics for adolescent males (p = 0.44) or 6–7 year old males (p = 0.79) or females (p = 0.47).

BMI distribution curve characteristics of ISAAC children and adolescents compared to an age and gender matched international reference population(21)

Figure 1 shows the various BMI distribution curve characteristics for children and adolescents of both genders across centres from different countries, relative to the historical reference population. The L values in both age groups and genders were greater than the reference population, indicating less skewness. In 6–7 year females and males the medians were similar to the reference population but the dispersion (S values) was greater than the reference population (Figure 1A and 1B). In 13–14 year old females, the median values and dispersion (S values) were both similar to the reference population (Figure 1C). In 13–14 year old males, the M values and dispersion (S values) were greater than the reference population (Figure 1D). BMI distribution curve characteristics are shown in Table 2 and actual BMI distribution histograms are shown for each country and centre in Supplementary Figure 3.

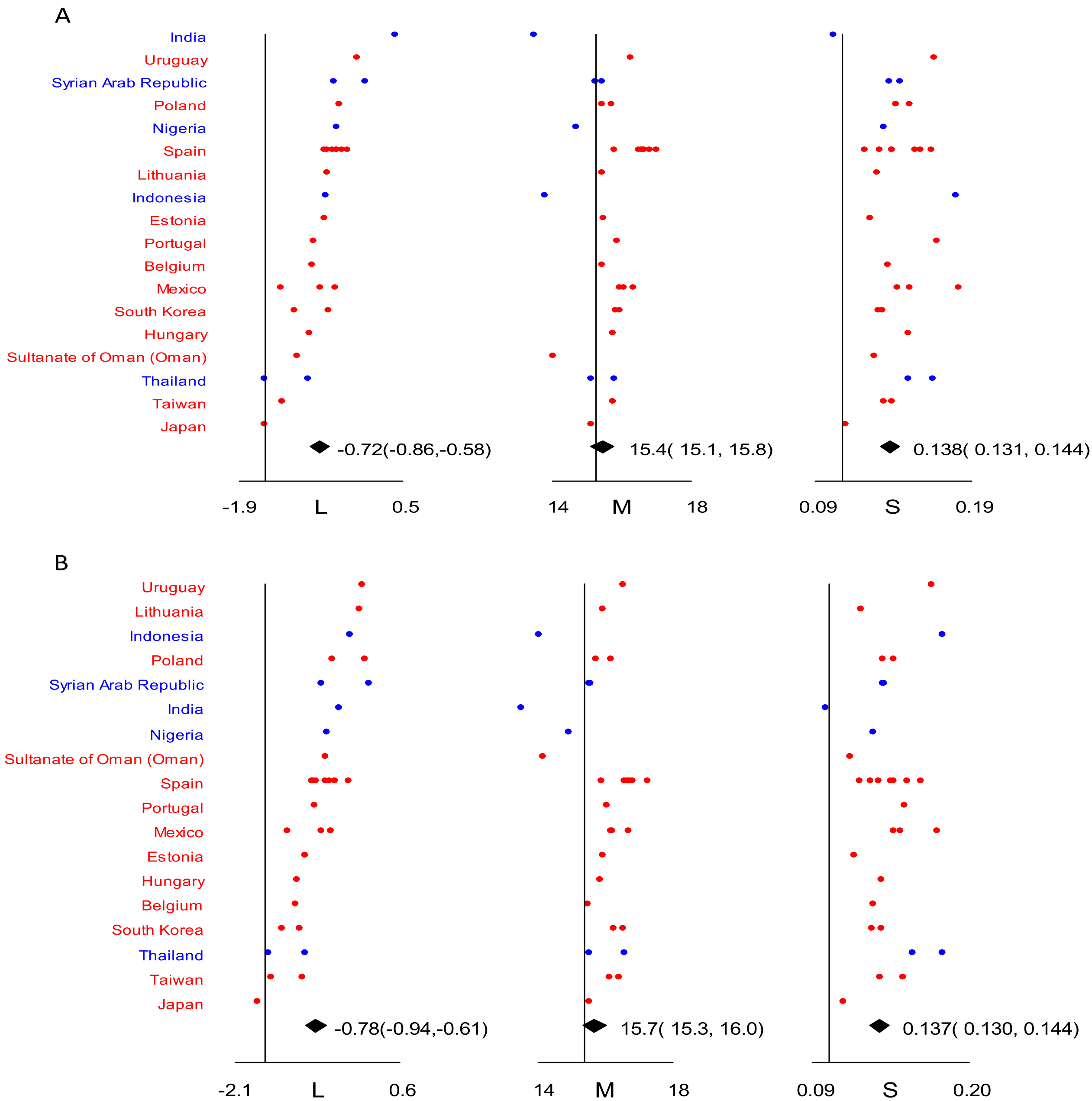

Figure 1 Plots showing from left to right: L (skewness), M (median) and S (coefficient of variation) values for each of the BMI distribution histograms from populations sampled of (a) 6–7 year old girls (b) 6–7 year old boys (c) 13–14 year old adolescent girls (d) 13–14 year old adolescent boys. Blue indicates countries of low GNI and red indicates countries of high GNI. Each dot represents data from one participating centre. Countries are ordered on their mean skewness. The solid vertical line is the IOTF reference for 7 or 14 year old boys or girls as appropriate. The diamond indicates the weighted mean of all values above the 95% confidence interval of that weighted mean. The weight used is the inverse of the variance of the estimate. An L value of 0 means that the BMI distribution is lognormal, while an L value of 1 indicates a normal distribution. Going from 0 to 1 indicates that there is reducing skew. The centres on the left of the reference have more skew than the centres on the right. Having less skew does not mean having fewer in the upper or lower tails, the medians and the spread matter too.

Discussion

Children and adolescents of both genders from low GNI countries had a significantly greater prevalence of underweight but similar prevalence of obesity compared with those from high GNI countries. This suggests a contribution of poverty in driving underweight, but no apparent threshold of national wealth as an enabler of obesity. However, this does not exclude a socioeconomic status threshold for permitting childhood obesity in lower

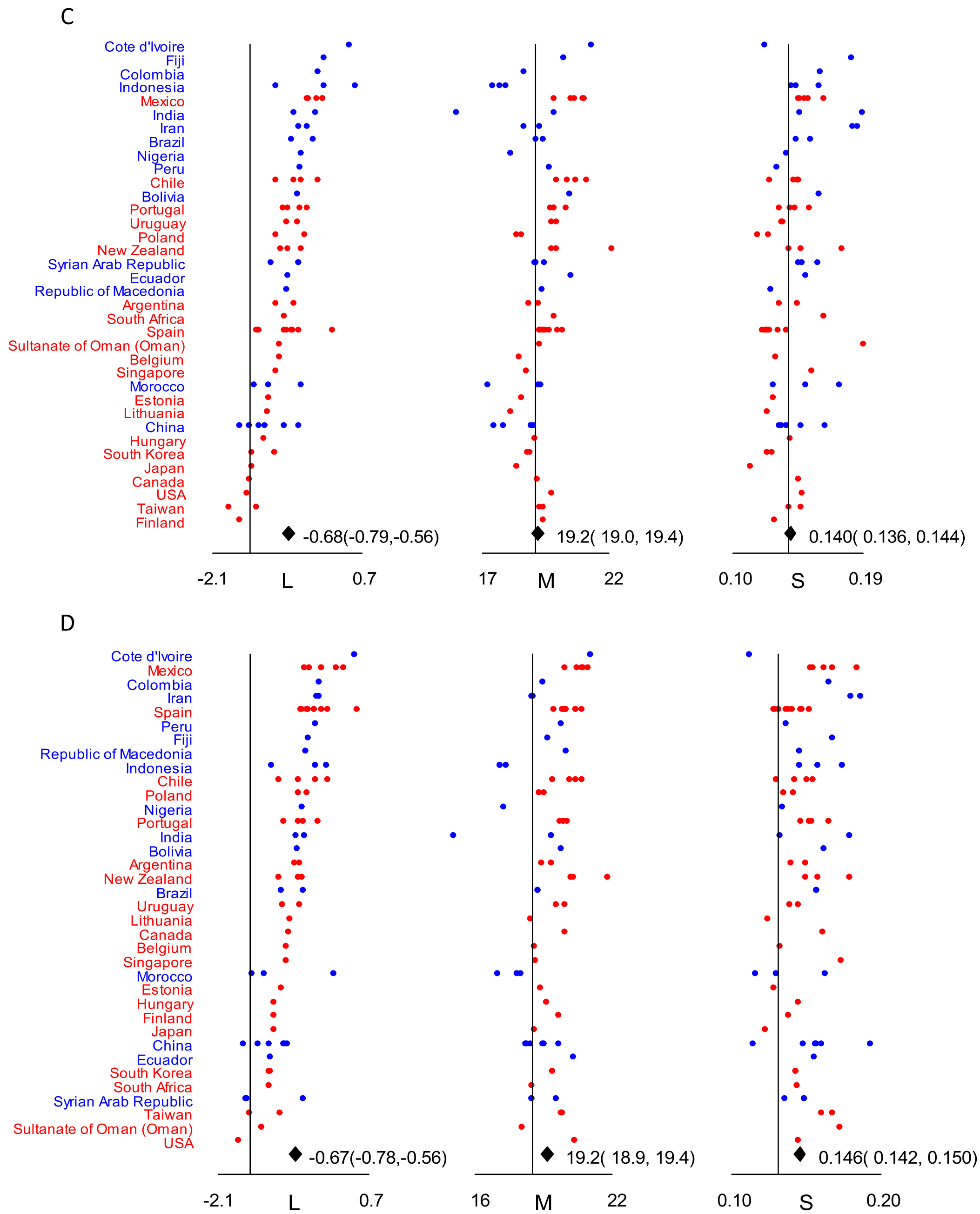

Figure 1 Continued.

income countries, as has been described in adults, resulting in an interaction between socioeconomic status and obesity by national wealth (15). The BMI distribution curves of children and adolescents from high GNI countries had higher median, compared to those from low GNI countries, but did not significantly differ in skewness or dispersion. While there was no longitudinal data from countries before and after economic prosperity, this observation is consistent with greater obesogenic risk factors operating within high GNI countries that affect all individuals similarly, rather than a vulnerable proportion.

The Gini index estimate of income inequality was not associated with any difference in the prevalence of underweight or obesity in children or adolescents of either gender. Only adolescent females from higher Gini index countries (greater income inequality) had significantly higher median BMI and less skewness without any difference in BMI dispersion. Gini index was also unrelated to the prevalence of adolescent overweight in a previous

Table 2 BMI distribution statistics in girls and boys (a) aged 6–7 years (b) aged 13–14 years by participating centre

		Girls (6–7 year old)			Boys (6–7 year old)		
		L	M	S	L	M	S
Country	**Centre**	−0.83	15.42	0.14	−1.12	15.46	0.13
Belgium	**1**						
Estonia	**1**	−0.67	15.47	0.13	−0.97	15.92	0.12
Hungary	**1**	−0.89	15.72	0.15	−1.11	15.86	0.14
India	**1**	0.39	13.45	0.10	−0.41	13.50	0.10
Indonesia	**1**	−0.63	13.78	0.18	−0.24	14.02	0.18
Japan	**1**	−1.55	15.10	0.11	−1.76	15.50	0.11
Lithuania	**1**	−0.62	15.41	0.13	−0.07	15.92	0.12
Mexico	**1**	−0.71	16.32	0.18	−0.55	16.70	0.18
	2	−0.50	16.05	0.15	−0.69	16.21	0.15
	3	−1.31	15.90	0.14	−1.27	16.17	0.15
Nigeria	**1**	−0.49	14.67	0.13	−0.60	14.91	0.13
Poland	**1**	−0.45	15.67	0.15	0.01	16.14	0.15
	2	−0.45	15.41	0.14	−0.53	15.72	0.14
Portugal	**1**	−0.82	15.83	0.17	−0.82	16.03	0.15
South Korea	**1**	−1.10	15.90	0.13	−1.34	16.54	0.14
	2	−0.60	15.79	0.13	−1.05	16.25	0.13
Spain	**1**	−0.65	16.97	0.16	−0.56	17.24	0.17
	2	−0.62	15.75	0.12	−0.84	15.87	0.12
	3	−0.48	16.56	0.14	−0.63	16.71	0.13
	4	−0.40	16.58	0.15	−0.49	16.68	0.15
	5	−0.54	16.47	0.16	−0.78	16.56	0.16
	6	−0.32	16.63	0.14	−0.26	16.81	0.15
	7	−0.48	16.77	0.13	−0.86	16.64	0.14
Sultanate of Oman (Oman)	**1**	−1.06	14.01	0.13	−0.63	14.14	0.12
Syrian Arab Republic	**1**	−0.07	15.39	0.14	0.09	15.55	0.14
	2	−0.52	15.22	0.14	−0.70	15.52	0.14
Taiwan	**1**	−1.29	15.71	0.13	−1.53	16.14	0.14
	2	−1.29	15.72	0.14	−1.02	16.39	0.15
Thailand	**1**	−0.90	15.78	0.17	−0.96	16.56	0.18
	2	−1.55	15.09	0.15	−1.57	15.52	0.16
Uruguay	**1**	−0.17	16.22	0.17	−0.02	16.54	0.17
		Girls (13–14 year old)			**Boys (13–14 year old)**		
		L	**M**	**S**	**L**	**M**	**S**
Country	**Centre**	−0.94	18.81	0.13	−0.69	18.90	0.14
Argentina	**1**						
	2	−0.59	19.19	0.15	−0.61	19.32	0.15
Belgium	**1**	−0.87	18.44	0.13	−0.85	18.57	0.13
Bolivia	**1**	−0.53	20.40	0.16	−0.64	19.74	0.16
Brazil	**1**	−0.64	19.39	0.15	−0.95	18.76	0.16
	2	−0.22	19.11	0.14	−0.53	18.77	0.16
Canada	**1**	−1.42	19.11	0.15	−0.81	19.91	0.16
Chile	**1**	−0.15	21.10	0.14	−0.32	20.67	0.14
	2	−0.46	20.32	0.15	−0.09	20.16	0.15
	3	−0.93	20.66	0.13	−0.99	20.40	0.13
	4	−0.59	19.91	0.15	−0.64	19.36	0.15
China	**1**	−0.49	18.87	0.13	−0.90	18.19	0.11
	2	−1.61	19.00	0.16	−1.18	19.68	0.19
	3	−1.24	17.80	0.13	−0.83	18.28	0.16
	4	−1.12	18.97	0.15	−1.38	18.95	0.16

Continues

Table 2. *Continued*

		Girls (6–7 year old)			Boys (6–7 year old)		
		L	M	S	L	M	S
	5	−0.77	17.43	0.14	−0.88	18.40	0.16
	6	−1.42	18.91	0.14	−1.66	19.02	0.15
Colombia	**1**	−0.13	18.61	0.16	−0.23	18.98	0.17
Cote d'Ivoire	**1**	0.45	21.27	0.12	0.42	21.07	0.11
Ecuador	**1**	−0.70	20.47	0.15	−1.15	20.30	0.16
Estonia	**1**	−1.07	18.53	0.13	−0.96	18.84	0.13
Fiji	**1**	−0.02	20.18	0.18	−0.44	19.15	0.17
Finland	**1**	−1.60	19.37	0.13	−1.08	19.67	0.14
Hungary	**1**	−1.16	19.04	0.14	−1.08	19.09	0.14
India	**1**	−0.18	19.83	0.19	−0.52	19.31	0.18
	2	−0.58	15.92	0.15	−0.66	15.04	0.13
Indonesia	**1**	0.55	17.35	0.16	−0.10	17.09	0.17
	2	−0.92	17.89	0.14	−1.13	17.08	0.15
	3	−0.03	17.64	0.14	−0.30	17.33	0.16
Iran	**1**	−0.35	18.62	0.18	−0.24	18.48	0.18
	2	−0.51	19.23	0.19	−0.29	18.52	0.19
Japan	**1**	−1.38	18.31	0.11	−1.08	18.56	0.12
Lithuania	**1**	−1.09	18.07	0.12	−0.79	18.44	0.12
Mexico	**1**	−0.05	20.49	0.16	0.09	20.72	0.18
	2	−0.16	20.94	0.15	−0.19	20.97	0.16
	3	−0.31	20.63	0.15	−0.52	20.47	0.15
	4	−0.06	19.79	0.15	0.22	19.91	0.15
	5	−0.34	20.98	0.15	−0.43	20.70	0.17
Morocco	**1**	−1.06	19.17	0.15	−1.50	17.99	0.13
	2	−0.45	19.27	0.17	0.02	17.81	0.16
	3	−1.34	17.18	0.13	−1.26	16.95	0.12
New Zealand	**1**	−0.70	19.71	0.15	−0.98	20.22	0.15
	2	−0.84	19.90	0.14	−0.628	20.30	0.16
	3	−0.45	22.08	0.18	−0.56	21.78	0.18
Nigeria	**1**	−0.46	18.09	0.14	−0.57	17.24	0.13
Peru	**1**	−0.48	19.63	0.13	−0.31	19.74	0.14
Poland	**1**	−0.38	18.51	0.12	−0.48	19.00	0.13
	2	−0.92	18.34	0.12	−0.62	18.80	0.14
Portugal	**1**	−0.34	20.27	0.15	−0.53	20.02	0.17
	2	−0.80	19.82	0.14	−0.64	19.88	0.15
	3	−0.70	19.66	0.14	−0.89	19.69	0.15
	4	−0.49	19.79	0.13	−0.27	19.89	0.15
Republic of Macedonia	**1**	−0.72	19.32	0.13	−0.50	19.98	0.15
Singapore	**1**	−0.93	18.71	0.16	−0.86	18.64	0.17
South Africa	**1**	−0.77	19.78	0.16	−1.17	18.49	0.14
South Korea	**1**	−1.38	18.75	0.13	−1.14	19.39	0.14
	2	−0.95	18.85	0.12	−1.17	19.41	0.14
Spain	**1**	−0.77	19.39	0.12	−0.20	19.96	0.13
	2	−0.62	19.27	0.12	−0.34	20.00	0.14
	3	−1.29	19.93	0.14	−0.57	20.66	0.15
	4	−0.73	19.59	0.13	−0.33	20.426	0.15
	5	0.13	20.14	0.12	0.46	20.40	0.13
	6	−1.26	19.21	0.12	−0.45	19.92	0.14
	7	−0.65	19.25	0.14	−0.46	19.45	0.15
	8	−1.25	19.38	0.12	−0.08	19.88	0.13
	9	−0.50	19.45	0.13	−0.58	19.82	0.14
Sultanate of Oman (Oman)	**1**	−0.86	19.21	0.19	−1.31	18.06	0.17
Syrian Arab Republic	**1**	−1.03	19.03	0.15	−1.60	18.46	0.15

Continues

Table 2. *Continued*

		Girls (6–7 year old)			Boys (6–7 year old)		
		L	**M**	**S**	**L**	**M**	**S**
	2	−0.51	19.41	0.15	−1.58	18.47	0.14
	3	−0.49	19.10	0.15	−0.54	19.53	0.15
Taiwan	**1**	−1.80	19.37	0.14	−1.54	19.81	0.16
	2	−1.30	19.24	0.15	−0.97	19.76	0.17
USA	**1**	−1.46	19.70	0.15	−1.75	20.33	0.15
Uruguay	**1**	−0.53	19.89	0.13	−0.61	19.92	0.15
	2	−0.72	19.73	0.14	−0.91	19.56	0.14

study, but there was an inverse social gradient reported in overweight within high-income countries (16). In contrast, studies in adults have found that increased income inequality is associated with increased prevalence of obesity in men and women (17), and average calorie intake as well as sedentary lifestyles (24). Income inequalities within societies may have a greater impact on the distribution of obesity at older ages than in this study, and there may be differences in impacts by gender resulting in an earlier BMI manifestation seen in adolescent girls.

When compared to an international reference population derived from surveys between 1963 and 1993 (21), the ISAAC populations of children and adolescents, that were assessed in 2000–2003, had distinct differences in the shape of their BMI distribution curves. While the median BMI values were similar to the reference population, ISAAC children had greater dispersion of their BMI distribution. Overall, ISAAC children and adolescents of both genders had less skewness. The cause of these differences are difficult to determine, and may be due to the effects of time period and/or range of countries sampled and/or sampling effects within countries. Serial cross-sectional surveys are required to determine how the population distribution of BMI in children and adolescents has changed over time.

Strengths of this study include the large number of countries and centres from a range of low and high-income countries, and the systematic application of inclusion and exclusion criteria in the data analysis. Nevertheless, this study has several limitations. While the centres that participated in the ISAAC study were not necessarily representative of the country as a whole, the sampling units were a minimum of 10 schools randomly selected per centre (or all schools) and were representative of the centres they were selected from, without selection by socioeconomic status or by urban or rural residence within that centre (22). However, most ISAAC centres were in urban areas and a minority of ISAAC centres were regions within a country or a whole country as previously described (22). The data collected in different countries may vary in quality with regards to reported height and weights and hence limit the internal validity of the data. However, there is no reason to suspect that measurement error would vary systematically with GNI or Gini index or alter the distribution of findings.

The data cleaning measures used may have inadvertently excluded some correctly measured heights and weights thereby limiting the actual degree of skewness at some centres, however when alternative data-cleaning criteria were applied such as removing those +/− 6 SDS for height and/or weight, this did not significantly alter the results. Measures of socioeconomic status or ethnicity, could be interacting factors with GNI, but these were not collected in the study. In contrast to high GNI countries where childhood obesity is more prevalent among those of lower socioeconomic status, childhood obesity within low GNI countries has been reported to be more prevalent among those of higher socioeconomic status (25). Constitutional underweight may be more prevalent in certain ethnic groups who are disproportionately represented in low GNI countries (26).

Finally, the indicators used for estimating wealth and wealth inequality at a country level in this study have several key limitations: GNI per capita that we used from the World Bank income classification does not take account the purchasing power of the nominal income in a country. This has a significant effect on real income, particularly in poorer countries where many products (particularly food) tend to be cheaper. The Gini index data, also obtained from the World Bank simply indicates the variation in income, which could vary between centres within the same country. The Gini index does not indicate absolute and relative levels of inequality, which is important in terms of spending power. For overall lower income countries, the same income inequality would result in dramatic differences in spending power on basic necessities. In addition, the presence or absence of government policies such as welfare programs to abate inequality may have important effects on overall inequality, which are not apparent in the Gini index. Finally, the relationships between

BMI distribution and GNI or Gini index are associations and do not necessarily imply causality.

In summary, this study shows that in comparison to low income countries, children and adolescents of both genders from high income countries have a higher median BMI without alterations in dispersion or skewness, suggesting that the obesogenic influences of national economic prosperity affects all children similarly rather than a susceptible proportion. Contrary to expectation, the BMI dispersion was not greater among countries with greater income inequality as estimated by Gini index. More accurate estimates of the change in BMI distribution in children and adolescents over time, and within different countries are needed, so that national strategies can be assessed in their global context according to local BMI distribution changes with time and policy.

Conflict of Interest disclosures

All authors declare that they have no conflicts of interest.

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Author Contributions

RM conceived the study and designed the analysis. AWS undertook the statistical analysis. EM acquired funding. RM drafted the manuscript. All authors reviewed and revised the manuscript. All authors read and reviewed the manuscript and have given approval for the manuscript to be submitted.

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Supporting Information

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

Supplementary Figure 1. Flow of participants through the study. Children are represented in panel (a) and adolescents in panel (b)
Supplementary Figure 2. Plot of mean BMI by centres which reported data for both 6–7 year old and 13–14 year olds. The upper, middle and lower lines indicate the difference in BMI that is 4 kg/m^2, 3 kg/m^2 or 2 kg/m^2 higher in adolescents aged 13–14 than in children aged 6–7 years.
Supplementary Figure 3. Histograms of BMI for (a) 6–7 year old girls (b) 6–7 year old boys (c) 13–14 year old girls (d) 13–14 year old boys, by participating centre. The solid curve is the IOTF reference BMI distribution for 7 or 14 year old boys or girls as appropriate (21)