**Original Article**

# The Epidemiological Transition and the Global Childhood Obesity Epidemic

Stephanie T. Broyles; PhD[1], Kara D. Denstel, MPh[1]; Timothy S. Church, MD, PhD[1]; Jean-Philippe Chaput, PhD[2]; Mikael Fogelholm, ScD[3]; Gang Hu, MD, PhD[1]; Rebecca Kuriyan, PhD[4]; Anura Kurpad, MD, PhD[4]; Estelle V. Lambert, PhD[5]; Carol Maher, PhD[6]; Jose Maia, PhD[7]; Victor Matsudo, MD, PhD[8]; Timothy Olds, PhD[6]; Vincent Onywera, PhD[9]; Olga L. Sarmiento, MD, PhD[10]; Martyn Standage, PhD[11]; Mark S. Tremblay, PhD[2]; Catrine Tudor-Locke, PhD[1,12] Pei Zhao, MD[13]; and Peter T. Katzmarzyk PhD[1]; for the ISCOLE Research Group

[1]Pennington Biomedical Research Center, Baton Rouge, LA
[2]Children's Hospital of Eastern Ontario Research Institute, Ottawa, Canada
[3]Department of Food and Environmental Sciences, University of Helsinki, Helsinki, Finland
[4]St. Johns Research Institute, Bangalore, India
[5]Division of Exercise Science and Sports Medicine, Department of Human Biology, Faculty of Health Sciences, University of Cape Town, Cape Town, South Africa
[6]Alliance for Research in Exercise Nutrition and Activity (ARENA), School of Health Sciences, University of South Australia, Adelaide, Australia
[7]CIFI[2]D, Faculdade de Desporto, University of Porto, Porto, Portugal
[8]Centro de Estudos do Laboratório de Aptidão Física de São Caetano do Sul, Sao Paulo, Brazil
[9]Department of Recreation Management and Exercise Science, Kenyatta University, Nairobi, Kenya
[10]School of Medicine, Universidad de los Andes, Bogota, Colombia
[11]Department for Health, University of Bath, Bath, United Kingdom
[12]Department of Kinesiology, University of Massachusetts Amherst, Amherst, United States
[13]Tianjin Women's and Children's Health Center, Tianjin, China

**Running Head:** Epidemiological Transition and Childhood Obesity

**Address for Correspondence and Reprints:** Peter T. Katzmarzyk, PhD, Pennington Biomedical Research Center, 6400 Perkins Road, Baton Rouge, LA 70808-4124; Phone (225) 763-2536; Fax: (225) 763-2927; Email: Peter.Katzmarzyk@pbrc.edu

**Abstract**

**Background/Objectives:** Childhood obesity is now recognized as a global public health issue. Social patterning of obesity, consistent with the theory of epidemiologic transition, has not been well described in children, and the limited research has focused on developed settings. The aim of this study was to describe the relationship between childhood obesity and household income using objective measures of adiposity and to explore how this relationship differs across levels of country human development.

**Subjects/Methods:** The International Study of Childhood Obesity, Lifestyle and the Environment (ISCOLE) was a multi-national cross-sectional study conducted in 12 urban/suburban study sites that represented all inhabited continents and wide ranges of development. ISCOLE collected objectively-measured height, body mass, and percentage body fat in 7 341 10-year-old children. Multi-level random-effects models were used to examine income gradients in several obesity measures.

**Results:** The mean age of the children was 10.4 years, and 12.6% were obese, ranging from 5.4% (Finland) to 23.8% (China). For both boys and girls, obesity prevalence, body fat percentage, and BMI z-score increased linearly with higher income at lower levels of development (all p for trend ≤0.0012), but decreased linearly with higher income at higher levels of development (all p for trend≤0.0003). Country human development explained 75% of the variation in the country-specific income-obesity relationships (r=-0.87, p=0.0003).

**Conclusions:** Results are consistent with the theory of epidemiologic transition. Global efforts to control obesity must account for socioeconomic factors within a country's context. Future research should seek to understand global socioeconomic patterns in obesity-related lifestyle behaviors.

**Keywords:** socioeconomic status, obesity, epidemiologic transition, nutrition transition, human development

**Trial Registration:** ClinicalTrials.gov: Identifier NCT01722500

## Introduction

Childhood obesity is now recognized as a global public health concern.[1] Because of the recent rise in obesity rates in both developed and developing countries,[2] the obesity epidemic is thought to be driven largely by environmental and social factors.[1] Social patterning of obesity, consistent with the theory of epidemiologic transition,[3] has been described in adults,[4-7] though research in children is more limited.[4,8]

For children, the limited research on socioeconomic gradients in obesity has been conducted predominantly in developed (high or very high human development) countries, with a preponderance of single-country studies, and studies have used inconsistent measures of individual socioeconomic status (SES) and adiposity.[4,6,8] These prior studies have highlighted inconsistent results across levels of development. To our knowledge, only one other published study[9] has investigated the relationship between a country's economic level and socioeconomic differences in overweight based on a large, multi-national sample of children. That study, however, failed to find a relationship. In contrast to the current (ISCOLE) study, the prior study used self-reported measures of body mass and height and did not include countries with low or middle levels of human development.

Both low childhood socioeconomic status[10-13] and childhood obesity[14,15] impart significant future health consequences. To address this current global epidemic and to plan for future health needs, it is essential to understand how childhood obesity relates to socioeconomic status across countries of varying levels of economic and social development. Thus, the aim of this study was to describe the relationship between childhood obesity and household income using several objective measures of adiposity and to explore how this relationship might differ across a wide range of country human development.

## Methods

The International Study of Childhood Obesity, Lifestyle and the Environment (ISCOLE) ISCOLE was a multi-national cross-sectional study that collected objectively-measured height, body mass, and percentage body fat in 7 341 children across 12 urban/suburban study sites. The rational, design and methods have been published in detail.[16] Each ISCOLE study site was responsible for recruiting and enrolling at least 500 children; a target sample size of 500 children per site was chosen based on a power calculation that suggested this size would provide 90% power to detect as significant predictors explaining 3% of the variability in BMI.[16] The primary sampling frame was schools, which was typically stratified by an indicator of socio-economic status in order to maximize variability within sites.[16] The Institutional Review Board at the Pennington Biomedical Research Center (coordinating center) approved the overarching ISCOLE protocol, and the Institutional/Ethical Review Boards at each participating institution also approved the local protocol. Written informed consent was obtained from parents or legal guardians, and child assent was obtained as required by local Institutional/Ethical Review Boards.

## Setting

The 12 urban/suburban sites included in ISCOLE represented countries ranging from low (0.509, Kenya) to very high (0.929, Australia) country human development (2011 Human Development Index, HDI[17]). Data were collected from September 2011 through December 2013. Data collection occurred during the school year, and each site completed their data collection over a single 12-month period. Across the study, data collection proceeded in a staggered fashion, with 2-5 sites engaged in data collection at any particular time.

## Participants

ISCOLE targeted 10-year-old children, and each study site determined the grade level to target that would ensure a sample with minimal variability around a mean age of 10 years. All children within the targeted grade level in a sampled school were eligible to participate; thus, the sample necessarily included children aged 9-11 years. A total of 7 372 boys and girls participated in the ISCOLE study, of which 7 341 remained in the analytic dataset after excluding participants who did not have valid BMI (n=31).

**Measurement**

*Anthropometry*

All ISCOLE sites collected objectively-measured height, body mass, and percentage body fat according to a common protocol, and all study personnel were required to complete a rigorous system of training and certification that included web-based training modules and regional in-person training meetings.[16] Standing height, body mass and body fat percentage were measured using standard procedures and instrumentation across all study sites. Height was measured without shoes, using a Seca 213 portable stadiometer (Hamburg, Germany), with the head in the Frankfort Plane. Body mass and body fat percentage were determined with a portable Tanita SC-240 bioelectrical impedance scale (Arlington Heights, IL), after all outer clothing, heavy pocket items and shoes were removed. Each measurement was repeated, and the average was used for analysis (a third measurement was obtained if the first two measurements were greater than 0.5 cm, 0.5 kg, or 2.0% apart for height, body mass and body fat percentage, respectively, and the average of the two closest measurements was used in analyses). The body mass index (BMI; $kg/m^2$) was calculated, and BMI z-scores were computed using age- and sex-specific reference data from the World Health Organization.[18] Participants were classified as obese (BMI z-score >+2 SD) or non-obese (BMI z-score ≤2 +SD).

*Household Income*

Parents self-reported household income levels across eight to ten country-specific categories determined by the study site. Within each country, income was collapsed into four levels to facilitate multi-country analysis. While not corresponding exactly to quartiles, the four levels were created to ensure the most balanced distribution possible within each country.

*Country Human Development Index*

The relationship between household income and adiposity was investigated across levels of human development, measured by the 2011 Human Development Index (HDI).[17] Values for the 2011 HDI corresponding to the $10^{th}$, $50^{th}$, and $90^{th}$ percentiles within the ISCOLE country sample were chosen to represent lower, middle, and higher levels of human development. Percentiles were calculated based on weighted averages. The use of sample-based percentiles ensures that the results are not extrapolated beyond the sample HDI range, and also reduces the likelihood of results being interpreted to correspond to specific countries in the sample.

**Treatment of Missing Data**

A total of 7 372 children participated in ISCOLE. BMI was missing for 31 (<1%) participants; these participants were excluded from all analyses. Body fat percentage was missing for an additional 76 (1%) participants; analysis of this outcome was conducted among participants with non-missing data.

Overall, 810 participants (11.0%) were missing data on household income. Four sites had missing income data in excess of 10%: UK (15.3%), Brazil (22.0%), Portugal (23.3%), and South Africa (32.6%). Participants missing income data were similar to those with complete data with respect to sex, age, obesity, BMI z-score, and body fat percentage.

Missing values for income were multiply-imputed to reduce the chance of bias due to exclusion of the cases with missing income data. Missing values were multiply-imputed (5 imputations) using fully conditional specification (FCS) methods, under missing at random (MAR) assumptions[19] and using SAS version 9.3 (PROC MI). Country-specific models were used to impute income categories, which were subsequently collapsed into the four income levels, as described above.

**Statistical Analysis**

Multi-level random effects models (PROC MIXED and PROC GLIMMIX) that accounted for clustering at both the school and country levels were used to examine income gradients in the various obesity measures. Denominator degrees of freedom for statistical tests pertaining to fixed effects were calculated using the Kenward and Roger approximation.[20] Interactions were used to test for differences in the income-obesity relationship across HDI levels (income-by-HDI interaction) and for differences between boys and girls (income-by-HDI-by-sex interaction). For presentation, least-square means for the obesity measures were estimated separately for boys and girls at values corresponding to the 10$^{th}$, 50$^{th}$, and 90$^{th}$ percentiles for the 2011 HDI within the ISCOLE sample. Linear regression “slopes-as-outcome” models overall and by sex, with the country-specific SES-obesity slope (SES level as ordinal, analyses stratified by study site) as the outcome and HDI as the predictor, were used to investigate the association of HDI with the between-country differences in the SES-obesity relationships.

To properly account for the multiply-imputed income data, results from all statistical analyses were averaged across the five imputed datasets, and the standard errors were adjusted using the MIANALYZE procedure in SAS. Sensitivity analyses were used to compare results from imputed datasets to those from analyses of participants with complete data, and results were similar.

**Results**

Descriptive characteristics of the study sample, stratified by sex and study site, are provided in Table 1. The mean age of the children was 10.4 years, and 12.6% of children were obese, which ranged from 5.4% (Finland) to 23.8% (China). ISCOLE study sites represented all inhabited continents and levels of human development (human development index, HDI) ranging from low (0.509, Kenya) to very high (0.929, Australia) (Table 2).

For both boys and girls, obesity was positively associated with income at lower levels of HDI and negatively associated with income at higher levels of HDI (Table 3 and Figure 1). There was a significant interaction between obesity prevalence and HDI in both boys (p=0.0351) and girls (p=0.0041), but no indication of different relationships between the two groups. Furthermore, this pattern – that the income gradient in obesity reverses itself as one moves from low to high levels of development – was consistent across all measures of adiposity (Figure 1 and Figure 2). For all adiposity measures, there was a significant interaction with HDI (Boys: BMI z-score (p=0.0002), body fat (p=0.0009); Girls: BMI z-score (p=0.0013), body fat (p=0.0071)); however, there was no indication of different income gradients for boys and girls. Finally, across successively higher levels of country human development, obesity levels decline in the highest income group, while they increase in the lowest income group.

Our analysis reveals a very strong negative relationship between HDI and the country-specific income-obesity gradients (Figure 3). Across countries, HDI explained 75% of the variation in the country-specific income-obesity relationships (r = -0.87, p=0.0003). The relationships were similar in boys and girls (p for interaction= 0.56). The income-obesity gradient is estimated to be zero for countries near a 2011 HDI of 0.76, with positive income gradients in obesity at lower levels of development and negative income gradients at higher levels. In stratified analysis, BMI z-score was significantly associated with income in six of the twelve ISCOLE countries.

**Discussion**

This is the first study of childhood obesity that included children from countries of low to very high levels of human development, that collected objective anthropometric measures, and that collected these measures according to a common protocol. Results demonstrated a strong relationship between childhood obesity and income, which is modified by the level of a country's development. For both boys and girls, obesity prevalence, body fat percentage, and BMI z-score were positively associated with income at lower levels of human development and negatively associated with income at higher levels of development.

For children, the limited research on socioeconomic gradients in obesity has been conducted predominantly in developed (high or very high HDI) countries, with a preponderance of single-country studies, and studies have used inconsistent measures of individual socioeconomic status and adiposity, precluding meta-analyses.[4,6,8] These prior studies have highlighted inconsistent results across levels of development. Results from the current study show that for countries with moderate levels of human development in which the income gradient would be plateauing before reversing, income gradients are generally non-significant. This observation could help to explain the inconsistent results from prior studies while also placing them within a clear pattern of income-obesity gradients across levels of country development.

To our knowledge, only one other published study[9] has investigated the relationship between a country's economic level and levels of socioeconomic differences in overweight based on a large, multi-national sample of children. That study, however, failed to find a relationship. In contrast to the current (ISCOLE) study, the prior study used self-reported measures of body mass and height and represented countries with more limited variability in human development (2011 HDI from 0.729 to 0.943). If the current (ISCOLE) analysis had been restricted to sites with comparable levels of human development, we would also have failed to identify the strong relationship between human development and income gradients in obesity, reinforcing the importance of including less-developed countries this research.

Our results are consistent with the theory of epidemiologic transition, which characterizes changes across levels of a country's development in patterns of morbidity and mortality from infectious causes to chronic and "man-made" diseases.[3] With respect to obesity, the epidemiologic transition encompasses both dietary changes (shifts from undernutrition and malnutrition to overnutrition, and from traditional diets to more energy-dense “western” diets) and changes in physical activity (shifts away from high levels of occupational and transportation-based physical activity to more sedentary lifestyles) often referred to as the “nutrition transition”[21] and the “physical activity” transition.[22]

The epidemiologic transition predicts a social patterning of obesity in countries in transition, such that groups with higher income, standards of living, and levels of nutrition shift first, resulting in higher levels of obesity compared to lower-income groups.[3] Furthermore, in these settings, obesity may be valued as an indicator of relative affluence, reinforcing the prevalence of obesity in higher-income groups. As a country’s development increases, food scarcity, famine, and malnutrition become less common, such that lower income groups experience less malnutrition, increasing their relative adiposity. The lack of a consistent relationship between income and obesity in mid-HDI countries may be related to increased access to low-cost, energy-dense foods coupled with the necessity of physically-intense labor among low income groups resulting in an increased obesity prevalence approaching that of high income populations in these countries. Then, as countries complete the transition to a more western “modern” lifestyle and standards of living increase, overfeeding and being less active become economically possible. At high HDI, the income-obesity gradient shifts with lower income groups experiencing higher levels of obesity, potentially related to lower costs of energy-dense foods[23] and decreased access to safe places to be physically active.[24,25]

The incidence of major cardiovascular events is currently highest in low-income countries, despite lower levels of obesity.[26] At present, policies in most low- and mid-HDI countries favor prevention of undernutrition, and only some countries have implemented policies to prevent obesity.[27] Consequently, as childhood obesity levels increase globally, lower income countries will be more impacted by cardiovascular disease and associated medical and social costs. Also, as global development increases, poorer segments of the population are projected to see the highest increases in obesity, further compounding the global burden of cardiovascular disease.

A particular strength of the current research is the wide variability in levels of human development present in the country sample and the analysis of objective obesity data collected under a rigorous, common protocol; as such, the ISCOLE sample provides clearer insights into how social determinants of health[28,29] may be impacting childhood obesity globally. The ISCOLE sample was limited to children in urban and suburban settings, so results may not generalize to rural settings; however, this aspect of the study design also prevents confounding by the extent of urbanization on the estimated relationships. Recent research in adults suggests that urban-rural differences in obesity seen in less-developed countries may be mainly attributable to socioeconomic status,[30] so our results may be relevant for rural settings as well.

In conclusion, childhood obesity prevalence is related to household income, though the strength and direction of this relationship differs according a country's level of human development. Consequently, as childhood obesity levels continue to rise, it will be important to account for socioeconomic factors within a country's context in the global effort to control the epidemic. This effort should include a better understanding of socioeconomic gradients in specific behaviors that contribute to obesity, namely diet, physical activity, and sedentary behavior. Finally, as global development increases, poorer segments of the population are projected to see the highest increases in obesity.

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**Conflicts of Interest**

MF has received a research grant from Fazer Finland and has received an honorarium for speaking for Merck. AK has been a member of the Advisory Boards of Dupont and McCain Foods. RK has received a research grant from Abbott Nutrition Research and Development. VM is a member of the Scientific Advisory Board of Actigraph and has received an honorarium for speaking for The Coca-Cola Company. TO has received an honorarium for speaking for The Coca-Cola Company. The authors reported no other potential conflicts of interest.

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**Figure Legends**

**Figure 1.** Income gradients in obesity prevalence across HDI levels in boys (**A**) and girls (**B**). Data are shown as least-square means at HDI levels corresponding to the $10^{th}$, $50^{th}$, and $90^{th}$

percentiles of the ISCOLE sample (HDI=0.52, HDI=0.72, and HDI=0.91, respectively). Tests for linear trend are indicated: *p<0.05, **p<0.001; ***p<0.0001.

**Figure 2.** Income gradients in adiposity measures across HDI levels in boys (**A**) and girls (**B**). Data are shown as least-square means at HDI levels corresponding to the $10^{th}$, $50^{th}$ , and $90^{th}$ percentiles of the ISCOLE sample (HDI=0.52, HDI=0.72, and HDI=0.91, respectively). Tests for linear trend are indicated: **p<0.001; ***p<0.0001.

**Figure 3.** Relationship between country-specific income-obesity gradients and HDI.

Table 1. Descriptive characteristics of International Study of Childhood Obesity, Lifestyle and the Environment (ISCOLE) participants stratified by sex and study site (n=7 341).

| Country (Site) | n | | Age (y) | | Obesity (%) | | BMI z-score | | Body Fat (%) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | *boys* | *girls* | *boys* | *girls* | *boys* | *girls* | *boys* | *girls* | *boys* | *girls* |
| Australia (Adelaide) | 243 | 285 | 10.4 (0.5) | 10.3 (0.6) | 11.5 | 9.5 | 0.6 (1.1) | 0.6 (1.1) | 18.9 (6.5) | 23.9 (7.2) |
| Brazil (São Paulo) | 277 | 287 | 10.0 (0.5) | 10.0 (0.5) | 28.9 | 14.6 | 1.0 (1.5) | 0.7 (1.3) | 21.3 (9.6) | 24.7 (8.4) |
| Canada (Ottawa) | 238 | 327 | 10.1 (0.4) | 10.0 (0.4) | 14.3 | 10.1 | 0.6 (1.2) | 0.3 (1.2) | 18.7 (7.2) | 21.9 (7.3) |
| China (Tianjin) | 293 | 258 | 9.4 (0.5) | 9.4 (0.5) | 33.4 | 12.8 | 1.1 (1.6) | 0.3 (1.3) | 20.2 (8.0) | 20.7 (8.1) |
| Colombia (Bogotá) | 454 | 462 | 10.0 (0.6) | 10.0 (0.7) | 7.9 | 3.7 | 0.3 (1.1) | 0.1 (1.0) | 18.4 (5.7) | 21.6 (5.5) |
| Finland (Helsinki, Espoo & Vantaa) | 253 | 282 | 10.0 (0.5) | 10.0 (0.4) | 7.5 | 3.6 | 0.3 (1.1) | 0.2 (1.0) | 16.9 (6.2) | 20.9 (6.8) |
| India (Bangalore) | 292 | 328 | 10.0 (0.6) | 10.0 (0.6) | 12.3 | 8.5 | 0.2 (1.5) | 0.3 (1.3) | 19.5 (7.5) | 23.7 (7.0) |
| Kenya (Nairobi) | 262 | 301 | 9.7 (0.7) | 9.8 (0.7) | 7.3 | 6.0 | 0.1 (1.3) | 0.0 (1.2) | 16.1 (7.0) | 17.1 (8.5) |
| Portugal (Porto) | 358 | 419 | 10.0 (0.2) | 10.0 (0.3) | 21.5 | 14.1 | 1.0 (1.2) | 0.8 (1.1) | 20.5 (7.2) | 24.9 (7.1) |
| South Africa (Cape Town) | 222 | 327 | 9.9 (0.7) | 9.8 (0.7) | 10.4 | 11.0 | 0.2 (1.3) | 0.3 (1.3) | 17.7 (7.2) | 22.8 (7.8) |
| United Kingdom (Bath & NE Somerset) | 237 | 287 | 10.4 (0.5) | 10.4 (0.5) | 10.1 | 9.4 | 0.5 (1.1) | 0.4 (1.2) | 18.2 (6.4) | 23.3 (6.7) |
| United States (Baton Rouge) | 281 | 368 | 9.6 (0.7) | 9.5 (0.6) | 19.6 | 18.2 | 0.9 (1.4) | 0.8 (1.3) | 20.9 (8.5) | 24.9 (7.9) |

BMI: Body Mass Index

Table 2. International Study of Childhood Obesity, Lifestyle and the Environment (ISCOLE) country socioeconomic indicators and country-specific sample income levels.

| | | ISCOLE sample income levels: Within-country %[1] Country currency range | | | |
|---|---|---|---|---|---|
| Country (Site) | 2011 Human Development Index | L1 (ISO Code[2]) | L2 | L3 | L4 |
| Australia | 0.929 | 23.9% | 30.2% | 24.5% | 21.4% |
| | | ≤$49 999 (AUD) | $50 000–$89 999 | $90 000–$139 999 | ≥$140 000 |
| Brazil | 0.718 | 38.4% | 24.4% | 21.5% | 15.7% |
| | | ≤R$19 620 (BRL) | R$19 621–$32 700 | R$32 701–$58 860 | >R$58 860 |
| Canada | 0.908 | 19.7% | 28.1% | 14.3% | 37.9% |
| | | ≤$59 999 (CAN) | $60 000–$109 999 | $110 000–$139 999 | >$140 000 |
| China | 0.687 | 19.8% | 19.5% | 28.5% | 32.2% |
| | | <¥20 000 (CNY) | ¥20 000–¥39 999 | ¥40 000–¥79 999 | >¥80 000 |
| Colombia | 0.710 | 35.0% | 24.8% | 17.7% | 22.6% |
| | | ≤$8 400 000 (COP) | $8 400 001–$12 000 000 | $12 000 001–$18 000 000 | >18 000 000 |
| Finland | 0.882 | 20.7% | 19.8% | 19.5% | 40.1% |
| | | ≤39 999€ (EUR) | 40 000€–59 999€ | 60 000€–79 999€ | >80 000€ |
| India | 0.547 | 23.5% | 19.9% | 18.7% | 38.0% |
| | | ≤Rs239 999 (INR) | Rs240 000–Rs479 999 | Rs480 000–Rs719 999 | >Rs720 000 |
| Kenya | 0.509 | 23.2% | 25.1% | 22.6% | 29.1% |
| | | ≤Ksh121 991 (KES) | Ksh121 992–Ksh466 727 | Ksh466 728–Ksh1 199 999 | >Ksh1 200 000 |
| Portugal | 0.809 | 20.8% | 30.8% | 27.7% | 20.6% |
| | | <€6 000 (EUR) | €6 000–€11 999 | €12 000–€23 999 | >€24 000 |
| South Africa | 0.619 | 50.4% | 21.4% | 16.1% | 12.1% |
| | | <R11 500 (ZAR) | R11 500–R30 000 | R30 001–R300 000 | >R300 000 |
| United Kingdom | 0.863 | 27.0% | 28.7% | 23.3% | 21.0% |
| | | ≤£19 999 (GBP) | £20 000–£39 999 | £40 000–£59 999 | >£60 000 |
| United States | 0.910 | 20.3% | 31.1% | 27.2% | 21.4% |
| | | <$10 000 (USD) | $10 000–$49 999 | $50 000–$139 999 | >$140 000 |

[1] Across imputed datasets (m=5)

[2] International Organization for Standardization (ISO) 4217 standard currency codes

Table 3. Least-square mean estimates for measures of adiposity[1] across income levels, by sex and human development index: the International Study of Childhood Obesity, Lifestyle, and the Environment (ISCOLE).

| | Level 1 | Level 2 | Level 3 | Level 4 | p for trend[2] |
|---|---|---|---|---|---|
| | | *Boys* | | | |
| ISCOLE 10th percentile of HDI | | | | | |
| Obesity prevalence | 5.0 (2.3) | 14.1 (5.4) | 13.4 (5.3) | 21.2 (6.8) | <0.001 |
| BMI z-score | -0.19 (0.20) | 0.27 (0.21) | 0.36 (0.21) | 0.77 (0.20) | <0.001 |
| Body Fat (%) | 15.8 (1.1) | 18.1 (1.1) | 18.6 (1.1) | 20.6 (1.1) | <0.001 |
| ISCOLE 50th percentile of HDI | | | | | |
| Obesity prevalence | 10.8 (2.2) | 14.8 (2.8) | 15.0 (2.9) | 14.3 (2.7) | 0.05 |
| BMI z-score | 0.40 (0.11) | 0.54 (0.11) | 0.55 (0.11) | 0.62 (0.11) | 0.003 |
| Body Fat (%) | 18.5 (0.6) | 19.0 (0.6) | 19.0 (0.6) | 19.2 (0.6) | 0.15 |
| ISCOLE 90th percentile of HDI | | | | | |
| Obesity prevalence | 20.9 (5.3) | 15.5 (4.1) | 16.6 (4.4) | 9.5 (2.9) | <0.001 |
| BMI z-score | 0.96 (0.16) | 0.80 (0.15) | 0.73 (0.15) | 0.48 (0.15) | <0.001 |
| Body Fat (%) | 21.1 (0.8) | 19.8 (0.8) | 19.5 (0.8) | 17.9 (0.8) | <0.001 |
| | | *Girls* | | | |
| ISCOLE 10th percentile of HDI | | | | | |
| Obesity prevalence | 4.8 (2.0) | 6.5 (2.6) | 8.9 (3.4) | 13.0 (4.3) | 0.001 |
| BMI z-score | -0.13 (0.16) | 0.10 (0.16) | 0.26 (0.16) | 0.50 (0.15) | <0.001 |
| Body Fat (%) | 19.2 (1.3) | 20.2 (1.2) | 21.1 (1.3) | 22.3 (1.2) | <0.001 |
| ISCOLE 50th percentile of HDI | | | | | |
| Obesity prevalence | 8.8 (1.6) | 9.2 (1.7) | 8.6 (1.6) | 8.9 (1.7) | 0.95 |
| BMI z-score | 0.30 (0.08) | 0.37 (0.08) | 0.38 (0.08) | 0.42 (0.08) | 0.07 |
| Body Fat (%) | 22.0 (0.6) | 22.2 (0.6) | 22.2 (0.7) | 22.4 (0.7) | 0.29 |
| ISCOLE 90th percentile of HDI | | | | | |
| Obesity prevalence | 15.2 (3.5) | 12.7 (3.0) | 8.3 (2.3) | 6.1 (1.8) | <0.001 |
| BMI z-score | 0.71 (0.12) | 0.63 (0.11) | 0.50 (0.12) | 0.34 (0.12) | <0.001 |
| Body Fat (%) | 24.6 (0.9) | 24.1 (0.9) | 23.3 (0.9) | 22.6 (0.9) | <0.001 |

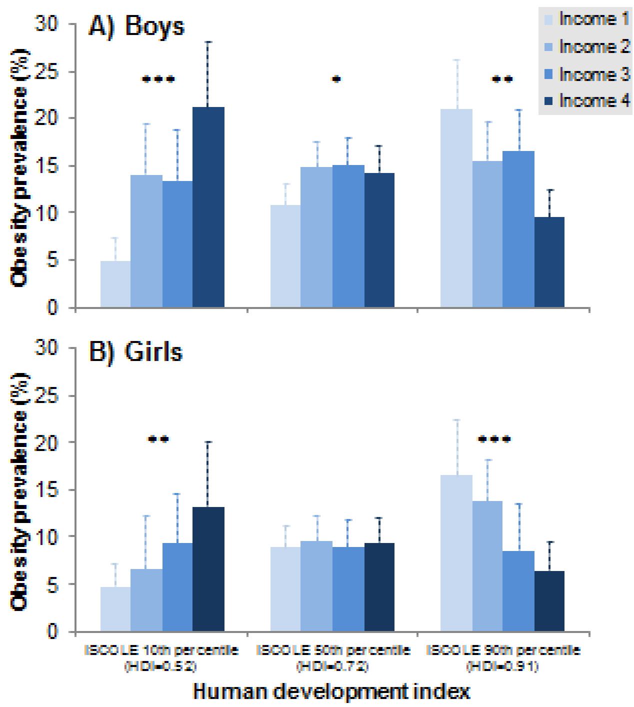
[1] Least-square mean estimates of adiposity measures at HDI levels corresponding to the 10th, 50th, and 90th percentiles of the ISCOLE country sample (HDI=0.52, HDI=0.72, and HDI=0.91, respectively).

[2] Test for linear trend (linear contrast) across the four income levels

HDI: Human Development Index; BMI: Body Mass Index

Figure 1. Income gradients in obesity prevalence across HDI levels in boys (**A**) and girls (**B**). Data are shown as least-square means at HDI levels corresponding to the 10th, 50th, and 90th percentiles of the ISCOLE sample (HDI=0.52, HDI=0.72, and HDI=0.91, respectively). Tests for linear trend are indicated: *p<0.05, **p<0.001; ***p<0.0001.

Figure 2. Income gradients in adiposity measures across HDI levels in boys (**A**) and girls (**B**). Data are shown as least-square means at HDI levels corresponding to the 10th, 50th , and 90th percentiles of the ISCOLE sample (HDI=0.52, HDI=0.72, and HDI=0.91, respectively). Tests for linear



trend are indicated: **p<0.001; ***p<0.0001.

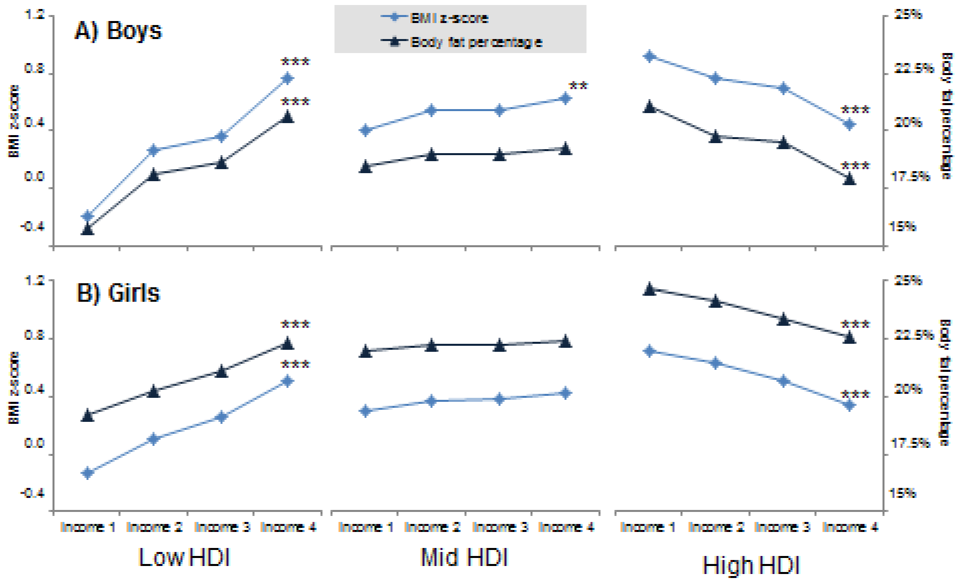
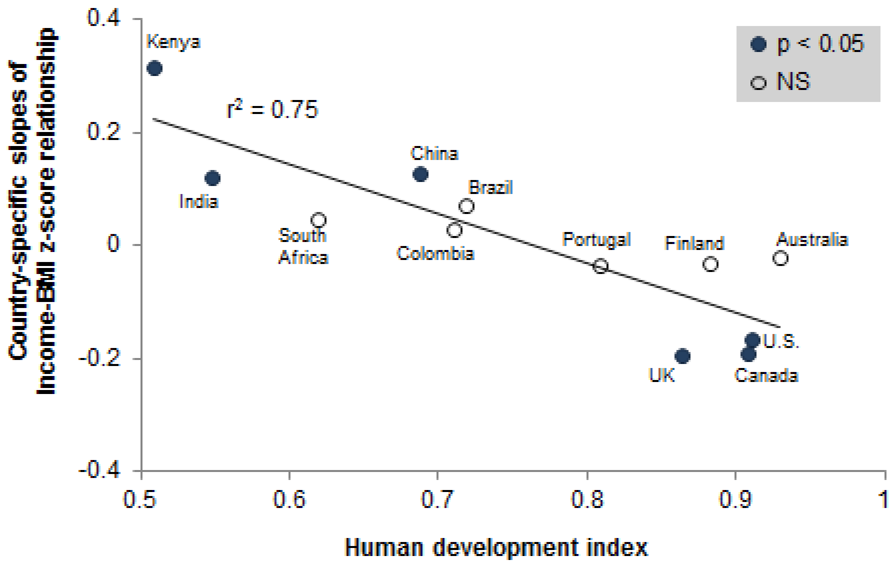



Figure 3. Relationship between country-specific income-obesity gradients and HDI.



0.4
0.2
0
-0.2
-0.4
0.5
0.6
0.7
0.8
0.9
1
Country-specific slopes of Income-BMI z-score relationship
Human development index
p < 0.05
NS
r² = 0.75
Kenya
India
South Africa
China
Brazil
Colombia
Portugal
Finland
Australia
U.S.
UK
Canada