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Worldwide trends in children's and adolescents' body mass index, underweight, overweight and obesity, in comparison with adults, from 1975 to 2016: a pooled analysis of 2,416 population-based measurement studies with 128.9 million participants

NCD Risk Factor Collaboration (NCD-RisC)*

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Summary

Background: Being underweight as well as overweight and obese in childhood and adolescence are associated with adverse health consequences throughout the life-course. Our aim was to estimate worldwide trends in mean body mass index (BMI) and a comprehensive set of BMI categories that cover the underweight to obese range in school-aged children and adolescents, and to compare trends with those of adults.

Methods: We re-analysed and pooled 2,416 population-based studies with measurements of height and weight on 128.9 million participants aged five years and older, including 31.5 million aged 5-19 years. We used a Bayesian hierarchical model to estimate trends from 1975 to 2016 for 200 countries in mean BMI and in prevalence of BMI in the following categories for children and adolescents aged 5-19 years: <-2SD from the median of the WHO growth reference (referred to as moderate and severe underweight hereafter), -2SD to <-1SD (mild underweight), -1SD to 1SD (normal weight), >1 SD to 2SD (overweight), and >2SD (obesity).

Findings: Regional change in age-standardised mean BMI in girls ranged from -0.01 kg/m^2 per decade (-0.42 to 0.39; PP of the observed decrease being a true decrease = 0.5098) in eastern Europe to 1.00 kg/m^2 per decade (0.69-1.35; PP > 0.9999) in central Latin America and 0.95 kg/m^2 per decade (0.64-1.25; PP > 0.9999) in Polynesia and Micronesia. The range for boys was from 0.09 kg/m^2 per decade (-0.33 to 0.49; PP = 0.6926) in eastern Europe to 0.77 kg/m^2 per decade (0.50-1.06 PP > 0.9999) in Polynesia and Micronesia. There has been a recent flattening of trends in northwestern Europe and the high-income English-speaking and Asia-Pacific regions for both sexes, southwestern Europe for boys, and central and Andean Latin America for girls. In contrast, the rise in BMI has accelerated in east and south Asia for both sexes, and southeast Asia for boys.

Global age-standardised prevalence of obesity increased from 0.7% (0.4-1.2) in 1975 to 5.6% (4.8-6.5) in 2016 in girls, and from 0.9% (0.5-1.3) to 7.8% (6.7-9.1) in boys; the prevalence of moderate and severe underweight decreased from 9.2% (6.0-12.9) to 8.4% (6.8-10.1) in girls and from 14.8% (10.4-19.5) to 12.4% (10.3-14.5) in boys. Prevalence of moderate and severe underweight was highest in India, 22.7% (16.7-29.6) among girls and 30.7% (23.5-38.0) among boys. Prevalence of obesity was >30% in girls in Nauru, the Cook Islands and Palau and boys in the Cook Islands, Nauru, Palau, Niue and American Samoa in 2016, and was also ~20% or more in several countries in Polynesia and Micronesia, the Middle East and north Africa, and the Caribbean as well as in the USA. The global number of moderately or severely underweight girls and boys was 75 million (44-117) and 117 million (70-178), respectively, in 2016; The number of obese girls and boys was 50 (24-89) and 74 (39-125) million, respectively.

Interpretation: The rise in children's and adolescents' BMI has plateaued in many high-income countries, albeit at high levels, but has accelerated in parts of Asia, with trends no longer correlated with those of adults.

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Research in Context

Evidence before this study

We searched Medline (via PubMed) using the search terms ("body size"[mh:noexp] OR "body height"[mh:noexp] OR "body weight"[mh:noexp] OR "birth weight"[mh:noexp] OR "overweight"[mh:noexp] OR "obesity"[mh] OR "thinness"[mh:noexp] OR "Waist-Hip Ratio"[mh:noexp] OR "Waist Circumference"[mh:noexp] OR "body mass index"[mh:noexp]) AND ("Humans"[mh]) AND ("Health Surveys"[mh] OR "Epidemiological Monitoring"[mh] OR "Prevalence"[mh]) NOT Comment[ptyp] NOT Case Reports[ptyp]. Articles were screened according to the inclusion and exclusion criteria described in the Appendix.

We identified three prior global analyses of mean body mass index (BMI) and/or prevalence of overweight and obesity among adults;[1-4] one of these studies also estimated the prevalence of underweight in adults.[4] One study also included data on overweight and obesity in children and adolescents,[3] using a combination of measured and self-reported height and weight, and analysed in the same model as adults. A few multi-country studies and systematic reviews have reported, quantitatively or qualitatively, trends in overweight and obesity in children and adolescents, some also reporting underweight. To our knowledge, there is no global analysis of mean BMI, which is a summary measure of population distribution, or prevalence of underweight among school-aged children and adolescents.

Added value of this study

This study provides a complete picture of trends in mean BMI and prevalence of BMI categories that cover the underweight to obese range among school-aged children and adolescents for all countries in the world with the longest observation period, and compares trends with those of adults. It includes the first global estimates of mean BMI and

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underweight prevalence for children and adolescents. We also present trends in the number of children, adolescents and adults who are moderately or severely underweight and obese, and thus at risk of adverse health outcomes.

Implications of all the available evidence

Over the past four decades, mean BMI and obesity in school-aged children and adolescents have increased in most regions and countries. Despite this rise, more school-aged children and adolescents are moderately or severely underweight than obese, with the burden of underweight increasingly concentrated in south Asia and central, east and west Africa. The rise in children's and adolescents' BMI has plateaued, albeit at high levels, in many high-income countries but has accelerated in parts of Asia.

Introduction

Being underweight as well as overweight or obese during childhood and adolescence are associated with adverse health consequences throughout the life-course. Underweight among children and adolescents is associated with higher risk of infectious diseases, and for girls of childbearing age, with adverse pregnancy outcomes, including maternal mortality, delivery complications, preterm birth and intrauterine growth retardation.[5,6] Preventing and reversing excess weight in children and adolescents is also important for a number of reasons:[7,8] First, weight loss and maintenance after weight loss are hard to achieve,[9] which means that gaining excess weight in childhood and adolescence is likely to lead to lifelong overweight and obesity.[10] Second, being overweight in childhood and adolescence is associated with greater risk and earlier onset of long-term (chronic) consequences such type 2 diabetes.[7,8,11-13] Third, childhood and adolescent obesity has adverse psychosocial consequences and lowers educational attainment.[7,8,14,15] Finally, children and adolescents are more vulnerable to food marketing than adults, which makes reducing children's exposure to obesogenic foods a matter of child protection.[7,16]

Although trends in children's and adolescents' weight status have been documented in specific countries, there is limited comparable information on worldwide trends, and none for mean BMI and underweight (Research in Context panel). We pooled population-based data to estimate trends from 1975 to 2016 in mean body mass index (BMI) and in the prevalence of a comprehensive set of BMI categories that cover the underweight to obese range among children and adolescents for all countries in the world. We also generated updated estimates for adults,[4] so that we can compare the trajectory of the obesity epidemic in children and adolescents with that of adults.

Methods

Study design

We pooled and analysed population-based studies that had measured height and weight in people aged five years and older to estimate trends from 1975 to 2016 in mean BMI and BMI categories in 200 countries and territories (Appendix Table 1). We started our analysis from five years of age because the definitions of underweight, overweight and obesity change at five years of age.[17] Further, children enter school at or around this age, which is associated with a change in their nutrition and physical activity.[18]

We present data on school-aged children and adolescents (ages 5-19 years) and on adults (20 years and older). We conducted separate analyses for children and adolescents and for adults for two reasons: First, cut-offs used to define underweight, overweight, and obesity for children and adolescents are different from those for adults and vary by age and sex because of the natural growth in childhood and adolescence.[19] Second, the trajectory of the obesity epidemic in children and adolescents may be different from that of adults,[20] motivating separate analyses of trends. Similarly, underweight in children and adolescents is typically targeted through school and community-based nutrition programmes, decoupling its trajectory from that of adults.

For children and adolescents, we analysed trends in mean BMI and prevalence of BMI in the following categories: <-2SD from the median of the WHO growth reference for children and adolescents[19] (referred to as moderate and severe underweight hereafter), -2SD to <-1SD (mild underweight), -1SD to 1SD (normal weight), >1SD to 2SD (overweight), and >2SD (obesity). The cut-offs for calculating prevalences in these BMI categories were all age-specific and were applied to data in single years of age. We used the WHO definition because

it includes a comprehensive set of BMI categories ranging from moderate and severe underweight to obesity, defined based on symmetric thresholds of SDs from the reference population median. For adults, we analysed trends in mean BMI and prevalence of a comprehensive set of BMI categories as described in detail elsewhere and in the Appendix.[4] Results for children and adolescents are presented in the main paper; updated results for adults are presented in the Appendix except when compared with children/adolescents.

Data sources

Our methods for identifying and accessing data sources, and our inclusion and exclusion criteria, are described in Appendix 1. In summary, we used a database of population-based data on cardiometabolic risk factors collated by the NCD Risk Factor Collaboration (NCD-RisC), a worldwide network of health researchers and practitioners whose aim is to document systematically the worldwide trends and variations in non-communicable disease (NCD) risk factors. The database was collated through multiple routes for identifying and accessing data. We accessed publicly available population-based multi-country and national measurement surveys as well as the WHO STEPwise approach to Surveillance (STEPS) surveys. We requested, via WHO and its regional and country offices, from ministries of health and other national health and statistical agencies to identify and access population-based surveys. Requests were also sent via the World Heart Federation to its national partners. We made a similar request to the co-authors of an earlier pooled analysis of cardiometabolic risk factors,[1,21-23] and invited them to reanalyse data from their studies and join NCD-RisC. To identify major sources not accessed through the above routes, we searched and reviewed published studies as detailed previously,[4] and invited all eligible studies to join NCD-RisC. Finally, NCD-RisC members are periodically asked to review the list of sources from their country, to suggest additional sources currently not in the database, and to verify that the

included data from their country meet the inclusion criteria as listed in Appendix 1 and that there are no duplicates.

The list of data sources and their characteristics is provided in Appendix Table 2. In summary, we included data collected on samples of a national, subnational (i.e. covering one or more subnational regions, or more than three communities) or community (one or a small number of communities) population, which had measured weight and height. We did not use self-reported height and weight because they are subject to biases that vary by geography, time, age, sex, and socioeconomic characteristics.[24-26] Because of these variations, current approaches to correcting self-reported data leave residual bias.

Statistical methods

The statistical models used to estimate mean and prevalence by country, year, and age are described in detail in a statistical paper and related substantive papers;[4,27-30] the computer code is available at www.ncdrisc.org. In summary, we organised countries into 21 regions, mostly on the basis of geography and national income (Appendix Table 1). The exception was a region consisting of high-income English-speaking countries, grouped together because BMI and other cardiometabolic risk factors have similar trends in these countries, which can be distinct from other countries in their geographical region.[4,28-30]

The model had a hierarchical structure in which estimates for each country and year were informed by its own data, if available, and by data from other years in the same country and from other countries, especially those in the same region with data for similar time periods. The extent to which estimates for each country-year are influenced by data from other years and other countries depends on whether the country has data, the sample size of data, whether

or not they are national, and the within-country and within-region variability of the available data. The model incorporated non-linear time trends comprising linear terms and a second-order random walk. The age association of BMI was modelled using a cubic spline to allow non-linear age patterns, which might vary across countries. The model accounted for the possibility that BMI in subnational and community samples might systematically differ from nationally representative ones, and have larger variation than in national studies. These features were implemented by including data-driven fixed-effect and random-effect terms for subnational and community data. The fixed effects adjust for systematic differences between subnational or community studies and national studies. The random effects allow national data to have larger influence on the estimates than subnational or community data with similar sample sizes. It also accounted for rural-urban differences in BMI, through the use of data-driven fixed effects for rural-only and urban-only studies. These rural and urban effects were weighted by the difference between study-level and country-level urbanisation in the year when the study was done. The statistical model included a covariate (proportion of national population living in urban areas; data from the World Urbanization Prospects, 2014 revision) that is associated with, and helps predict, BMI.[31] Results of model validation are reported elsewhere.[4] We performed all analyses by sex, because there are differences in BMI levels and trends in relation to sex.[4]

We analysed the data on mean BMI and on each of the above prevalence categories separately. We re-scaled the estimated prevalence categories so that the sum of different categories was 1.0 in each age, sex, country and year. The average scaling factors across draws ranged from 1.03 to 1.07, i.e., the sum of the separately estimated prevalence categories was close to 1.0.

We fitted the statistical model with the Markov chain Monte Carlo (MCMC) algorithm, and obtained 5,000 post-burn-in samples from the posterior distribution of model parameters, which were in turn used to obtain the posterior distributions of the above primary outcomes, i.e., mean BMI and each of the prevalence categories. For model fitting, data on participants aged 5-19 years were included in the analysis of trends in children and adolescents, and on participants aged 18 years and older in the analysis of trends in adults. Data on participants aged 18 and 19 years were included in both sets of models because these groups form a transitional age from adolescence to adulthood, and hence help inform the estimates in both groups. Posterior estimates were made in one-year age groups for ages 5-19 years and in five-year age groups for those aged 20 years and older. For presentation, we used the posterior estimates for age 5-19 years for children and adolescents, and for ages 20 years and above for adults. Age-standardised estimates were generated by taking weighted averages of age-sex-specific estimates, separately for children and adolescents and for adults, with use of age weights from the WHO standard population.[32] Estimates for regions and the world were calculated as population-weighted averages of the constituent country estimates by age group and sex. The number of children, adolescents and adults who are underweight, overweight or obese was calculated by multiplying the corresponding age-specific prevalence by the population at the country, year and sex level.

The reported credible intervals (CrI) represent the 2.5th-97.5th percentiles of the posterior distributions. The uncertainties of our estimates, represented by the widths of the credible intervals, arise from uncertainty due to sampling in each data source; uncertainty associated with the variability of national data beyond what is accounted for by sampling; additional uncertainty associated with subnational and community data, and data that are from rural-only or urban-only samples; and uncertainty due to making estimates by country, year and

age when data were missing or scarce, in the country-year-age group unit for which estimates are made, in proximate time periods and ages in that country and in other countries in the same region. We also report the posterior probability (PP) that an estimated increase or decrease represents a truly increasing or decreasing trend.

Role of funding source

The funder of the study had no role in study design, data collection, analysis, interpretation, or writing of the report. Country and Regional Data Group members, JB, MDC, VB, HB and BZ had full access to the data in the study. The corresponding author had final responsibility for the decision to submit for publication.

Results[1]

Data sources

We pooled 2,416 population-based data sources (Appendix Figure 1 and Appendix Figure 2) with measured height and weight in 128.9 million people aged five years and older (Appendix Table 3). 1,099 sources included data on 24.1 million participants aged 5-17 years, 848 on 7.4 million participants aged 18-19 years, and 1,820 on 97.4 million participants aged 20 years and older (Appendix Figure 3 and Appendix Table 3). Additional information on the age distribution of data sources and participants is shown in Appendix Figure 3 and Appendix Table 3. 1,187 (49%) of our data sources were from national samples, 390 (16%) covered one or more subnational regions, and the remaining 839 (35%) were from one or a small number of communities (Appendix Figure 2). 583 (24%) data sources were from years before 1995 and another 1,833 (76%) were from 1995 and later (Appendix Figure 2). The number of data

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[1] Interactive visualisations and downloadable files on country results are available at www.ncdrisc.org.

sources per country in different regions ranged from 3.4 in the Caribbean to 54.0 in the high-income Asia-Pacific region (Appendix Figure 2).

Mean BMI (global and regional)

In 1975, global age-standardised mean BMI of school-aged children and adolescents aged 5-19 years was 17.2 kg/m^2 (95% CrI 16.8-17.6) for girls and 16.8 kg/m^2 (16.3-17.2) for boys (Figure 1). Mean BMI was lowest in south Asia, with an age-standardised mean of 15.8 kg/m^2 (15.2-16.3) for girls and 15.0 kg/m^2 (14.5-15.6) for boys, followed by east Africa. Girls in Melanesia, Polynesia and Micronesia, and the high-income English-speaking region had the highest age-standardised mean BMI in 1975, all above 19.0 kg/m^2. The highest mean BMIs for boys were those in Polynesia and Micronesia (19.1 kg/m^2; 18.0-20.2), followed by the high-income English-speaking region.

From 1975 to 2016, children's and adolescents' age-standardised mean BMI increased globally and in most regions (Figure 1). The global increase was 0.32 kg/m^2 per decade (0.23-0.41; PP of the observed increase being a true increase >0.9999) for girls and 0.40 kg/m^2 per decade (0.30-0.50; PP >0.9999) for boys, leading to virtually-identical age-standardised mean BMIs of 18.6 kg/m^2 (18.4-18.7) and 18.5 kg/m^2 (18.3-18.7), respectively, in 2016. The corresponding figures for adults were 24.8 kg/m^2 (24.6-25.0) in women and 24.5 kg/m^2 (24.3-24.6) in men.

Regional change in girls ranged from virtually no change (-0.01 kg/m^2 per decade (-0.42 to 0.39; PP of the observed decrease being a true decrease = 0.5098)) in eastern Europe to 1.00 kg/m^2 increase per decade (0.69-1.35; PP > 0.9999) in central Latin America and 0.95 kg/m^2 per decade (0.64-1.25; PP > 0.9999) in Polynesia and Micronesia. The range for boys was

from 0.09 kg/m^2 per decade (-0.33 to 0.49; PP = 0.6926) in eastern Europe to 0.77 kg/m^2 per decade (0.50-1.06 PP > 0.9999) in Polynesia and Micronesia. In some regions, children's and adolescents' BMI increased gradually over the four decades of analysis (Figure 1). However, there has been a recent flattening of trends in northwestern Europe and the high-income English-speaking and Asia-Pacific regions for both sexes, southwestern Europe for boys, and central and Andean Latin America for girls. With the exception of women in high-income Asia-Pacific region, adult mean BMI is still increasing in all of these regions and sexes (Figure 1). In contrast to this plateauing, the rise in mean BMI has accelerated since around 2000 in east and south Asia for both sexes, and in southeast Asia for boys.

The lowest child and adolescent BMIs in 2016 were still those in south Asia and east Africa, with age-standardised mean BMIs between 16.9 and 17.9 kg/m^2 for boys and girls; the highest were those in Polynesia and Micronesia for both sexes, followed by Melanesia and the high-income English-speaking region. Age-standardised mean BMIs of girls and boys in Polynesia and Micronesia, which were 23.1 kg/m^2 (22.4-23.8) and 22.4 kg/m^2 (21.6-23.1), respectively, were higher than those of adults in some regions. Children's and adolescents' age-standardised mean BMI was also >20 kg/m^2 in Melanesia and many parts of Latin America and the Caribbean.

The regional rankings in 2016 differed slightly between children aged 5-9 years and adolescents aged 10-19 years (Appendix Figure 4). For example, the lowest mean BMI in 5-9-year olds was seen in east Africa in both sexes, whereas in those aged 10-19 years, south Asian boys and girls had lower mean BMI than their African peers. Polynesians/Micronesians had the highest mean BMI in 5-9-year as well as 10-19-year olds, with the subsequent spots held by the high-income English-speaking region, regions in Latin

America and the Caribbean, and Melanesia. Among these regions, central Latin America had a poorer ranking (i.e., higher BMI relative to other regions) at 10-19 years than at 5-9 years of age, as did boys in the high-income English-speaking region. In contrast, East Asia performed worse in ranking in 5-9 years of age than it did in 10-19 years.

Mean BMI (country)

The lowest age-standardised mean BMI over the 42 years of analysis among girls was that of Bangladeshi girls in 1975 (15.6 kg/m^2; 13.2-17.9), and among boys that of Ethiopian boys in 1975 (14.4 kg/m^2; 11.9-17.0) (Figures 2 and 3). Age-standardised mean BMI in 1975 was <21 kg/m^2 in every country, except for girls in American Samoa, who had an age-standardised mean BMI of 21.2 kg/m^2 (20.6-21.9). From 1975 to 2016, age-standardised mean BMI increased by >0.25 kg/m^2 per decade in 155 countries in girls, with the rise >1.0 kg/m^2 per decade in some countries in Polynesia and in Mexico (PP of being a true rise >0.9999); in boys, the rise was >0.25 kg/m^2 per decade in 189 countries and >1.0 kg/m^2 per decade in the Cook Islands. When subsets of the analysis period are considered, before the year 2000, age-standardised mean BMI increased in virtually every country. After 2000, there were non-significant declines in mean BMI in 29 countries for girls and 12 (mostly western) countries for boys.

In 2016, Ethiopia had the lowest age-standardised mean BMI for both sexes, 16.8 kg/m^2 (15.6-17.9) for girls and 15.5 kg/m^2 (14.4-16.6) for boys (Figures 2 and 3). Other countries with low BMI in both sexes in 2016 were Niger, Senegal, India, Bangladesh, Myanmar and Cambodia. At the other extreme, age-standardised mean BMI was >24 kg/m^2 in girls and boys in Cook Islands and Niue and girls in Samoa, which was greater than that for adults of the same sex in 36 countries for females and 59 countries for males. Age-standardised mean

BMI was between 22 and 24 kg/m^2 in another 11 countries for girls and 10 countries for boys, including in Polynesian/Micronesian islands, girls in Bahamas and Chile, and boys in Qatar and Kuwait.

The age-standardised mean BMI for children and adolescents and for adults were correlated in 1975 and 2016 (correlation coefficients = 0.80 and 0.85 for females and 0.92 and 0.89 for males) (Figure 4a). Changes in age-standardised mean BMI were moderately correlated between the two age groups before 2000 (correlation coefficient = 0.52 for females and 0.51 for males) but only weakly after 2000 (correlation coefficient = 0.14 for females and 0.21 for males) (Figure 4b). The decoupling of BMI trends in children and adolescents and those of adults is due to a set of distinct regional phenomena: Adults continued to gain weight in most high-income western countries, where children's and adolescents' mean BMI stopped rising or even declined slightly. In contrast, in Oceania, the rise in adult BMI seems to have plateaued, albeit at high levels, whereas children's and adolescents' BMI continues to rise. In Latin America and the Caribbean, there is more variation in the rate of BMI increase in children and adolescents than in adults.

In 1975, girls had higher age-standardised mean BMI than boys in most countries in sub-Saharan Africa, south Asia and the Middle East and north Africa, and lower age-standardised mean BMI than boys in many countries in Europe and Latin America and the Caribbean (Figure 5). Higher BMI in girls than boys was still seen in 2016 in many sub-Saharan African and south Asian countries. By contrast, the gender gap in BMI in the Middle East and north Africa reversed as boys gained more weight than girls. In Europe and Latin America, girls gained more weight than boys, removing the gender gap in BMI.

Prevalence of BMI categories (global and regional)

Over the 42 years of analysis, the global age-standardised prevalence of obesity in children and adolescents increased from 0.7% (0.4-1.2) to 5.6% (4.8-6.5) in girls, and from 0.9% (0.5-1.3) to 7.8% (6.7-9.1) in boys (Figure 6). Obesity increased in every region, with proportional rise being smallest in high-income regions (on average 30-50% per decade) and largest in Southern Africa (~ four folds per decade).

Globally, the prevalence of moderate and severe underweight changed less than the rise in obesity, from 9.2% (6.0-12.9) to 8.4% (6.8-10.1) in girls and from 14.8% (10.4-19.5) to 12.4% (10.3-14.5) in boys. The relatively small change in moderate and severe underweight prevalence at the global level, however, was partly due to faster population growth in regions where underweight prevalence is higher (e.g., the share of school-aged children and adolescents living in south Asia, where prevalence is highest, increased from 20.5% to 26.4% in girls, and 21.1% to 27.1% in boys from 1975 to 2016) while prevalence declined in most regions. The largest proportional decline in the prevalence of moderate and severe underweight occurred in Polynesia and Micronesia and in Southern Africa in both sexes, where prevalence declined by an average of up to one third per decade for girls and by about one fifth per decade for boys from 1975 to 2016 (Figure 6). There was a non-significant rise of about 6% per decade (PP = 0.6630) in underweight in girls in Southeast Asia. Nonetheless, in most regions the increase in the prevalence of overweight and obesity was larger than the decline in the prevalence of underweight (Figure 6), i.e. an increase in the width of the BMI distribution.

Regionally, moderate and severe underweight prevalence was highest in south Asia over the entire analysis period, at 20.3% (15.3-25.8) in girls and 28.6% (22.3-35.0) in boys in 2016,

having declined from 23.0% (13.9-33.6) and 37.8% (26.6-49.2), respectively, in 1975. Prevalence of obesity was highest in Polynesia and Micronesia in both sexes, 25.4% (16.8-35.2) in girls and 22.4% (13.4-32.9) in boys, followed by the high-income English-speaking region.

Prevalence of BMI categories (country)

Nationally, the prevalence of moderate and severe underweight was <1% among girls in 45 countries and among boys in 29 countries in 2016 (Figure 2). Prevalence was high throughout south Asia, reaching 22.7% (16.7-29.6) among girls and 30.7% (23.5-38.0) among boys in India. Obesity prevalence was between 1 and 2% among girls in Cambodia, Burkina Faso, Viet Nam, Ethiopia, India, Madagascar, Congo, Japan, Nepal, Niger and Chad. Among boys, it was <1% among boys in Uganda, Rwanda, Niger, Burkina Faso, Ethiopia, Guinea, Chad and Senegal and 1-2% in another 24 countries.

Conversely, obesity was >30% in girls in Nauru, the Cook Islands and Palau and boys in the Cook Islands, Nauru, Palau, Niue and American Samoa in 2016, and was also high, around or above 20%, in some countries in Polynesia and Micronesia, the Middle East and north Africa (e.g., Egypt, Kuwait, Qatar and Saudi Arabia), the Caribbean (Bermuda and Puerto Rico) as well as in the USA. In 1975, prevalence had been <20% in every country, and was >10% only in Nauru and Bermuda. From 1975 to 2016, obesity prevalence increased in every country, although the increase was statistically not significant in some high-income countries.

Number of underweight and obese people

The global number of moderately and severely underweight girls and boys peaked around the year 2000 and subsequently declined to 75 million (44-117) girls and 117 million (70-178)

boys in 2016, slightly higher than the 1975 number (Figure 7). In most regions, the number of moderately and severely underweight children and adolescents declined despite population growth. The exceptions were south Asia, southeast Asia and central, east and west Africa where population growth led to an increase in the absolute underweight burden, despite declining prevalence. 63% of the world's moderately and severely underweight girls (47.5 million) and 63% of underweight boys (73.6 million) lived in south Asia in 2016, substantially higher than its 27% share of the child/adolescent population.

The number of obese girls increased from 5 (1-14) million in 1975 to 50 (24-89) million in 2016. For boys, the number increased from 6 (1-19) million in 1975 to 74 (39-125) million in 2016. 73% of the increase in the number of obese children and adolescents was due to increase in prevalence of obesity, 3% due to population growth and changes in age structure of the child and adolescent population, and another 24% due to the interaction of the two (Appendix Figure 5). The regions with the largest absolute increase were east Asia, the Middle East and north Africa, south Asia and the high-income English-speaking region. The number of obese adult women increased from 69 (57-83) million in 1975 to 390 (363-418) million in 2016; for men, the number increased from 31 (24-39) million in 1975 to 281 (257-307) million in 2016.

Discussion

We have documented a worldwide rise in mean BMI and prevalence of obesity in school-aged children and adolescents from 1975 to 2016, with the rate of change in mean BMI moderately correlated with that of adults until around 2000 but only weakly correlated afterwards. The rise in children's and adolescents' mean BMI has plateaued, albeit at high levels, in many high-income countries since around 2000 but has accelerated in east, south

and southeast Asia. Despite this rise, globally more school-aged children and adolescents are moderately or severely underweight than obese. However, if post-2000 trends continue, child and adolescent obesity is expected to surpass moderate and severe underweight by 2022.

There are no prior global analyses of mean BMI and underweight in school-aged children and adolescents. For overweight and obesity, our results are not directly comparable with those of Ng et al.[3] because the two studies covered slightly different age ranges (2-19 years by Ng et al[3] compared to 5-19 years in ours), used different classification systems for defining overweight and obesity (WHO in our study versus International Obesity Task Force, IOTF, by Ng et al;[3] see below for comparison of the two definitions), and differed in criteria for including data (only measured height and weight in our study versus measured as well as self-reported by Ng et al[3]). Nonetheless, both studies concluded that the rise in excess weight in children and adolescents has plateaued in high-income countries but continues in low- and middle-income countries. The plateau in children's and adolescents' overweight and obesity in the high-income countries[33-35] and the relatively rapid transition from underweight to overweight and obesity in low- and middle-income nations[36,37] have also been noted in specific countries.

Our study is the first to make comparable estimates of mean BMI as well as the prevalence of a complete set of BMI categories with clinical and public health relevance – from underweight to obesity. We used an unprecedented amount of population-based data from the great majority of the world's countries, while maintaining a high standard of data quality and using only measured height and weight data to avoid the bias in self-reported data. Characteristics of data sources were verified through repeated checks by Collaborating Group members, and data that could be systematically different from the general population were

excluded, e.g., those from samples of students or of ever-married women in ages and countries with low school enrolment or marriage rates. Data were analysed according to a common protocol to obtain the required mean and prevalence by age and sex. Finally, we used a statistical model that used all available data while giving more weight to national data than subnational and community studies, and, as described in Methods, took into account the epidemiological features of outcomes such as BMI by using non-linear time trends and age associations, and differences between rural and urban populations.

Despite using the most comprehensive global database of human anthropometry to date, some countries and regions had fewer data sources, especially those in the Caribbean, Polynesia and Micronesia, Melanesia and central Asia. The scarcity of data is reflected in wider uncertainty intervals of our estimates for these countries and regions. Of sources with data on children and adolescents, 39.9% had data in 5-9 years of age, 50.3% in 10-14 years, and 78.9% in 15-19 years. Many sources with data on children aged 5-9 years were school-based measurement studies in high-income countries where school enrolment is virtually universal. The relative paucity of data on children aged 5-9 years restricted our capacity to compare trends in this age group with those of adolescents, despite some evidence from high-income countries that trends are somewhat different before and after ten years of age.[34] Finally, although the age-dependent cut-offs for defining overweight and obesity in children and adolescents reflect natural growth in these ages, they are based on BMI distributions in a reference population, and not explicitly selected to represent optimal BMI levels for health in prospective studies, as done for adults, or optimal nutritional status, as done for children under five years of age. The reference population used by the WHO,[19] and the cut-offs for defining overweight and obesity, differ from those used by IOTF[38,39] and the US Centers for Disease Control and Prevention. Specifically, in the WHO classification, a BMI of 30 kg/m^2

at ages 18-19 years corresponds to 2SD (i.e. ~97.5[th] percentile) from the median of reference population;[19] in the IOTF classification, a BMI of 30 kg/m^2 at age 18 years corresponds to 98.6[th] percentile for girls and 98.9[th] percentile for boys.[39] While at 18 years the two systems classify the same children as obese, at younger ages a smaller proportion are classified as obese according to the IOTF definition compared with the WHO definition (see Figure 6 in Cole and Lobstein[39]). For this reason, comparisons of overweight and obesity prevalence based on the three definitions[37,40-43] found that prevalence using the WHO classification was higher than those of IOTF and CDC, but that trends are similar.

The effectiveness of interventions for overweight and obesity in children and adolescents has been reviewed in a number of systematic reviews and modelling studies,[7,44-48] but how they are selected for implementation and their post-implementation effects at the population level are rarely evaluated.[49] For this reason, there is no systematic information on the determinants of the divergent trends in BMI in children and adolescents and in adults, be it on food environments and behaviours or on policies that affect them. The plateauing of children's and adolescents' BMI in high-income countries as adult BMI continues to increase may be due to specific initiatives by governments, community groups, schools, and notable individuals that have increased public awareness about overweight and obesity in children, leading to changes in nutrition and activity that are sufficient to curb the rise in mean BMI.

A general feature of current policies that target overweight and obesity in children and adolescents in high-income countries is a reluctance to use taxes and industry regulations to change eating and drinking behaviours.[16,50] Some middle-income countries are also adopting policies to combat overweight and obesity in children and adolescents, in some cases with a stronger emphasis on regulation and taxes than in high-income countries.[49] While momentum

may be gathering to use taxes and regulations to reduce the consumption of energy-dense foods, few policies and programmes attempt to make healthy foods such as whole grains and fresh fruits and vegetables more affordable through targeted price subsidies, (conditional) cash transfers and food vouchers, or healthy school meals.[51] Unaffordability of healthy food options not only leads to social inequalities in overweight and obesity,[52,53] but may also limit the impacts of policies that target unhealthy foods. Finally, efforts on population-based prevention of overweight and obesity in children and adolescents should be matched with enhancing access to healthcare interventions for weight management and for reducing the adverse effects of obesity, including intensive behavioural therapy to change diet and exercise; screening for and management of hypertension, glucose intolerance, dyslipidaemia, and abnormal liver function in obese children and adolescents; and in extreme cases bariatric surgery.[8,54,55]

Our finding that the number of school-aged children and adolescents who are moderately or severely underweight remains larger than those who are obese demonstrates the continued need for policies that enhance food security in poor countries and households, especially in South Asia. Yet the experiences of east Asia and Latin America and the Caribbean show that the transition from underweight to overweight and obesity can be rapid, and overwhelm the national capacity needed to engender a healthy transition. More broadly, in an unhealthy nutritional transition, an increase in nutrient-poor, energy-dense foods can lead to stunted growth along with weight gain in children, adolescents and adults, resulting in higher BMI and worse health outcomes throughout the life-course. Therefore, the findings from our comprehensive analysis of trends in underweight as well as overweight and obesity highlights the disconnect between the global dialogue on overweight and obesity, which has largely overlooked the remaining undernutrition burden, and the initiatives and donors focusing on

undernutrition that have paid little attention to the looming burden of overweight and obesity, itself a risk factor for adverse pregnancy outcomes.[6] The SDGs, which address poverty, education, nutrition, and universal health coverage, provide an opportunity for integrating policies that coherently address underweight and overweight in children and adolescents, and their health consequences, effectively and equitably. Doing so would require commitment from national and international agencies and donors for replacing the fragmented focus with an integrated approach.

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Contributions

ME designed the study and oversaw research. Members of the Country and Regional Data Group collected and reanalysed data, and checked pooled data for accuracy of information about their study and other studies in their country. MDC, VB, HB, BZ led data collection. JB led the statistical analysis and prepared results. Members of the Pooled Analysis and Writing Group contributed to study design, collated data, checked all data sources in consultation with the Country and Regional Data Group, analysed pooled data, and prepared results. ME wrote the first draft of the report with input from other members of Pooled Analysis and Writing Group. Members of Country and Regional Data Group commented on draft report. The authors alone are responsible for the views expressed in this Article and they do not necessarily represent the views, decisions, or policies of the institutions with which they are affiliated.

Conflict of interest

ME reports a charitable grant from the AstraZeneca Young Health Programme, and personal fees from Prudential, Scor and Third Bridge, outside the submitted work.

Figure 1: Trends in age-standardised mean body mass index (BMI) by sex and region in school-aged children and adolescents (aged 5-19 years) and adults (aged 20 years and older). The lines show the posterior mean estimates and the shaded area shows the 95% credible interval. See Appendix Figure 6 for trends by country.

Figure 2: Age-standardised mean BMI, prevalence of obesity (BMI >2SD) and prevalence of moderate and severe underweight (BMI<-2SD) by sex and country in 2016 in school-aged children and adolescents (aged 5-19 years). See Appendix Figure 7 for results for adults.

Figure 3: Age-standardised mean BMI in children and adolescents in 1975 and 2016. Each line shows one country.

Figure 4: Comparison of (A) age-standardised mean BMI in school-aged children and adolescents (aged 5-19 years) and in adults (aged 20 years and older) in 1975 and 2016 and (B) change in age-standardised mean BMI in school-aged children and adolescents and in adults in the periods 1975-2000 and 2000-2016. Each point shows one country.

Figure 5: Comparison of age-standardised mean BMI in 1975 and 2016, and change per decade in age-standardised mean BMI from 1975 to 2016, in girls and boys. Each point shows one country.

Figure 6: Trends in age-standardised prevalence of BMI categories for school-aged children and adolescents (aged 5-19 years) by region. See Appendix Figure 8 for results for adults.

Figure 7: Trends in the number of obese and moderately/severely underweight school-aged children and adolescents (aged 5-19 years) by region. See Appendix Figure 9 for results for adults.

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