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Health Effects of Overweight and Obesity in 195 Countries over 25 Years

The GBD 2015 Obesity Collaborators*

ABSTRACT

BACKGROUND

Although the rising pandemic of obesity has received major attention in many countries, the effects of this attention on trends and the disease burden of obesity remain uncertain.

METHODS

We analyzed data from 68.5 million persons to assess the trends in the prevalence of overweight and obesity among children and adults between 1980 and 2015. Using the Global Burden of Disease study data and methods, we also quantified the burden of disease related to high body-mass index (BMI), according to age, sex, cause, and BMI in 195 countries between 1990 and 2015.

RESULTS

In 2015, a total of 107.7 million children and 603.7 million adults were obese. Since 1980, the prevalence of obesity has doubled in more than 70 countries and has continuously increased in most other countries. Although the prevalence of obesity among children has been lower than that among adults, the rate of increase in childhood obesity in many countries has been greater than the rate of increase in adult obesity. High BMI accounted for 4.0 million deaths globally, nearly 40% of which occurred in persons who were not obese. More than two thirds of deaths related to high BMI were due to cardiovascular disease. The disease burden related to high BMI has increased since 1990; however, the rate of this increase has been attenuated owing to decreases in underlying rates of death from cardiovascular disease.

CONCLUSIONS

The rapid increase in the prevalence and disease burden of elevated BMI highlights the need for continued focus on surveillance of BMI and identification, implementation, and evaluation of evidence-based interventions to address this problem. (Funded by the Bill and Melinda Gates Foundation.)

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A Quick Take is available at NEJM.org

The prevalence of overweight and obesity is increasing worldwide.[1] Epidemiologic studies have identified high body-mass index (BMI, the weight in kilograms divided by the square of the height in meters) as a risk factor for an expanding set of chronic diseases, including cardiovascular disease,[2,3] diabetes mellitus, chronic kidney disease,[2] many cancers,[4] and an array of musculoskeletal disorders.[5,6] As the global health community works to develop treatments and prevention policies to address obesity, timely information about levels of high BMI and health effects at the population level is needed.

In recent years, increasing efforts have been made to assess the trends in BMI within and across nations.[7,8] Other studies have quantified the potential effects of high BMI on a variety of health outcomes.[2,4] These efforts, while useful, did not consider the relationship of high BMI with broader socioeconomic development; they also excluded many data sources, focused exclusively on adults, inadequately captured the skewed distribution of BMI, did not capture emerging evidence on additional outcomes, and did not assess the effect of epidemiologic and demographic transition on disease burden. The BMI that is associated with the lowest risk of death has also been questioned.[9,10]

To address these gaps in knowledge, we systematically evaluated the trends in the prevalence of overweight and obesity as well as the patterns of deaths and disability-adjusted life-years related to high BMI, according to age and sex, in 195 countries. This analysis supersedes all previous results from the Global Burden of Disease study with respect to high BMI by comprehensively reanalyzing all data from 1990 through 2015 using consistent methods and definitions.

Methods

Prevalence and Disease Burden of Overweight and Obesity

We systematically estimated the prevalence of overweight and obesity among children (<20 years of age) and adults between 1980 and 2015. Using the comparative-risk-assessment approach from the Global Burden of Disease study, we also quantified the burden of disease related to high BMI during the period from 1990 through 2015. The burden of disease was assessed by deaths and disability-adjusted life-years, a composite metric computed as the sum of years lived with disability and years of life lost due to high BMI. In this analysis, we used the distribution of BMI according to age, sex, country, and year; the effect size of the change in BMI on disease end points; the BMI associated with the lowest risk of death from all causes; and disease-specific mortality and morbidity according to age, sex, country, and year.

Global Distribution of BMI

We systematically searched Medline for studies that provide nationally or subnationally representative estimates of BMI, overweight, or obesity among children or adults. We included studies if they used standard cutoff points of BMI to define overweight (BMI, 25 to 29) and obesity (BMI, ≥30) among adults or standards of the International Obesity Task Force to define overweight and obesity among children. The search terms, selection criteria, and flow diagrams of screening are provided in the Methods section in the Supplementary Appendix, available with the full text of this article at NEJM.org. In addition, we searched the Global Health Data Exchange (http://ghdx.healthdata.org) for multicountry survey programs, national surveys, and longitudinal studies that provide self-reported or measured data on height and weight for children or adults.

With respect to data regarding adults, we identified 1276 unique data sources (855 measured and 421 self-report) from 176 countries that provide data on BMI, 1333 sources (802 measured and 531 self-report) from 176 countries that provide data on overweight, and 1514 sources (713 measured and 801 self-report) from 174 countries that provide data on obesity. With respect to data regarding children, we identified 1211 unique data sources (800 measured and 411 self-report) from 173 countries that provide data on BMI, 1236 sources (832 measured and 404 self-report) from 174 countries that provide data on overweight, and 1437 sources (928 measured and 509 self-report) from 175 countries that provide data on obesity. Using mixed-effects linear-regression models, we separately estimated and corrected for self-reporting bias among men and women according to geographic region and age group. We characterized the age and sex patterns for BMI, overweight, and obesity and applied these patterns to split aggregated data into

5-year age groups according to sex (see the Methods section in the Supplementary Appendix).

We used spatiotemporal Gaussian process regression to estimate the mean prevalence of obesity and overweight.[11] To improve our estimates in data-sparse countries, we tested a wide range of covariates with plausible relationships to overweight and obesity. We selected three country-level covariates with best fit and coefficients in the expected direction, as have been used in other studies.[8] These factors included 10-year lag-distributed energy intake (i.e., time-weighted average of daily energy intake) per capita, the absolute latitude of the country, and the proportion of persons living in urban areas. To estimate the mean BMI, we first used mixed-effects linear regression to characterize the relationship between BMI, overweight, and obesity in sources containing information on all three measures. We applied the coefficients of this regression to the prevalence of overweight and of obesity generated through spatiotemporal Gaussian process regression to estimate the mean BMI for each country, according to age, sex, and year. Among the 195 countries and territories that are included in the present study, data regarding overweight, obesity, or BMI were unavailable for only 8: Antigua and Barbuda, Bermuda, Brunei, Northern Mariana Islands, Saint Vincent and the Grenadines, the Bahamas, Turkmenistan, and Venezuela. The estimates in these countries were constructed purely from the covariates used in the estimation of the linear model and the weighted and smoothed residuals from data for neighboring countries.

To identify the appropriate distribution of BMI at the population level, we examined how various distributions (i.e., log-normal, gamma, inverse Gaussian, and beta) approximated the distribution of actual data from national surveys in six countries; the best fit was provided by the beta distribution.[12] We characterized the shape of the beta distribution on the basis of the mean BMI and the prevalence of overweight and obesity in each country according to age, sex, and year. Details of this approach have been described previously.[12]

EFFECT OF HIGH BMI ON HEALTH OUTCOMES

We used Bradford Hill's criteria for causation and the evidence-grading criteria of the World Cancer Research Fund to systematically evaluate epidemiologic evidence supporting the causal relationship between high BMI and various disease end points among adults 25 years of age or older.[13] We found convincing or probable evidence for an association with 20 health outcomes (Table S1 in the Supplementary Appendix). For each outcome, we obtained the relative risk from a dose–response meta-analysis of prospective observational studies (Table S2 in the Supplementary Appendix). Using pooled analyses of prospective cohort studies, we estimated the relative risk associated with a change of five units of BMI in 5-year age groups for ischemic heart disease, ischemic stroke, hemorrhagic stroke, hypertensive heart disease, and diabetes mellitus. For breast cancer, we calculated the relative risk for premenopausal and postmenopausal women according to region (as specified in the Global Burden of Disease study) because of evidence that overweight and obesity have a protective effect against breast cancer in premenopausal women in all countries except for the Asia–Pacific regions,[14,15] whereas a positive association between high BMI and the incidence of postmenopausal breast cancer has been observed worldwide.[15]

THE LOWEST-RISK BMI

We used the most recent pooled analysis of prospective observational studies to determine the BMI associated with the lowest overall risk of death.[9] To address the limitations of previous studies on this topic, which have included residual confounding among smokers and reverse causation due to preexisting chronic diseases,[10] the analysis was restricted to never-smokers without identified chronic diseases who survived 5 years after recruitment. The lowest overall risk of death was observed for a BMI of 20 to 25.

STATISTICAL ANALYSIS

To quantify the burden of disease related to high BMI for each disease end point, we calculated the population attributable fraction according to country, age, sex, and year.[16] We computed the numbers of deaths and disability-adjusted life-years related to high BMI for each country, according to age, sex, year, and cause, by multiplying the population attributable fraction by the total number of deaths or disability-adjusted life-years, as estimated in the Global Burden of Disease study for that country, age, sex, year, and cause. We calculated the total disease burden

related to high BMI as the sum of disease-specific burdens. To understand where in the distribution of BMI most of the burden occurs, we estimated population attributable fractions for three ranges of BMI (20 to 24, 25 to 29, and ≥30) and for five groups of disease end points (cardiovascular disease, diabetes mellitus, chronic kidney disease, cancers, and musculoskeletal disorders).

Using the methods developed by Das Gupta,[17] we broke down the change in the numbers of deaths and the numbers of disability-adjusted life-years that are attributed to high BMI between population growth, population age structure, risk exposure to high BMI, and rates of risk-deleted mortality and disability-adjusted life-years. (Risk-deleted rates are the burden of disease in the absence of the risk factor — for example, rates of death from cardiovascular disease that would have been observed if everyone had been at the lowest-risk BMI.)

We computed 95% uncertainty intervals for all results using Monte Carlo simulations, keeping 1000 draws of each quantity of interest to propagate uncertainty into final estimates. The model included uncertainty from examination surveys, the relative risks for each outcome from the pooled analyses or meta-analyses of cohorts, the lowest-risk BMI, and the number of deaths and disability-adjusted life-years estimated for each country, age, sex, year, and outcome from the Global Burden of Disease 2015 study. According to the methods outlined in that study, we used a sociodemographic index (SDI) — a summary measure of lag-distributed income per capita, average educational attainment among persons over the age of 15 years, and total fertility rate — to position countries on the development continuum. We then generated quintiles of SDI to categorize countries as low, low-middle, middle, high-middle, and high development level (Table S3 in the Supplementary Appendix).[13]

RESULTS

PREVALENCE OF OBESITY (1980–2015)

Global Level

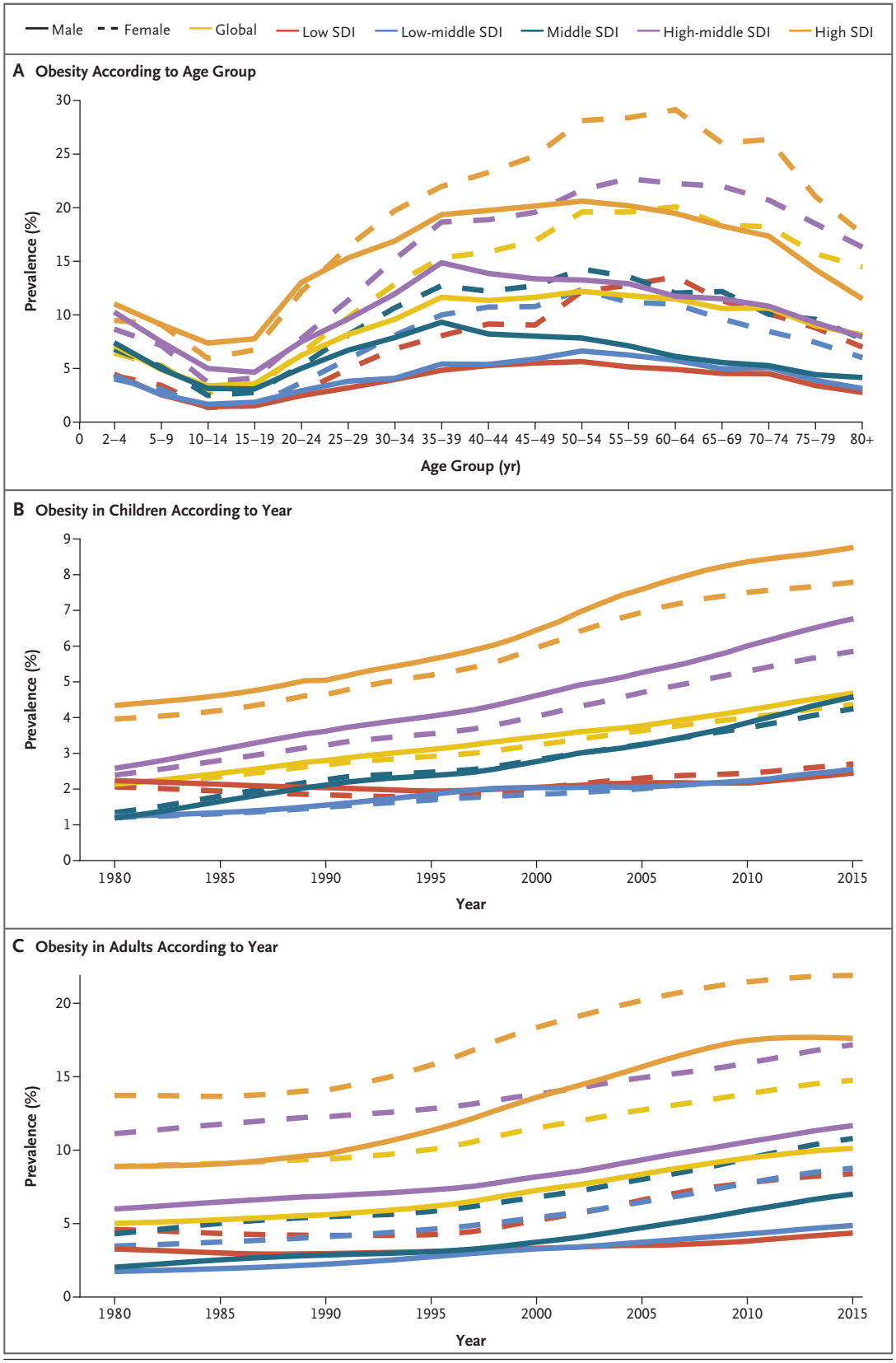
In 2015, we estimated that 107.7 million children (uncertainty interval, 101.1 to 115.1) and 603.7 million adults (uncertainty interval, 592.9 to 615.6) were obese worldwide. The overall prevalence of obesity was 5.0% among children and 12.0% among adults. Among adults, the prevalence of obesity was generally higher among women than among men in all age brackets (Fig. 1). The peak in the prevalence of obesity was observed between the ages of 60 and 64 years among women and between the ages of 50 and 54 years among men. The rates of increase in obesity between 1980 and 2015 did not differ significantly between women and men in any age bracket; for both groups, the rates of increase were highest in early adulthood. Among children, the prevalence of obesity in 2015 decreased with age until the age of 14 years and then increased; no sex differences were observed in obesity prevalence before the age of 20 years. Between 1980 and 2015, the rates of increase in global childhood obesity were equal for boys and girls in all age brackets.

Figure 1 (facing page). Prevalence of Obesity at the Global Level, According to Sociodemographic Index (SDI).

Shown is the age-specific prevalence of obesity at the global level and according to SDI quintile in 2015 (Panel A) and age-standardized prevalence trends at the global level and according to SDI quintile from 1980 through 2015 among children (Panel B) and adults (Panel C).

SDI Level

In 2015, at all SDI levels and for all age groups, the prevalence of obesity was generally higher for women than for men, with the highest prevalence among women between the ages of 60 to 64 years living in countries with a high SDI (Fig. 1). In general, the prevalence of obesity among both women and men increased with the increase in the SDI across all age groups. An exception was the prevalence of obesity among women living in countries with a low SDI, since after the age of 55 years, the prevalence was higher than that observed for women in countries with a low-middle SDI (Fig. 1). During the period from 1980 to 2015, the most rapid relative increase in the prevalence of obesity occurred among men between the ages of 25 and 29 years who were living in countries with a low-middle SDI — from 1.1% (uncertainty interval, 0.9 to 1.5) in 1980 to 3.8% (95% uncertainty interval, 3.1 to 4.8) in 2015. During the same time period, the prevalence of obesity increased by a factor of 1.7 among both men and women in countries with a low-middle SDI.



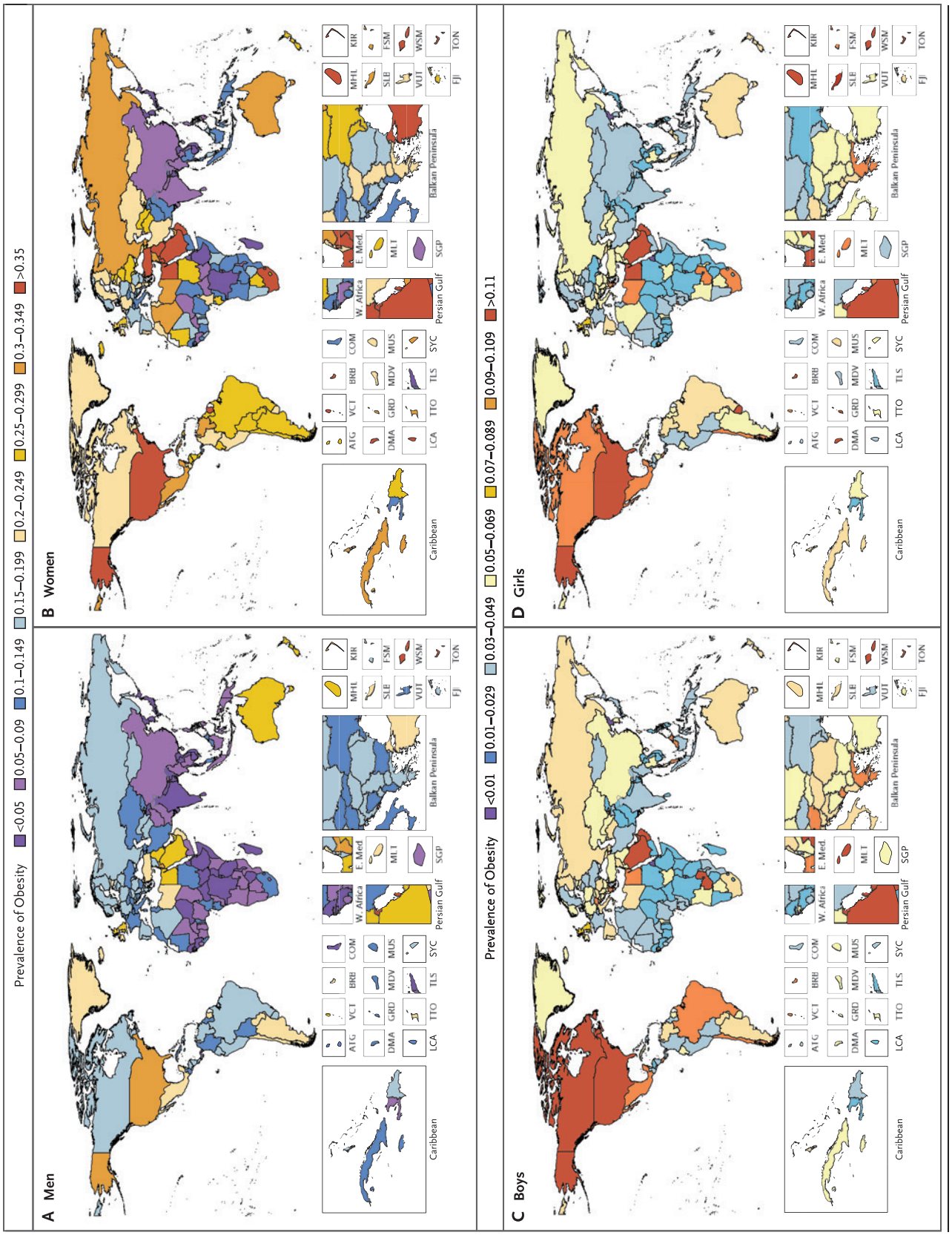


Figure 2 (facing page). Age-Standardized Prevalence of Obesity Worldwide in 2015.

Shown is the age-standardized prevalence of obesity among adults (Panel A [men] and Panel B [women]) and among children (Panel C [boys] and Panel D [girls]) in 2015. Children were defined as being under the age of 20 years. Values for prevalence are provided as decimals. ATG denotes Antigua and Barbuda, BRB Barbados, COM Comoros, DMA Dominica, E. Med. Eastern Mediterranean, FJI Fiji, FSM Federated States of Micronesia, GRD Grenada, KIR Kiribati, LCA Saint Lucia, MDV Maldives, MHL Marshall Islands, MLT Malta, MUS Mauritius, SGP Singapore, SLB Solomon Islands, SYC Seychelles, TLS Timor-Leste, TON Tonga, TTO Trinidad and Tobago, VCT Saint Vincent and the Grenadines, VUT Vanuatu, W. Africa Western Africa, and WSM Samoa.

Among children, the prevalence of obesity was greater in countries with higher SDI levels (Fig. 1). At most SDI levels, the prevalence of obesity was lowest among both boys and girls between ages of 10 and 14 years. In countries with high and high-middle SDI levels, the prevalence was generally greater among boys than among girls, although this difference reversed beginning with late adolescence (Fig. 1). Between 1980 and 2015, there was a significant relative increase of 20.0% (95% uncertainty interval, 5.5 to 35.3) in the prevalence of obesity in countries with a low SDI among both girls and boys. During that period, the highest rates of increase were observed in countries with a middle SDI among both girls and boys.

National Level

The prevalence of obesity among children and adults has doubled in 73 countries since 1980 and has shown a continuous increase in most other countries. Although the prevalence of childhood obesity has been lower than the prevalence of adult obesity, the rate of increase in childhood obesity in many countries has been greater than the rate of increase in adult obesity. The estimated age-standardized prevalence of overweight and obesity among children and adults for all 195 countries and territories is provided in Table S3 in the Supplementary Appendix. A complete data set of all results for each country according to age, sex, and year is available on the Global Health Data Exchange website (http://ghdx.healthdata.org/), and an interactive data visualization of the prevalence of overweight and obesity is provided online (https://vizhub.healthdata.org/obesity/). Here we highlight the findings related to obesity in the most populous countries (Fig. 2).

In 2015, among the 20 most populous countries, the highest level of age-standardized adult obesity was observed in Egypt (35.3%; 95% uncertainty interval, 33.6 to 37.1), and the highest level of age-standardized childhood obesity was observed in the United States (12.7%; 95% uncertainty interval, 12.2 to 13.2). The prevalence was lowest among adults in Vietnam (1.6%; 95% uncertainty interval, 1.4 to 2.0) and among children in Bangladesh (1.2%; 95% uncertainty interval, 0.9 to 1.7). Between 1980 and 2015, the age-standardized prevalence of obesity increased by a factor of 2 or more in 13 of the 20 countries; only the Democratic Republic of Congo had no increase (Figs. S1 and S2 in the Supplementary Appendix). In 2015, China and India had the highest numbers of obese children, whereas the United States and China had the highest numbers of obese adults.

BURDEN OF DISEASE RELATED TO HIGH BMI (1990–2015)

Global Level

In 2015, high BMI contributed to 4.0 million deaths (95% uncertainty interval, 2.7 to 5.3), which represented 7.1% (95% uncertainty interval, 4.9 to 9.6) of the deaths from any cause; it also contributed to 120 million disability-adjusted life-years (95% uncertainty interval, 84 to 158), which represented 4.9% (95% uncertainty interval, 3.5 to 6.4) of disability-adjusted life-years from any cause among adults globally. A total of 39% of the deaths and 37% of the disability-adjusted life-years that were related to high BMI occurred in persons with a BMI of less than 30 (Fig. 3).

Cardiovascular disease was the leading cause of death and disability-adjusted life-years related to high BMI and accounted for 2.7 million deaths (95% uncertainty interval, 1.8 to 3.7) and 66.3 million disability-adjusted life-years (95% uncertainty interval, 45.3 to 88.5) (Table S4 in the Supplementary Appendix). Globally, 41% of BMI-related deaths and 34% of BMI-related disability-adjusted life-years were due to cardiovascular disease among obese persons. Diabetes was the second leading cause of BMI-related deaths in 2015 and contributed to 0.6 million deaths (95% uncertainty interval, 0.4 to 0.7) and

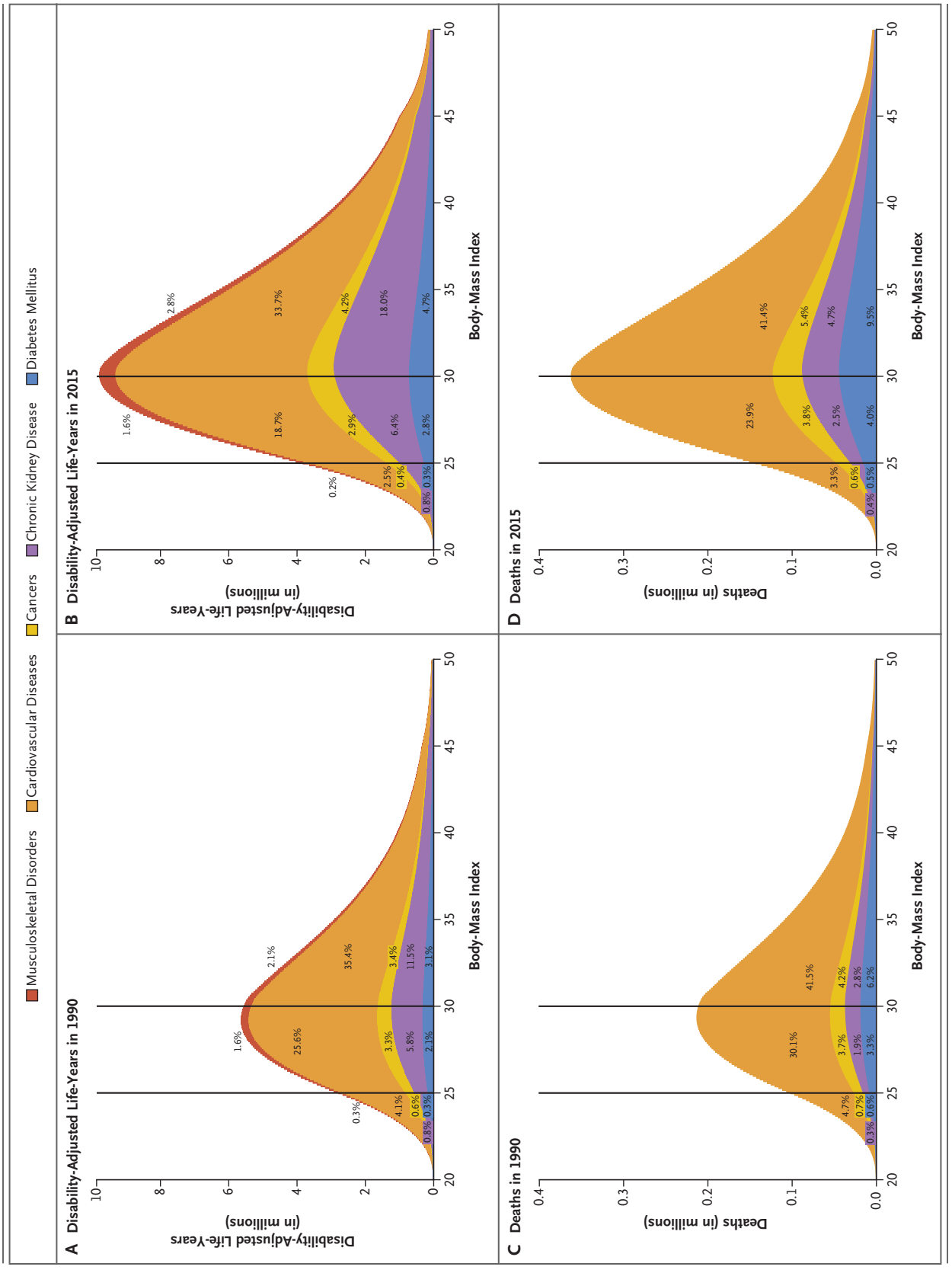


Figure 3 (facing page). Global Disability-Adjusted Life-Years and Deaths Associated with a High Body-Mass Index (1990–2015).

Shown are the number of global disability-adjusted life-years (in millions) related to a high body-mass index (BMI) among adults according to the cause and the level of BMI in 1990 (Panel A) and in 2015 (Panel B) and the number of global deaths (in millions) related to high BMI in 1990 (Panel C) and in 2015 (Panel D). The two vertical lines mark the BMI thresholds for overweight (25 to 29) and for obesity (≥30). The percentages indicate the proportion of the total number of disability-adjusted life-years or deaths that were contributed by each of the listed disorders.

30.4 million disability-adjusted life-years (95% uncertainty interval, 21.5 to 39.9); among all BMI-related deaths that were due to diabetes, 9.5% occurred at a BMI of 30 or more and 4.5% occurred at a BMI of less than 30. Chronic kidney disease was the second leading cause of BMI-related disability-adjusted life-years in 2015; 18.0% of disability-adjusted life-years occurred at a BMI of 30 or more and 7.2% at a BMI of less than 30. Chronic kidney disease and cancers each accounted for less than 10% of all BMI-related deaths in 2015, whereas cancers, diabetes, and musculoskeletal disorders each contributed less than 10% of BMI-related disability-adjusted life-years (Fig. 3).

High BMI also accounted for 28.6 million years lived with disability (95% uncertainty interval, 17.8 to 41.4), which accounted for 3.6% (95% uncertainty interval, 2.7 to 4.6) of years lived with disability due to any cause globally. Diabetes was the leading cause of years lived with disability related to BMI (17.1 million; 95% uncertainty interval, 10.6 to 24.4), followed by musculoskeletal disorders (5.7 million; 95% uncertainty interval, 3.4 to 8.8) and cardiovascular disease (3.3 million; 95% uncertainty interval, 2.0 to 4.9).

From 1990 through 2015, there was a relative increase of 28.3% in the global rate of death related to high BMI, from 41.9 deaths per 100,000 population in 1990 to 53.7 deaths per 100,000 population in 2015. However, there was no significant change in age-standardized rates of death during this period, with a rate of 64.0 (95% uncertainty interval, 41.7 to 89.7) per 100,000 population in 1990 and 60.2 (95% uncertainty interval, 41.4 to 81.5) per 100,000 population in 2015. Similarly, during the same period, there was a relative increase of 35.8% in the rate of BMI-related disability-adjusted life-years, from 1200 per 100,000 population to 1630 per 100,000 population, whereas there was no significant change in age-standardized rates. Globally, the increases in BMI-related deaths and disability-adjusted life-years due to population growth, population aging, and increasing risk exposure were partially offset by reductions in underlying rates of death and disability-adjusted life-years (Fig. 4). Of the disease end points that

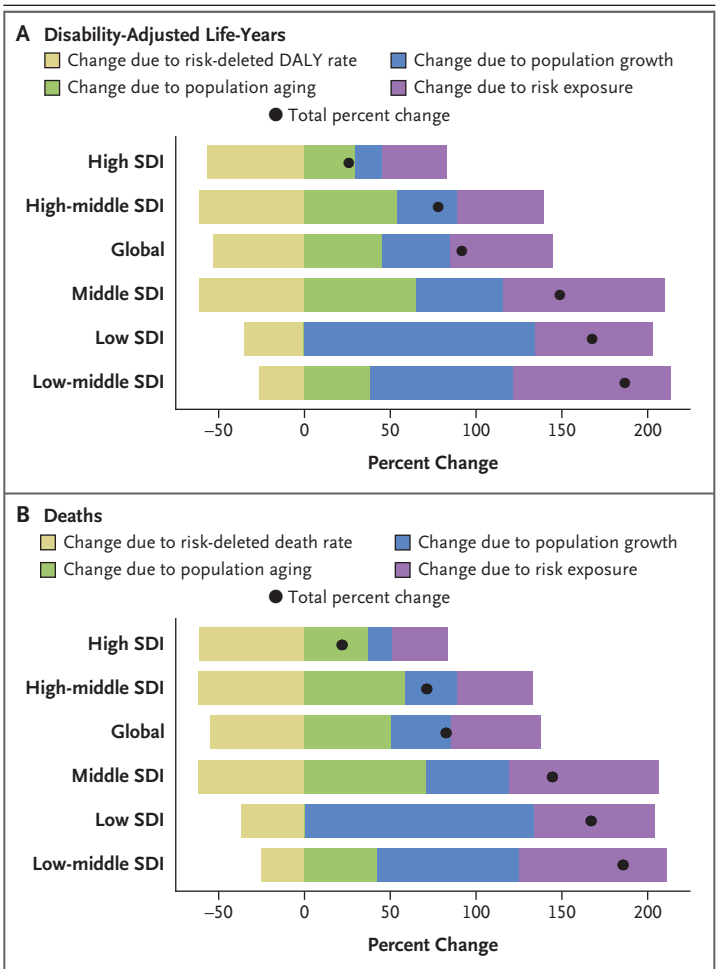


Figure 4. Percent Changes and Drivers of Change in Disability-Adjusted Life-Years and Deaths at the Global Level, According to SDI (1990–2015).

Shown is a breakdown in percent changes from 1990 to 2015 in disability-adjusted life-years (DALYs) from any cause (Panel A) and deaths (Panel B) related to a high BMI, according to whether the changes were attributed to population aging, population growth, exposure to high BMI, or risk-deleted rates of disability-adjusted life-years or death. (Risk-deleted rates are the underlying rates of disease that would have occurred in the absence of the risk factor.) The percent changes have been estimated according to SDI as well as at the global level. The black circles indicate the total percent change.

were considered in this study, decreases in risk-deleted rates of death from cardiovascular disease contributed the most to this pattern. Changes that were due to the risk of exposure to elevated BMI and aging of the population were roughly equal in terms of their contribution to the percent changes in BMI-related deaths and disability-adjusted life-years globally from 1990 through 2015.

SDI Level

In 2015, the age-standardized rates of BMI-related deaths and disability-adjusted life-years were greatest in countries with high-middle SDI levels, with a rate of death of 68.1 (95% uncertainty interval, 47.1 to 91.6) per 100,000 population and a rate of disability-adjusted life-years of 1890 (95% uncertainty interval, 1330 to 2460) per 100,000 population. The rates of both measures were lowest in countries with high SDI levels, with a rate of death of 52.6 (95% uncertainty interval, 38.7 to 67.9) per 100,000 population and a rate of disability-adjusted life-years of 1530 (95% uncertainty interval, 1160 to 1920) per 100,000 population. The rate of BMI-related deaths increased between 1990 and 2015 at all SDI levels, with the highest observed rate of 90.6 (95% uncertainty interval, 65.8 to 117.3) per 100,000 population occurring in countries with a high SDI in 2005. The age-standardized rates of death in countries with high or high-middle SDI decreased between 1990 and 2015; in the lowest quintiles of SDI, age-standardized BMI-related rates of death increased. With increasing SDI levels, the contribution of risk-deleted mortality to the percent change in BMI-related deaths increased, whereas the contribution of population growth to the percent change in BMI-related deaths decreased (Fig. 4). The contribution of risk exposure to the percent change in BMI-related deaths was also generally inversely related to the SDI. Patterns in the breakdown of the sources of change in BMI-related disability-adjusted life-years were parallel to those observed for mortality. In a disease-specific breakdown, risk-deleted mortality and disability-adjusted life-years showed a declining trend for most causes across all SDI levels (Table S5 in the Supplementary Appendix). The largest decreases in the risk-deleted rates of death and disability-adjusted life-years were observed for cardiovascular disease, whereas cancers and musculoskeletal disorders showed the least decline.

National Level

In 2015, among the 20 most populous countries, the highest rates of BMI-related death and disability-adjusted life-years were observed in Russia, and the lowest rates were observed in the Democratic Republic of Congo (Fig. S3 in the Supplementary Appendix). Between 1990 and 2015, the greatest percent changes in age-standardized BMI-related deaths and disability-adjusted life-years occurred in Bangladesh, with relative increases of 133.6% (95% uncertainty interval, 66.3 to 265.7) and 139.4% (95% uncertainty interval, 77.2 to 273.0), respectively. During the same period, Turkey had the largest significant decrease in age-standardized BMI-related burden, with a decrease of 43.7% (95% uncertainty interval, 36.9 to 49.8) in deaths and 37.2% (95% uncertainty interval, 29.9 to 44.0) in disability-adjusted life-years (Table S6 in the Supplementary Appendix).

DISCUSSION

In our systematic evaluation of the health effects of high BMI, we found that excess body weight accounted for about 4 million deaths and 120 million disability-adjusted life-years worldwide in 2015. Nearly 70% of the deaths that were related to high BMI were due to cardiovascular disease, and more than 60% of those deaths occurred among obese persons. The prevalence of obesity has increased during the past three decades and at a faster pace than the related disease burden. However, both the trend and magnitude of the BMI-related disease burden vary widely across countries.

Among the leading health risks that were assessed in the Global Burden of Disease 2015 study, high BMI continues to have one of the highest rates of increase. Across levels of development, the prevalence of obesity has increased over recent decades, which indicates that the problem is not simply a function of income or wealth.[13] Changes in the food environment and food systems are probably major drivers.[18] Increased availability, accessibility, and affordability of energy-dense foods, along with intense marketing of such foods, could explain excess energy intake and weight gain among different populations.[18] The reduced opportunities for physical activity that have followed urbanization and other changes in the built environment have also been considered as potential drivers; however,

these changes generally preceded the global increase in obesity and are less likely to be major contributors.[18]

During the past decade, researchers have proposed a range of interventions to reduce obesity.[19] Among such interventions are restricting the advertisement of unhealthy foods to children, improving school meals, using taxation to reduce consumption of unhealthy foods and providing subsidies to increase intake of healthy foods, and using supply-chain incentives to increase the production of healthy foods.[19] However, the effectiveness, feasibility of widespread implementation, and sustainability of such interventions need to be evaluated in various settings. In recent years, some countries have started to implement some of these policies,[1] but no major population success has yet been shown. Many of the countries with the highest increases in the prevalence of obesity are those that have a low or middle SDI and simultaneously have high rates of other forms of malnutrition. These countries generally have limited financial resources for nutrition programs and mostly rely on external donors whose programs often preferentially target undernutrition; consequently, food security frequently takes precedence over obesity in these countries.[20] In 2013, the World Health Organization (WHO) called for zero increase in the prevalence of overweight among children and in the prevalence of obesity among adults.[21] However, given the current pace of increase and the existing challenges in implementing food policies, achieving this goal appears unlikely in the near future.

Our study showed a greater increase in the rate of exposure to high BMI than in the rate of the related disease burden. This difference was driven mainly by the decline in risk-deleted mortality, particularly for cardiovascular disease; factors such as improved treatment or changes in other risks have resulted in decreases in the rate of cardiovascular disease despite increases in BMI. Existing evidence-based policies, even if fully implemented, are unlikely to rapidly reduce the prevalence of obesity. Clinical interventions, however, have proved to be effective in controlling high levels of systolic blood pressure, cholesterol, and fasting plasma glucose — the major risk factors for cardiovascular disease.[22] The expanded use of such interventions among overweight and obese persons could effectively reduce the disease burden related to high BMI. A recent pooled cohort analysis involving 1.8 million participants showed that nearly half the excess risk for ischemic heart disease and more than 75% of the excess risk for stroke that was related to high BMI were mediated through a combination of raised levels of blood pressure, total serum cholesterol, and fasting plasma glucose.[23] Together, these findings suggest that clinical interventions to reduce the underlying rate of cardiovascular disease could substantially reduce the burden of disease related to high BMI, although maintaining a normal body weight remains necessary to achieve full benefit.

Globally, 39% of deaths and 37% of disability-adjusted life-years that were related to high BMI occurred among nonobese persons. Although some studies have suggested that overweight is associated with a lower risk of death from any cause than is a normal range of BMI (18 to 25),[2,10] recent evidence from a meta-analysis[14] and pooled analysis[9] of prospective observational studies showed a continuous increase in the risk of death associated with a BMI of more than 25. These studies are particularly notable since they addressed major sources of bias in previous studies (i.e., residual confounding due to smoking and reverse causation due to preexisting chronic disease) by restricting the analysis to persons who had never smoked and who did not have chronic diseases. In addition, the pooled-cohort analysis controlled for the same set of covariates, provided cause-specific relative risks, and evaluated the relationship between BMI and mortality across different regions. The balance of evidence thus supports our minimum risk level of 20 to 25 for BMI. At the same time, to date, there remains insufficient evidence to support the argument that the most beneficial level of BMI should vary according to geographic location or ethnic group[9] because of differences in the relationship between BMI and body-fat distribution.

We found that 5% of the disability-adjusted life-years that were related to high BMI were from musculoskeletal disorders. Although high BMI is a major risk factor contributing to years lived with disability globally, and the economic costs associated with treatment are substantial,[24] these nonfatal but debilitating health outcomes have received comparatively little policy attention. Weight loss is beneficial in the prevention and treatment of musculoskeletal pain.[25] A combina-

tion of modest weight loss and moderate exercise provides better overall improvement in musculoskeletal pain than either intervention alone[26]; however, surgical interventions may be most effective for the morbidly obese.[27]

Our systematic evaluation of prospective observational studies showed sufficient evidence supporting a causal relationship between high BMI and cancers of the esophagus, colon and rectum, liver, gallbladder and biliary tract, pancreas, breast, uterus, ovary, kidney, and thyroid, along with leukemia. A recent review by the International Agency for Research on Cancer (IARC)[4] comes to largely similar conclusions, except with respect to leukemia. (We included leukemia on the basis of a systematic review and meta-analysis of 21 prospective cohort studies.[28]) In addition, even though the IARC report acknowledged consistent inverse associations between BMI and the risk of premenopausal breast cancer, inconsistent findings from studies that evaluated the effect of waist circumference or body-weight gain resulted in the exclusion of premenopausal breast cancer from its list. However, since high BMI was the exposure of interest in our analysis, we included the protective effect of high BMI on breast cancer in premenopausal women. We did not evaluate the effect of high BMI on gastric cancer (cardia) and meningioma because of a lack of sufficient data to separately estimate the incidence and mortality of these cancers at the population level.

Our study has several important strengths. We have addressed the major limitations of previous studies by including more data sources and quantifying the prevalence of obesity among children. We also systematically evaluated the strength of evidence for the causal relationship between high BMI and health outcomes and included all BMI–outcome pairs for which sufficient evidence with respect to causal relationship was available. We used a beta distribution to characterize the distribution of BMI at the population level, a method that captures the proportion of the population with high BMI more accurately than other distributions.[12] We used the best available evidence to determine the lowest-risk BMI. We quantified the trends in high BMI and the associated disease burden across levels of development and estimated the contribution of demographic transition and epidemiologic transition to changes in BMI-related burden.

The potential limitations of our study should also be considered. We used both self-reported and measured data with respect to height and weight and corrected the bias in self-reported data using measured data at each age, sex, and geographic region. To apply a consistent definition for childhood overweight and obesity across sources, we used the definition of the International Obesity Task Force and excluded studies that used the WHO definition. We did not propagate the uncertainty in the age pattern and sex pattern that were used to split the aggregated data. We did not incorporate the uncertainty of the BMI regression coefficients in our analysis. Data were sparse for some locations, particularly in earlier years, and estimates in these locations were based on country-level covariates and regional data. We did not identify a consistent pattern in the relationship between nationally representative data and data representing only urban or rural areas and were not able to correct those data for potential bias. We did not evaluate the trends in other measures of adiposity that may better relate to specific health outcomes, including waist circumference and waist-to-hip ratio. Since we obtained the effect size of BMI on health outcomes from prospective observational studies, the possibility of confounding by lifestyle habits cannot be excluded. Our estimation of relative risks did not capture possible differences owing to ethnic group and did not account for the possibility of geographic variation in relative-risk curves or the lowest-risk BMI. In addition, these studies generally excluded people with prevalent chronic diseases from the analysis of relative-risk estimation. Thus, our estimates represent the effect of BMI among persons without underlying diseases. This issue might be particularly important for older age groups, in which the prevalence of chronic disease increases. Finally, other probable complications or forms of BMI-related burden (e.g., disease burden in children) were not included.

In conclusion, our study provides a comprehensive assessment of the trends in high BMI and the associated disease burden. Our results show that both the prevalence and disease burden of high BMI are increasing globally. These findings highlight the need for implementation of multicomponent interventions to reduce the prevalence and disease burden of high BMI.

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APPENDIX

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