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How much do universal anthropometric standards bias the global monitoring of obesity and undernutrition?

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Summary

Each year, hundreds of articles in population health and nutrition, many in high-profile journals, use standard cutoffs based on weight and height as assessments of obesity and undernutrition. These global efforts to monitor overweight and underweight often rest on the assumption that ethnic differences in underlying body form are sufficiently small to permit universal anthropometric cutoffs for comparing excess and insufficient body fat across populations. However, a century of work in human biological variation suggests that human populations can vary dramatically in underlying body form in a way that may require population-sensitive cutoffs for monitoring. Here, we describe recently developed methods that can provide population-sensitive assessments of both excess and insufficient energy reserves in a wide range of countries. We use this approach to illustrate how worldwide variation in human body form is far more widespread than previously thought, and that it can occur at several geographic scales, including the level of world regions, countries and populations within countries. The findings also suggest that using standard cutoffs that ignore this variation can underestimate current obesity levels in adults by more than 400–500 million while also incorrectly prioritizing high-risk areas for undernutrition in children in key regions around the world.

Keywords: Anthropometric, body mass index, growth standards, undernutrition, weight-for-height.

Abbreviation: BMI, body mass index; DXA, dual X-ray absorptiometry; GDP, gross domestic product; WHZ, weight-for-height *z*-score; WHO, World Health Organization; bBMI, basal BMI; bWHZ, basal WHZ;

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Background

One of the first line tools for the population monitoring of both overweight and undernutrition is the simple ratio of a person's weight to height. For infants and children, researchers use *z*-scores of weight divided by height against a universal reference to assess moderate and severe wasting (1). Among adults, body mass index (BMI), another weight-for-height measure, is the most commonly used tool for monitoring global prevalence and change in obesity (2–4). In addition to monitoring overnutrition, researchers have also used BMI to assess population undernutrition in adults (5,6). Despite the recognition that weight-for-height is only one of many ways to monitor population differences and changes in obesity, undernutrition and risk for related disease states (7–10), a balance between ease and informativeness contributes to its continued use in a wide range of settings worldwide.

Current standards for assessing both overnutrition and undernutrition with such anthropometric measures have generally relied on single, one-size-fits-all cutoffs. In 2006, for example, the WHO published child growth standards based on a systematic comparison of breastfed infants and appropriately fed children in six cities around the world – Davis, USA; Muscat, Oman; Oslo, Norway; Pelotas, Brazil; Accra, Ghana; and South Delhi, India (1,11). The authors of the report concluded from this study that the effect of ethnic differences on the growth of infants and young children is small compared with the effects of environment. Moreover, it concluded that for practical purposes, these ethnic differences are too small to challenge the general use of WHO growth standards for monitoring undernutrition globally. Based on the WHO's recommendation, these standards have been endorsed by a number of international organizations, including the United Nations Standing Committee on Nutrition, the International Union of Nutritional Sciences and International Pediatric Association. As of 2011, these standards had been adopted by 125 countries (12).

Among adults, guidelines for the individual identification and population monitoring of obesity rely heavily on standard BMI cutoffs, with a BMI of 25 to 29.9 $\mathrm{kg\,m^{-2}}$ indicating overweight and BMI $\geq$30 $\mathrm{kg\,m^{-2}}$ indicating obesity (2,3,13). However, compared with infant growth standards, there has been more open debate about the appropriateness of these specific cutoffs as well as the use of BMI more generally for identifying and monitoring excess body fat. Based on these discussions, a joint enterprise by the Regional Office for the Western Pacific of the World Health Organization, the International Association for the Study of Obesity and the International Obesity Task Force published new recommended criteria in 2000 for overweight and obesity for populations from the Asia-Pacific region (14,15). The report recommended different cutoffs according to three broad population groupings with overweight defined among Asian populations at BMI $\geq$23 $\mathrm{kg\,m^{-2}}$, European populations at BMI $\geq$ 25 $\mathrm{kg\,m^{-2}}$ and Pacific Island populations BMI $\geq$ 27 $\mathrm{kg\,m^{-2}}$. The cutoffs for obesity were, respectively, 25, 30 and 32 $\mathrm{kg\,m^{-2}}$. Two years later, the WHO expert consultation on BMI in Asian populations met to weigh the evidence for Asia-specific cutoffs. It concluded that although evidence suggested Asian populations have substantial risk of type 2 diabetes and cardiovascular disease at BMI <25 $\mathrm{kg\,m^{-2}}$, that available data suggested too much variability within Asian populations to support a single revised cutoff. It concluded that the standard WHO BMI cutoffs should be retained, but also identified additional action points (e.g. BMI $\geq$23, 27.5 $\mathrm{kg\,m^{-2}}$) that individual countries could use for making decisions about increased risk for their own populations. Independently, representatives from at least three countries, Japan, India and China, have crafted their own guidelines based on studies of body composition and epidemiological studies showing that some East and South Asian populations exhibit increased risk of diabetes and cardiovascular disease at much lower levels of BMI than the European ancestry populations on which current WHO guidelines were based (16–19). Despite these rare country-specific modifications, little attention is given to potentially broader variation in body composition that might systematically bias BMI as an indicator of excess adiposity across populations (2), and even less attention is given to variability within major world regions, such as sub-Saharan Africa or South Asia.

The broadly used universal standards for monitoring undernutrition and overnutrition rely on a basic assumption that the effects of diet, physical activity and other environmental inputs strongly outweigh any pre-existing ethnic differences in body composition (1,20,21). In the case of child growth, for example, the underlying assumption is that children raised in suitable environments will all grow approximately the same. In contrast to this universal model of human growth, an ecological model suggests that populations can vary substantially in underlying body form (22). The key study underlying current universal WHO standards for infant growth, the WHO Multicentre Growth Reference Study, attempted to address this issue by focusing on six international field sites (1,11). However, it is not clear how well these six sites represent the global range of variation in body form. In terms of adult body mass, direct measures of lean and fat mass in a few select populations have shown remarkable variation in body composition in adults (23–25). However, the degree to which these differences generalize to adults and children in a wider range of global samples, especially those in sub-Saharan Africa, Latin America, North Africa and the Middle East, is currently unknown.

In this paper, we describe recently developed methods that can estimate such population differences in body composition based on the concept of basal slenderness – the expected weight-for-height in a population living outside of known obesogenic environments where regular depletion of energy reserves is typical. Basal slenderness is operationalized as basal BMI in adults and basal weight-for-height z-scores in children. The estimates from these new methods suggests that a universal model underlying current standards introduces substantial bias in the identification and monitoring of overweight and undernutrition in a wide range of contexts. Moreover, the current set of comparisons focused on East and South Asian populations are very likely only the tip of the iceberg of human worldwide variation. After reviewing key measures of slenderness, we map substantial variation in the estimated slenderness of populations that appears to be independent of recent nutrition transitions. Indeed, the range of variation in body mass due to variation in slenderness spans at least 1.5 standard deviations in weight-for-height z-scores among children and 6.4 $\mathrm{kg\,m^{-2}}$ in BMI among adults. Next, we show how this variation can lead to: (1) under-reporting of overnutrition in adults and undernutrition in children in select populations, and (2) incorrectly inferring population differences in undernutrition and overnutrition across populations that are in fact due to variation in slenderness. We finish by discussing key open questions about variation in slenderness and its implications for monitoring individual and population health.

What are key axes of variation in slenderness?

Human biologists have identified a number of dimensions along which human slenderness varies (22,24–31). A key axis of variation is the relative length of one's legs to trunk, often assessed as the ratio of sitting height to total height (sitting height ratio). A higher sitting height ratio indicates that the trunk comprises a larger portion of a person's stature. A second axis of variation is the slenderness of limbs – measured with wrist and knee width (26) – and slenderness of the trunk – measured with pelvic breadth and shoulder breadth (32). Variation along any of these axes can change the relationship between height and fat-free mass. For example, trunks can contribute more fat-free mass than legs for the same increase in stature, and stockier trunks and limbs can contribute more fat-free mass than thinner trunks and limbs.

Population differences in underlying slenderness can create very different relationships between body mass indices and body fat across ethnic groups, with populations having a more slender build holding much higher quantities of body fat for the same BMI or WHZ (23–25,33–40).

In addition to proxies of slenderness based on the width of wrists and knees, there are two methods for estimating whole body slenderness at the population level. First, variability in slenderness can be detected through direct measures of fat mass and fat-free mass, such as dual X-ray absorptiometry (DXA). It is important to point out here that raw fat-free mass measured with these techniques is not a straightforward proxy for slenderness since accruing fat mass also leads to increasing fat-free mass in two ways – as a component of adipose tissue and as a result of muscle strengthening from an increased load. Based on modelling approaches developed by Garrow, Webster and Burton, it is possible to parse out this fat-dependent lean mass to estimate one measure of whole body slenderness from direct measures of fat and fat-free mass – BMI_0. This measure can be interpreted as the mean BMI in a population at the hypothetical limit of zero body fat (23,41–43). A few observations illustrate why it is important to interpret BMI_0 as a hypothetical end point that permits us to compare populations, rather than as a statement about a realizable physiological state. First, the human body requires some fat to survive. Second, in situations of severe starvation and anorexia, the relationship between body fat and fat-free mass appears to diverge from linearity (44–46). While potentially useful for comparing populations, direct measures of body composition and thus estimates of BMI_0 have been limited to a rarified set of human populations in middle-income and high-income countries, such as the USA, New Zealand and Malaysia (23,24,47).

To expand the existing set of samples beyond the constraints imposed by direct measures, researchers have recently developed an alternative estimate of slenderness – *basal body mass index* in adults and *basal weight-for-height* in children – using anthropometric measures from populations living in extreme poverty and not yet experiencing a substantial nutrition transitions (48,49). An advantage of this construct over BMI_0 is that it represents the BMI of real populations, and thus also includes the component of fat that would exist in these populations even though they are experiencing substantial deprivation. Specifically, basal BMI is always greater than BMI_0, because basal BMI also includes gender-specific basal levels of adipose tissue as well as fat-free mass accumulated in part to support that adipose tissue. Existing Demographic and Health Surveys in over 50 low-income and middle-income countries provide relevant data for both adults and children living in extreme poverty (see Table S5 for countries and current estimates). At the level of both country and ethnolinguistic group, estimates of basal BMI for adults and basal weight-for-height for children are reliable across age and sex and are stable over decades (49–51). The intra-class correlation across surveys within a country is 0.92 for basal BMI and 0.87 for basal WHZ, and GDP in a survey year cannot account for any of the between-survey variation in slenderness within countries (see supplemental materials). As we will describe later, these indirect estimates of slenderness are also unrelated to diseases associated with excess or deficient fat mass (49–51).

What is the extent of population variation in slenderness?

Estimates of slenderness from both direct and indirect measures of fat-free mass exhibit striking variation across populations. For example, DXA-based estimates of BMI_0 from a very limited set of populations residing in the USA and New Zealand exhibited a range of more than 4 $\mathrm{kg\,m^{-2}}$ between the least slender (New Zealand Pacific Islander) and most slender populations (New Zealand South Asian) (23). That is, if we compare two individuals from these populations with the same quantity of fat, we would expect the BMI of the Pacific Islander to be on average 4 $\mathrm{kg\,m^{-2}}$ greater than the South Asian.

The fuller array of worldwide populations considered with indirect measures of slenderness exhibit even greater variation. For example, in the over 50 low-income and middle-income countries covered by Demographic and Health Surveys, adult female basal BMI shows a range of

$5.0\,\mathrm{kg\,m^{-2}}$ across countries and $6.4\,\mathrm{kg\,m^{-2}}$ across ethnolinguistic groups (49,51). Similarly, basal weight-for-height *z*-scores among children show a range of greater than 1 SD across countries and 1.5 SD across ethnolinguistic groups (50,51). It is important to emphasize that these differences in basal BMI and basal WHZ were estimated among populations that all live in situations of extreme poverty and have not yet experienced a substantial nutrition transition. Thus, these differences cannot be attributed to differences in wealth or nutrition. Indeed, there are only low correlations between slenderness estimates and country-level estimates of GDP or ethnicity-level estimates of household wealth (49–51).

Notably, these estimates of basal BMI and WHZ are also consistent with classic population differences observed by human biologists and anthropologists. For example, one of the populations with the lowest estimates of basal BMI and basal WHZ are the Nuer of East Africa, a group that human biologists have traditionally used to represent the extreme end of human variation in slenderness (51). There are similarly low levels of basal BMI and WHZ among South Asian populations, which are consistent with an emerging body of literature on body composition in that region (17).

The variation observed in slenderness is of comparable magnitude to the increases in body mass observed with improving economic conditions and nutrition. For example, women in the wealthiest households in Demographic and Health Survey datasets (>20,000 USD 2011 equivalent, purchasing power parity) have approximately $5\,\mathrm{kg\,m^{-2}}$ greater raw BMI than women in the poorest households (<200 USD 2011 equivalent, purchasing power parity) (49) (Table 1). This spread is of comparable magnitude to the maximally estimated differences across populations in basal BMI ($5.0\,\mathrm{kg\,m^{-2}}$ across countries and $6.4\,\mathrm{kg\,m^{-2}}$ across ethnolinguistic groupthe). As another point of comparison, the maximally estimated differences in basal BMI are larger than the mean gain in age-adjusted BMI among U.S. white, U.S. women (> 20 years) during the 40-year rise of obesity in the USA ($4.4\,\mathrm{kg\,m^{-2}}$, 1970–2010) (52,53) (Table 1). Child populations show even greater variation in basal weight-for-height relative to observed variation because of economic resources. For example, children in the wealthiest households in Demographic and Health datasets have on average 0.5 SD greater raw weight-for-height *z*-scores than children in the poorest households, while the maximally estimated difference in basal WHZ is 1.0 SD across countries and 1.5 SD across ethnolinguistic groups (54).

Although much of this variation in basal BMI arises at the coarse-grained level of world regions, there is also substantial variation within world regions. For example, if we estimate basal slenderness at the level of administrative subdistricts within low-income and middle-income countries, we can estimate how much of the variation in slenderness occurs at different regional scales – between major World Bank regions, between countries and between administrative subdistricts (see supplemental materials, SM). On average, most of the variations in bBMI and bWHZ in these samples occur between countries (84% of bBMI and 85% of bWHZ), and there is substantial variation both across World Bank regions and between countries within World Bank regions (SM Table S.3).

Substantial geographic variation also exists *within* a number of countries, most notably countries bordering the African Sahel (Cameroon, Chad, Mauritania and Nigeria) and countries at the border of South Asia and Central Asia (Nepal, Pakistan and India) (all with SD in bWHZ >0.20 SD and SD in bBMI $>0.50\,\mathrm{kg\,m^{-2}}$) (SM Table S.4).

These population differences in basal slenderness account for a non-trivial portion of the overall variance in age-adjusted BMI and WHZ (Table 2, see SM for analyses). Specifically, they account for over 50% of the variance in age-adjusted BMI and WHZ between World Bank regions and between countries. They also account for 25% of the variance in BMI and 71% of the variance in WHZ observed between subdistricts within countries. These results suggest that basal slenderness in both adults and children accounts for a substantial portion of the variance in observed BMI and WHZ at several geographic scales.

Where do these differences come from?

As most research efforts have been devoted to the origins of variation in fat mass and obesity, we know comparatively

Table 1 Maximal estimated between-population difference in basal body mass and between-population difference attributable to economic resources or nutrition transitions

	Maximally estimated differences in basal body mass	Maximally observed differences across economic strata and nutrition transitions
Female adult BMI	$6.4\,\mathrm{kg\,m^{-2}}$	$5.0\,\mathrm{kg\,m^{-2}}$
Child WHZ	1.5 SD	0.5 SD

BMI, body mass index; WHZ, weight-for-height *z*-score.

Table 2 Proportion of variance in age-adjusted BMI and WHZ accounted for by basal BMI and basal WHZ across subdistricts (5 regions, 54 countries, 525 subdistricts)

	BMI (%)	WHZ (%)
Between World Bank regions	70	96
Between countries (within World Bank regions)	62	94
Between subdistricts (within countries)	25	71
Overall	60	92

BMI, body mass index; WHZ, weight-for-height *z*-score.

less about what gives rise to population variation in fat-free mass. There are a number of possible reasons for these differences. Variation in nutritional ecology and the proportion of calories coming from protein and other macronutritients may play a role (51). Additionally, variation in activities that lead to muscle strengthening or muscle loss, variation in exposure to infectious diseases, underlying genetic variation, as well as effects of the intrauterine environment are all possible explanations (51).

Recent evidence, however, puts relatively strong constraints on how and when such population differences arise. First, population differences in slenderness are highly conserved over the life course, with children's weight-for-height *z*-scores strongly correlated with adult's basal BMI (49,50,55). Moreover, most of the variation in bBMI and bWHZ can be attributed to genetic affinity between populations, with very little additional association of environmental variables (51). Future work should explore the degree to which nutritional ecology (e.g. child feeding) and mode of subsistence (e.g. pastoralists vs. agriculturalists) play a role in these differences, as well as potential genetic mechanisms and interactions with environmental inputs.

Are population differences big enough to matter for public health monitoring?

Converging lines of evidence suggest that these substantial population differences in slenderness can lead to underestimation of disease risk in specific regions. For example, a growing body of literature focusing on the 'thin–fat' phenotype in south Asian populations, and to a lesser extent East Asian populations, suggests that risk for diabetes, metabolic disorders, cardiovascular disease and all-cause mortality begin at much lower BMIs than for European populations (17–19,56–68).

These findings are consistent with a two-compartment model of body mass. The first component comprises the underlying or basal weight-for-height expected in a population before accruing additional body fat through contemporary nutrition transitions. This basal level of slenderness should be uncorrelated with diseases associated with either excess fat (e.g. diabetes) or deficient energy reserves (e.g. infectious diseases). The second component – referred to here as residual body mass – is the additional mass accrued as fat is deposited. This second component should be correlated positively with diabetes and fat-linked metabolic disorders and negatively associated with infectious diseases. Our own research has demonstrated that indeed population slenderness is largely uncorrelated with these disease states, while residual body mass reflecting accumulated fat mass in adults is positively associated with the prevalence of diabetes (51) and residual WHZ reflecting energy reserves in children is negatively associated with infectious disease risk (Hadley and Hruschka, submitted). As expected from a two-compartment model, bBMI and bWHZ are also uncorrelated with the depth of calorie deficits estimated from food balance sheets, while residual BMI and residual WHZ show substantial negative correlations with such calorie deficits (Table S1).

To illustrate how disregarding differences in basal BMI can lead to misclassification, we can assign each country an adjusted BMI cutoff for overweight and obesity as follows. If the basal BMI of the original European ancestry reference populations is $\mathrm{bBMI}_{\mathrm{ref}}$ and the basal BMI estimate for the country of interest is $\mathrm{bBMI}_{\mathrm{i}}$, then the adjusted cutoff for that country would be $25 - \mathrm{bBMI}_{\mathrm{ref}} + \mathrm{bBMI}_{\mathrm{i}}$ for overweight and $30 - \mathrm{bBMI}_{\mathrm{ref}} + \mathrm{bBMI}_{\mathrm{i}}$ for obesity. Although no European countries satisfy the strict conditions for estimating bBMI, the best estimate we have for $\mathrm{bBMI}_{\mathrm{ref}}$ from the original reference populations – European ancestry populations – is Albania (bBMI = 22.4). This leads to an adjusted overweight cutoffs varying from less than 22 in India and Yemen to 22.7 in Ethiopia and 22.4 in Timor L'Este to over 25.5 in Bolivia and Lesotho. Using these cutoffs, we find underestimation of overweight in a number of countries by 40% or more in a wide range of countries in sub-Saharan Africa, South Asia and Southeast Asia (Fig. 1). Importantly, there is also dramatic variation within World Bank regions in the degree of underestimation. For example, Lesotho, Egypt and Rwanda show almost no difference between prevalence estimates from raw and adjusted cutoffs as their basal BMI estimates are quite close to the European reference.

These adjusted cutoffs suggest that global estimates of overweight based on a universal BMI standard currently underestimate the number of overweight adults globally by more than 300 million (3), with the excess concentrated in South Asia (254 million) and sub-Saharan Africa

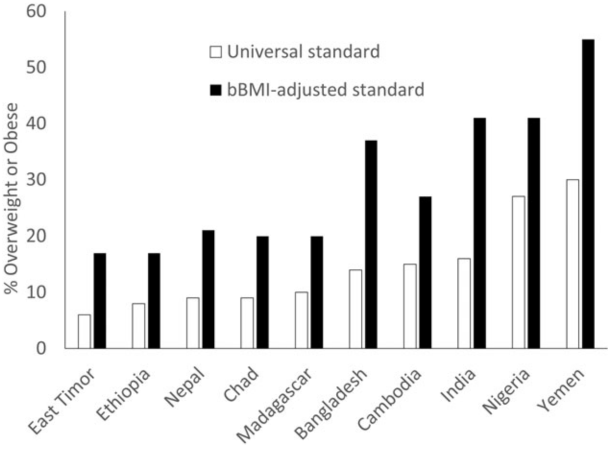

Figure 1 Comparing age-adjusted prevalence of overweight using universal and BMI-adjusted cutoffs in countries with >40% underestimation of prevalence.

(45 million). Notably, this figure does not include many countries with large populations from East and Southeast Asia – China, Indonesia, Japan, Philippines, Vietnam, Thailand, Myanmar and South Korea – where populations likely also have much higher levels of overweight than suggested by current WHO standards (69). Using Asia-specific or China-specific cutoffs in China alone would be estimated to add another 100-200 million cases of overweight to current estimates based on universal cutoffs (69). Thus, universal cutoffs conservatively underestimate global overweight in adults by more than 400–500 million cases.

Conversely, in those populations with greater average stockiness, we find substantial underdetection of underweight in adults. Specifically, underweight among adult women is underestimated by more than 30% in many countries in Latin American (Bolivia, Honduras, Nicaragua and Peru) and southeastern Africa (Lesotho and Swaziland). A similar problem arises with detection of moderate undernutrition in children. For example, the ranking of countries by the prevalence of moderate wasting shifts dramatically in a number of regions when adjusting for basal WHZ. When adjusted for basal WHZ, we see an increasing priority of countries in West Africa (Sao Tome and Principe 1st from 16th, Benin 2nd from 13th, Sierra Leone 5th from 25th, Nigeria 4th from 9th), North Africa (Morocco 11th from 35th, Egypt 12th from 43rd), and southeastern Africa (Malawi 13th from 38th, Zambia 21st from 41st, Mozambique 26th from 36th, Lesotho 37th from 44th, Swaziland 39th from 48th, Zimbabwe 29th from 42nd). Thus, relying on unadjusted weight-for-height *z*-scores for population monitoring can potentially lead to skewed prioritization of high-risk areas. For example, if one simply maps WHZ across Africa, it would appear that countries in West Africa (Sierra Leone and Benin) and southeastern Africa (Lesotho, Swaziland, Mozambique and Zimbabwe) have much lower levels of undernutrition than Madagascar or regions bordering the Sahel (70–72). Estimates of basal WHZ, however, suggest that much of this variation reflects differences in basal body form.

These differences in body form also raise important challenges when interpreting population differences in BMI and bWHZ as reflecting nutritional and health differences between these populations. This is most apparent for comparisons between world regions, such as South Asia versus sub-Saharan Africa (73). For example, Dreze and Deaton recently interpreted lower weight-for-height scores in India relative to sub-Saharan Africa as an indicator of worse nutritional status and health. It is equally possible that these differences could result from underlying differences in body form. The possibility for substantial regional and ethnic variability in slenderness *within* some countries also highlights the importance of interpreting ethnic or regional differences in BMI or WHZ with caution (74).

How do these differences affect the interpretation of other anthropometric standards?

Body mass index and weight-for-height *z*-scores are some of the most commonly used first line indicators of excess fat or undernutrition. However, they are only two of a number of fast and practical measurements used by researchers for these purposes. Other measures included waist circumference (75–77), waist-to-hip ratio (7) and waist-to-height ratio (78) as assessments of abdominal obesity in adults and mid-upper arm circumference for assessing undernutrition in children and adults (8,79). With new advances in mobile data collection and integration, one might also imagine novel techniques that can integrate multiple photographs from a cell phone to identify new dimensions of body shape (80). Though diverse, these techniques all rely on external assessments of body form and the assumption that this can tell us something about internal body composition and disease risk. As such, standards based on these techniques face the same potential challenges we have outlined for universal standards based on weight-for-height. Specifically, universal standards applied to any of these diverse measurements would require the assumption that human bodies are built in sufficiently similar ways that similar external measurements imply similar internal states. Given the very large variation in basal BMI and basal WHZ estimated here, it is highly plausible that these other measures of body form will also confound population variation in slenderness with variation in fat and energy reserves. Indeed, as an empirical database begins to emerge for these other measures of body shape, such as waist circumference, public health researchers have begun to make preliminary population-based recommendations for such measures as well (15). An approach that acknowledges the possibility for population variation at multiple scales, from the world regional to the sub-national, will likely be required to identify when and at what scales sufficiently large bias is introduced by universal standards to warrant context-sensitive standards.

Conclusion

Studies of select populations in South Asia, East Asia and Southeast Asia have demonstrated substantial cross-population variation in slenderness that can strongly bias weight-for-height as an indicator of fat-linked disease risk. Our indirect measures of slenderness from demographic and health surveys in a much wider global sample further suggest that such biases are far more widespread. Moreover, there is substantial between-country variation in slenderness within world regions, such as South Asia and sub-Saharan Africa, as well as remarkable variation in estimated slenderness within select countries. The existence of substantial variation at multiple geographic scales further suggests that broad population groupings for population-specific cutoffs (e.g. 'Asian', 'East Asian', 'South Asian' and 'African') may still mask considerable variation in slenderness within countries and world regions. These differences in slenderness have been most studied for adults, but they mirror differences in infants that may also alter the meaning of WHZ as an indicator of wasting and undernutrition. We have also described how such biases can potentially lead to inappropriate comparisons of disease risk between world regions, between countries and in some cases between populations within countries.

These indirect measures give a glimpse of the potential worldwide variation in slenderness and its impact on monitoring of excess and deficient energy reserves. However, these current estimates are based on indirect methods, and future studies are needed to assess how well these indirect estimates accurately reflect slenderness variation in understudied populations from sub-Saharan Africa, North Africa and the Middle East, Latin America various regions across South Asia. This will become increasingly important as populations in these understudied regions begin to bear the burden of emerging nutrition transitions. Immigration studies that examine how slenderness and body composition change (or do not change) as immigrants move to new host populations will hopefully shed light on the degree to which such differences in slenderness can arise from changing nutrition and physical activity. If such differences in slenderness are relatively stable within populations, as recent studies suggest (24,51), then it should be possible to validate these indirect measures of slenderness through targeted sampling of immigrant populations where direct measures of body composition – for example, dual X-ray absorptiometry – are readily available. In addition to identifying countries and regions as higher priority areas than current assessments would indicate (e.g. Yemen and parts of sub-Saharan Africa for obesity-linked diseases and parts of West Africa, North Africa and southeastern Africa for undernutrition), validated estimates could provide important guidance for health practitioners in multicultural settings, such as the U.S., when assessing risk and aiming prevention at groups from diverse world regions (14).

Simple, common standards for assessing disease risk provide a number of important benefits. They can increase the efficiency of global health monitoring and clinical assessment, can avoid confusion in health promotion and can facilitate communication about risk across diverse academic, clinical and public health fields (14). Common standards can also play a role in ensuring a shared, equitable benchmark for identifying those individuals and populations most at risk (81). For these reasons, universality of standards is an important goal in public health practice and communication. Another equally important goal is to ensure that these standards have similar meanings in terms of physiology and disease risk when applied across a diverse range of human populations. Given well-established biological variation that exists across human groups, these two aims must inevitably be traded off in any decision about when and under what conditions it is sufficient to have a single universal standard. We review a range of emerging evidence that current tandards of weight-for-height can introduce substantial bias in assessment of body composition and related disease risk at global, regional and national scales. A key challenge in future work will be to determine at what scales context-specific standards will provide the best balance between the two important aims of simplicity of implementation and accuracy in informing public health priorities and clinical decisions.

Competing interests

The authors declare that they have no competing interests.

Conflicts of interest

The authors declare no conflicts of interest related to this paper.

Authors' Contribution

DH and CH developed the concept of slenderness and how to estimate it indirectly as basal body mass index and basal weight-for-height z-scores. DH carried out the new estimation and statistical analyses reported in this manuscript. DH and CH conceived of the study, and participated in its design and coordination and helped to draft the manuscript. All authors read and approved the final manuscript.

Supporting information

Additional Supporting Information may be found in the online version of this article, http://dx.doi.org/10.1111/obr.12449

Table S1. Association of basal and residual body mass with depth of calorie deficit and ln(GDP per capita).

Table S2. Reliability of bBMI and bWHZ and within-country dependence on ln(GDP per cap).

Table S3. Proportion of variance in bBMI and bWHZ at three spatial scales: between subdistricts within countries, between countries within World Bank Regions, between World Bank Regions (5 regions, 54 countries, 525 subdistricts).

Table S4. Countries with high between-subdistrict variability in both bWHZ and bBMI (SD bWHZ $>$ 0.25, SD bBMI $>$ 0.50).

Table S5. Country-level bBMI and bWHZ estimates with sample sizes and standard errors of prediction.

Figure S1. Relationship between bBMI and bWHZ estimates at the country-level.

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