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Validity of the WHO cutoffs for biologically implausible values of weight, height, and BMI in children and adolescents in NHANES from 1999 through 2012[1,,2]

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Abstract

Background—The WHO cutoffs to classify biologically implausible values (BIVs) for weight, height, and weight-for-height in children and adolescents are widely used in data cleaning.

Objectives—We assess *1*) the prevalence of these BIVs, *2*) whether they were consistent with information on waist circumference, arm circumference, and leg lengths, and *3*) the effect of their exclusion on the estimated prevalence of obesity in 2- to 19-y-olds in the NHANES, which is a study in which extreme values were verified when recorded.

Design—We conducted cross-sectional analyses in 26,480 children and adolescents in the NHANES from 1999–2000 through 2011–2012.

Results—The overall prevalence for a BIV for any body-size measure was 0.9% (*n* = 277), and almost all BIVs were due to extremely high, rather than low, values. Of 186 subjects who had a high BIV for weight or body mass index (BMI), all but one subject had both arm and waist circumferences that were greater than the sex- and age-specific 95th percentiles; 75% of subjects had circumferences greater than the 99th percentile. Of 63 subjects with a high height BIV, 75% of them had a leg length that was greater than the 95th percentile. The exclusion of children and adolescents with a BIV reduced the overall prevalence of obesity by ~0.5 percentage points and by 1.7% in non-Hispanic blacks.

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None of the authors reported a conflict of interest related to the study.

Conclusions—Most of the extremely high values of weight, height, and BMI flagged as BIVs in the NHANES are very likely correct. The increase of *z* score cutoffs or the use of an alternative method to detect possible errors could improve the balance between removing incorrect values and retaining extremely high, but accurate, values in other data sets.

Keywords

BIV; BMI; body size; children; NHANES; outliers

INTRODUCTION

Since the early 1970s, the prevalence of obesity in the United States has increased by more than a factor of 3 in 6- to 19-y-olds and by ~70% in 2- to 5-y-olds (1, 2). In response to these secular trends, much data on the weight and height of children and adolescents have been collected in schools (3–7) and clinics (8–11). Because the quality of these measured weight and height data can vary substantially, investigators must decide how to address extreme values that could represent errors. These decisions would influence estimates of the prevalence of obesity (12), trends over time, and associations with other characteristics.

Cutoffs that are based on *z* scores of weight, height, and BMI (in kg/m^2) that are considered to be biologically implausible values (BIVs)[7] are included in the SAS program for the 2000 CDC growth charts (13, 14). These cutoffs, which were based on recommendations made by a WHO expert committee in the mid-1990s (15), have been widely used (3, 4, 10, 11, 16–18), and extreme values are flagged by the program. However, other than stating that the proposed cutoffs are “likely to be errors and may be treated as missing” [15(p217)], no justification was given for the specific cutoffs that were chosen. Furthermore, it is difficult to know how the exclusion of BIVs would influence the accuracy of the prevalence of obesity.

It is possible that the exclusion of these BIVs resembles other techniques that have been used to exclude data that are considered to be incorrect or confounded but have eventually been shown to result in various biases (19–22). The application of these BIV cutoffs to data from the United States and other countries that have a high prevalence of obesity could exclude subjects who have very high, but correct, BMIs and, therefore, underestimate the prevalence of obesity. Estimates of the prevalence of obesity in the NHANES (1, 2) do not exclude BIVs.

Our objectives were to evaluate the distribution of weight, height, and BMI in 2- to 19-y-olds in NHANES 1999–2000 to 2011–2012 and to assess the prevalence of BIVs on the basis of WHO cutoffs with the use of CDC growth charts. We also assessed other body-size measures to determine whether the BIVs are consistent with information on waist and arm circumferences and leg length.

[7]Abbreviations used: BIV, biologically implausible value; BMI_{MZ}, modified BMI *z* score; $height_{MZ}$, modified height *z* score; $weight_{MZ}$, modified weight *z* score.

METHODS

Sample

The NHANES uses a multistage, stratified, cluster-sampling design to select a representative sample of the US civilian, noninstitutionalized population. The surveys were approved by the Ethics Review Board of the National Center for Health Statistics; parental permission was obtained for minors <18 y old, and consent was obtained for all adults.

Race and ethnicity were self-reported, and we classify participants as non-Hispanic white, non-Hispanic black, Mexican American, and other. Pregnant women and adolescents were oversampled in 1999–2006, and these subjects were excluded from all analyses as were the 568 examined subjects (2%) who did not have a weight or height measurement. The final sample size was n = 26,480 on the basis of data from 1999–2000 through 2011–2012, and overall response rates varied from 73% to 84% (http://www.cdc.gov/nchs/nhanes/response_rates_cps.htm).

During the NHANES physical examination, weight, height, waist circumference, midupper arm circumference, and leg length were measured in a standardized fashion (23). Height and weight values were automatically transmitted from stadiometers and scales to the Integrated Survey Information System database; circumferences and leg length were entered manually into this database (leg length was measured only in 8- to 19-y-olds.) This database was designed to reduce data errors and contains age- and sex-specific edit ranges for each body-size measure on the basis of previous NHANES data. If an entry was outside this range, the recorder was alerted that the value was unusual and was required to verify the measurement (23).

Calculation of *z* scores in CDC growth charts

BMI was calculated as weight divided by the square of height. Weight, height, and BMI *z* scores and percentiles were calculated with the use of CDC 2000 growth charts and expressed a subject's values relative to those in children and adolescents of the same sex and age from 1963–1965 to either 1976–1980 (6- to 19-y-olds) or 1988–1994 (2- to 5-y-olds) (14). Obesity was defined as BMI greater than or equal to the 95th percentile of these growth charts (24).

Although *z* scores calculated from the *L* (power transformed for skewness), *M* (mean), and *S* (CV) variables (25) in the CDC growth charts capture the distribution of height, weight, and BMI of most subjects, projections into the upper tails are problematic (26, 27). This problem may be exacerbated in the CDC growth charts because the LMS variables were derived from smoothed percentiles rather than from the underlying distributions (28).

Because the upper *z* score limit at most ages in the CDC growth charts is ~3.0–3.5 (27), a modified *z* score (z score$_M$) approach was used to identify extremely high values. One-half of the difference between a *z* score of 0 and 2 was extended outwards to estimate a subject's modified *z* score; this modification allowed for *z* scores that were much higher than 3.5. A somewhat similar approach was used in the WHO growth standards, but the extrapolation was based on the distance between 2 and 3 *z* scores (29, 30).

These scores are referred to as a *z* $score_M$ or a modified weight *z* score ($weight_{MZ}$), modified height *z* score ($height_{MZ}$), and modified BMI *z* score (BMI_{MZ}). The following ranges are currently flagged as BIVs by the SAS program for the 2000 CDC growth charts (13): $weight_{MZ}$ less than −5 or greater than +5; $height_{MZ}$ less than −5 or greater than +3; and BMI_{MZ} less than −4 or greater than +5.

We considered body-size measures below these cutoffs to be low BIVs and values above these cutoffs to be high BIVs. These cutoffs for weight and height were based on those proposed by the WHO in 1995, whereas the cutoffs for BMI correspond to those used for weight-for-height (15).

Of the 146 subjects with a high BMI BIV, 7 subjects were missing information for both arm and waist circumferences. Of the sixty-six 8- to 19-y-olds who had a high height BMI, 3 subjects did not have a leg-length measurement. Subjects with missing circumferences or leg lengths were excluded only from analyses that made use of these measurements.

Statistical analyses

All analyses were performed in the R program (31), and with the exception of the quantile-quantile plots, all estimates used the sample weights and accounted for the complex survey design (32). Because many of the estimated proportions for the BIVs were close to zero, 95% CIs were calculated with the use of the modification proposed by Korn and Graubard (33).

After describing the prevalence of BIVs for weight, height, and BMI, we examined the distributions of body-size measures with the use of quantile-quantile plots (http://onlinestatbook.com/2/advanced_graphs/q-q_plots.html). In these figures, the observed *z* $scores_M$ were plotted (*y* axis) against their expected quantiles from a normal distribution (*x* axis). Additional analyses (34) indicated that the distribution of positive *z* $scores_M$ for weight and BMI approximated an exponential distribution with rate parameters of 1.11 and 1.07, respectively. For BMI *z* $scores_M$ with this distribution, the probability of observing a value that was at least as extreme would have decreased by 66% ($1 - \exp(-1.07)$) for each 1-unit increase. Although 2.5% of values in a normal distribution would be expected to have a *z* $score_M$ ≥1.96, the comparable percentage would be 12.3% for this exponential distribution.

We examined the circumferences (waist and arm) and leg lengths of the 2- to 19-y-olds. Both of the circumferences were highly correlated with BMI and, along with sex and age, accounted for (R^2) 92–93% of the variability in BMI. The R^2 of a similar model that predicted height from leg length, sex, and age was lower (0.88); leg length was measured only in 8- to 19-y-olds. Because percentiles of waist circumference, arm circumference, and leg length were not estimated in the CDC growth charts, we used quantile regression (35–37) to estimate these smoothed, weighted percentiles in the current study. Rather than estimating the mean response by minimizing the sum of the squared errors as in ordinary least-squares regression, quantile regression minimized the absolute error around various percentiles of the outcome variable.

Within each sex, we modeled the 85th, 95th, and 99th percentiles of the circumferences and leg length as a function of age with the use of restricted cubic splines with 5 knots (38). The circumferences of subjects who had a high BMI BIV were overlaid on various percentiles of the circumferences, and the leg lengths of subjects with a high height BIV were overlaid on the corresponding percentiles of leg length. If BIVs were data errors, it would be expected that the circumferences and leg lengths of subjects who had a BIV would be scattered throughout the distribution.

We also examined inconsistent values of BMI and waist circumference with the use of Studentized (leave-one-out) residuals. These residuals, which indicate possible outliers, have a SD of 1.0 and are calculated by ignoring the current observation. These residuals were derived from a regression model that predicted BMI from sex, age, waist circumference, and various interactions. BMI and waist circumference were log transformed in this model to improve normality.

Although we also assessed the skinfold thicknesses of children and adolescents with BIVs, ~50% of subjects with a high weight or BMI BIV were missing data on either the triceps or subscapular skinfold thickness. Of the 61 subjects who had a high BMI BIV and a non-missing subscapular skinfold thickness, 56 subjects had a skinfold thickness greater than the 95th percentile.

RESULTS

Descriptive characteristics of the children and adolescents are shown in Table 1. Overall, the prevalence of obesity was 16%, but it varied by sex, race-ethnicity, and age. Approximately 0.9% (n = 277) of subjects had a BIV for weight, height, or BMI, and almost all instances (n = 275) were due to extremely high values. [One child (a 4-y-old girl) had a high height BIV (135 cm) along with a low BMI BIV (8.0).] Of subjects who had a high BIV, 138 participants had high weight, 92 participants had high height, and 146 participants had high BMI; 89 subjects had a high BIV for both weight and BMI. Twelve of the 92 subjects who had a high height BIV also had a high weight BIV.

The prevalence of BIVs was consistently greater in boys than in girls and most BIV prevalences differed by race-ethnicity; estimates for height and BMI BIVs differed by age group. The exclusion of the 277 subjects who had a BIV from the analysis reduced the overall prevalence of obesity from 16.0% to 15.5%, but the prevalence of obesity in non-Hispanic blacks decreased by greater than one percentage point (from 20.3% to 19.0%). In non-Hispanic black boys, the prevalence of obesity decreased from 18.3% to 16.6%.

Figure 1 shows the distribution of weight_{MZ}, height_{MZ}, and BMI_{MZ}. In contrast with the 275 children and adolescents who had a high BIV, there were only 3 subjects who had a low BIV (open triangles) as follows: a 15-y-old with had a height of 120 cm, a 2-y-old with BMI of 11.5, and a 4-y-old with BMI of 8.0. The distributions of both weight_{MZ} and BMI_{MZ} were skewed with very heavy right tails, and the distribution of positive values for both weight_{MZ} and BMI_{MZ} were consistent with an exponential distribution with rate parameters of 1.11 (weight) and 1.07 (BMI). With the possible exception of the very-highest value of

$height_{MZ}$, the distribution of extremely high $height_{MZ}$ values appeared to be fairly continuous with little evidence that the distance between the highest values were larger than might be expected. (This result was in contrast to that observed for 2 of the low BIVs.) Although levels of $height_{MZ}$ were approximately normally distributed, there were 92 subjects who had a high height BIV (z $score_M \geq 3.0$).

We examined the waist circumferences of children and adolescents who had BMIs that were considered to be implausibly high (Figure 2, top panels). Lines represent the 85th, 95th, and 99th percentiles of waist circumference in all 2- to 19-y-olds, and circles represent waist circumferences of the 113 subjects who had a BMI_{MZ} between 5 and 6.9; the solid triangles represent circumferences of the 26 subjects with a $BMI_{MZ} \geq 7.0$. As noted in Table 1, the prevalence of BMI BIVs varied substantially by age (Table 1).

With only one exception, all of the children and adolescents with a high BMI BIV also had a waist circumference that was greater than the 95th percentile (middle smoothed lines); 79% of children had a waist circumference greater than the 99th percentile. Furthermore, the very highest BMI_{MZ} values (solid triangles) were generally associated with the highest waist circumferences. Fairly similar results were seen in analyses that focused on the arm circumferences of subjects with a high BMI BIV (Figure 2, middle panels). None of the subjects who had a BMI BIV had an arm circumference less than the 95th percentile, and 74% of subjects had an arm circumference greater than the 99th percentile. Similar results were seen in subjects who had a high weight BIV with almost all of them having waist and arm circumferences greater than the 95th percentile (data not shown).

Comparable analyses of the leg length of the 63 children and adolescents who had a high height BIV (Figure 2, bottom panels) indicated that 47 subjects had a leg length that was greater than or equal to the 95th percentile, and 30 subjects had a leg length that was greater than or equal to the 99th percentile. (Leg length was measured only in 8- to 19-y-olds. However, there were 4 subjects who had a leg length less than the 85th percentile, and 1 subject who had a leg length that was slightly less than the 50th percentile.)

We also assessed the Studentized (leave-one-out) residuals of a regression model that predicted BMI from sex, age, and waist circumference (data not shown). The 3 subjects with the largest absolute residuals had relatively high BMI (81st to 98th percentiles) together with a waist circumference less than the 10th percentile. Of 100 subjects with the largest residuals, only 5 subjects had a high BMI BIV; 2 subjects had a waist circumference greater than the 99th percentile, 2 subjects had a waist circumference between the 98th and 99th percentiles, and 1 subject had a waist circumference between the 95th and 96th percentiles.

Table 2 shows levels of several of the body-size measures for children and adolescents who had *1*) a high BMI or weight BIV and one or both circumferences less than the 97th percentile (top 8 rows), *2*) a $BMI_{MZ} \geq 8$ and a $weight_{MZ} \geq 8$ (middle 6 rows), or *3*) a $height_{MZ} \geq 3.75$ (bottom 8 rows). (These cutoffs were used only to illustrate possible inconsistencies between BIVs and levels of circumferences and leg length.) Levels of BMI_{MZ} in subjects who had at least one circumference less than the 97th percentile ranged from 3.3 to 5.6, whereas all waist and arm circumferences of subjects with a $BMI_{MZ} > 8$ and a $weight_{MZ}$ > 8 were greater than or equal to the 99th percentile. All subjects who had a $height_{MZ}$ ≥3.75 also had a leg length greater than or equal to the 97th percentile with the exception of an 11-y-old boy who was at the 87th percentile.

Table 3 shows the minimum and maximum values of the body-size measures by year of age, with age-specific sample sizes that varied from 1280 to 1774. With the exception of 3-and 4-y-olds, maximum BMI_{MZ} values ranged from 5.8 (10 y of age) to 9.2 (7 y of age) across ages; however, maximum values in 3- and 4-y-olds were ≥10.6. A fairly similar pattern across ages was also seen for the maximum values of $weight_{MZ}$, and the highest $height_{MZ}$ (5.8) was also seen in 4-y-olds. Although the minimum and maximum values of weight, height, and BMI generally increased with age, there were some exceptions. For example, the lowest minimum BMI was seen in 4-y-olds (8), whereas a 16-y-old had the highest maximum weight (215 kg). Note that in contrast to the CDC/WHO cutoff for low BMI BIVs (−5 z $scores_M$), the minimum BMI_{MZ} values in 5- to 19-y-olds were approximately −3.0 (data not shown).

There were substantial sex differences in the maximum values of weight, height, and BMI after 10 y of age (data not shown). For example, in 19-y-olds, the maximum values in boys were 23 kg higher (weight), 16 cm higher (height), and 3.5 higher (BMI) than those in girls.

DISCUSSION

Almost 1% (n = 277) of the children and adolescents examined in the NHANES from 1999 to 2012 had a body-size measure that was flagged as being biologically implausible on the basis of the 1995 WHO cutoffs (15) and with the use of the CDC growth charts. Of subjects who had a BIV for weight or BMI, most had arm and waist circumferences that were greater than the 99th percentile, and only one subject had a circumference that was less than the 95th percentile. The prevalence of high leg lengths in subjects with a height BIV was lower, but 75% of subjects had a leg length that was greater than the 95th percentile. Although the NHANES data collected from 1999 to 2012 are likely to have very few errors for extreme body-size values because of extensive quality control, our analyses provide additional support for the validity of the extreme values and indicate that many high BIVs are very unlikely to be errors. If these flagged values had been incorrectly treated as errors, the overall prevalence of obesity would have been reduced by 0.5% (from 16.0% to 15.5%) in all subjects and by 1.7% in non-Hispanic black boys.

The use of BIVs in anthropometric measures was addressed in a 1995 WHO report (15) which recommended that z $scores_M$ >3 (height) or >5 (weight and weight-for-height) should be treated as improbable and set to missing. Although little justification was provided for these specific cutoffs, it was stated that they were the “criteria for anthropometric values that are most likely to represent errors.” These cutoffs may have been selected in part on the basis of the very-low probability that values this extreme occur in a normal [N(0,1)] distribution; a z $score_M$ > 5 would be expected only once in a sample of 4 million observations. However, the distributions of BMI_{MZ} and $weight_{MZ}$ in the current study had very heavy right tails, which resulted in positive z $scores_M$ being approximately exponentially distributed. The prevalence high BMI BIV values (0.37%), e.g., was ~12,000

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times higher than that expected for a normally distributed variable. Although $height_{MZ}$ values were closer to being normally distributed, 0.4% of subjects also had height that was considered to be biologically implausible.

The CDC program to calculate BMI *z* scores and percentiles (13), which also flags values considered to be biologically implausible, has been widely used (3, 4, 10, 11, 16, 17). Previous studies have also noted that the use of the WHO cutoffs can result in a large number of extremely high values, which are unlikely to be errors, being identified as biologically implausible. For example, Lo et al. (39) used several data-cleaning methods and showed that, after the exclusion of 30 children who had a height BIVand 3 children who had extremely low values (e.g., weight < 4.5 kg), only 14 of 237 weight and height BIVs in 43,000 3- to 5-y-olds were errors. Dennison et al. (16) also showed that 25 (of 616) infants had a BIV for weight, height, or BMI, but these values remained consistently high over time. The high prevalence of BIVs in NHANES data has also been noted by others (40), and our analyses of circumferences and leg lengths indicated that these extremely high values were not implausible.

Although the current cutoffs may incorrectly flag many of the extremely high values as being BIVs, the optimal solution may depend on the purpose of the analysis and the data set. In data sets that have not been as carefully measured, recorded, and cleaned as has the NHANES data, a substantial percentage of high BIVs could be errors. By increasing *z* $score_M$ cutoffs to ~8 (for BMI and weight) and ~4 (height), which are values that are close to the age-specific maximums that we observed (Table 3), the number of accurate values flagged as BIVs could be reduced. However, it is likely that even more-extreme values would have been observed in a larger sample than in the NHANES, and it is possible that a single cutoff across all ages is not optimal. For example, we observed that the maximum BMI *z* $score_M$ for each year of age varied almost 2-fold from 5.8 (10 y of age) to 11 (2 and 3 y or age). An alternative BIV criterion could use the maximum values (or a percentage, such as 110%, of these maximums) observed in the NHANES for each year of age. The latter approach would have the advantage of being easier to understand because it does not depend on the use of the *L*, *M*, and *S* variables for extrapolation. Analyses of larger data sets with longitudinal measurements may help to assess the performance of different cutoffs.

The limitations of our analyses should be considered. Although it is likely that the upper range of valid values for weight, height, and BMI could be expanded, our relatively small sample limited our ability to determine optimal cutoffs. Furthermore, although the very-high values we observed were almost certainly correct, this outcome was largely because of the substantial quality control and data editing performed in the NHANES 1999–2012; high BIVs in other data sets would likely include a larger number of errors. Furthermore, other than the 3 children who had low BIVs, the minimum values of weight, height, and BMI that we observed were substantially higher than the WHO cutoffs for low BIVs. It should also be realized that data errors can occur throughout the entire distribution [inliers (41)], and our analyses did not address this aspect of data cleaning. (These inliers, however, could possibly be identified by with the use of Studentized residuals.) There is also the possibility that, if participation was related to very extreme levels of weight, height or BMI, our estimate of the prevalence of BIVs would be biased downward.

Our results indicate that the simply deleting data on the basis of the WHO BIV cutoffs in the CDC growth charts can result in the exclusion of a large number of high values that are plausible and are likely to be correct. This finding may in part be the result of the secular trends in body weight that have altered the distributions of the body-size measures. When BIVs are evaluated, other data from the child, such as circumferences, skinfold thicknesses, or repeated measurements over time, could be used to assess whether data considered to be a BIV are consistent with other data (9, 22, 41). In the current study, e.g., an analysis of the Studentized residuals indicated that, of the 100 subjects who showed the largest disagreement (absolute residual) between waist circumference and BMI, 95% of them had a BMI_{MZ} <5. Even if information on other body-size measures is available for only a subset, this type of analysis may indicate what percentages of BIVs are consistent with other measures.

In conclusion, if no additional data are available, the use of higher z $score_M$ cutoffs or a comparison of the extremely high values with the maximum values observed in the NHANES could provide guidance. Compared with the WHO cutoffs, the use of higher BIV cutoffs may provide a better balance between excluding errors and retaining extremely high values that are likely to be correct. The CDC will be evaluating the implications of these findings for the classification of BIVs in the CDC growth charts.

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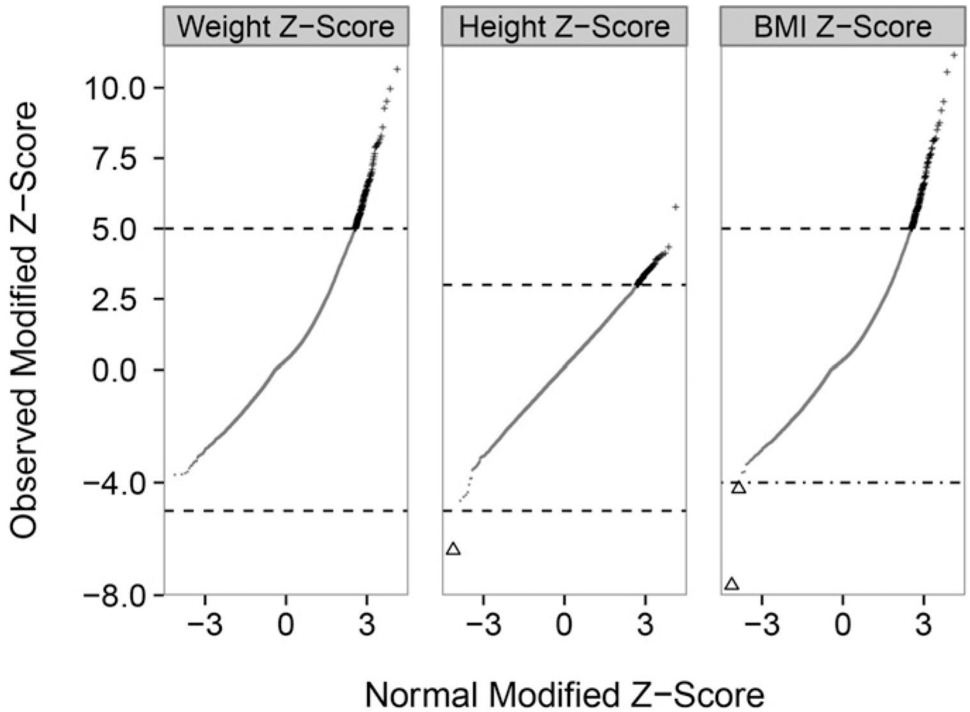

FIGURE 1.

Quantile-quantile plots of weight$_{MZ}$ (left panel), height$_{MZ}$ (middle panel), and BMI$_{MZ}$ (right panel) in 2–19-y-olds in the NHANES. Black points represent high BIVs, and triangles represent low BIVs; gray points represent data for values considered to be biologically plausible on the basis of WHO cutoffs. Horizontal lines represent cutoffs for high BIVs (+5 for weight$_{MZ}$ and BMI$_{MZ}$; +3 for height$_{MZ}$) and for low BIVs (−5 for weight$_{MZ}$ and height$_{MZ}$; −4 for BMI$_{MZ}$). If the data were normally distributed, all points would fall on a diagonal line. Both weight and BMI were skewed to the right with very heavy tails, whereas the distribution of height was closer to that of a normal distribution. BIV, biologically implausible value; BMI$_{MZ}$, modified BMI *z* score; height$_{MZ}$, modified height *z* score; weight$_{MZ}$, modified weight *z* score.

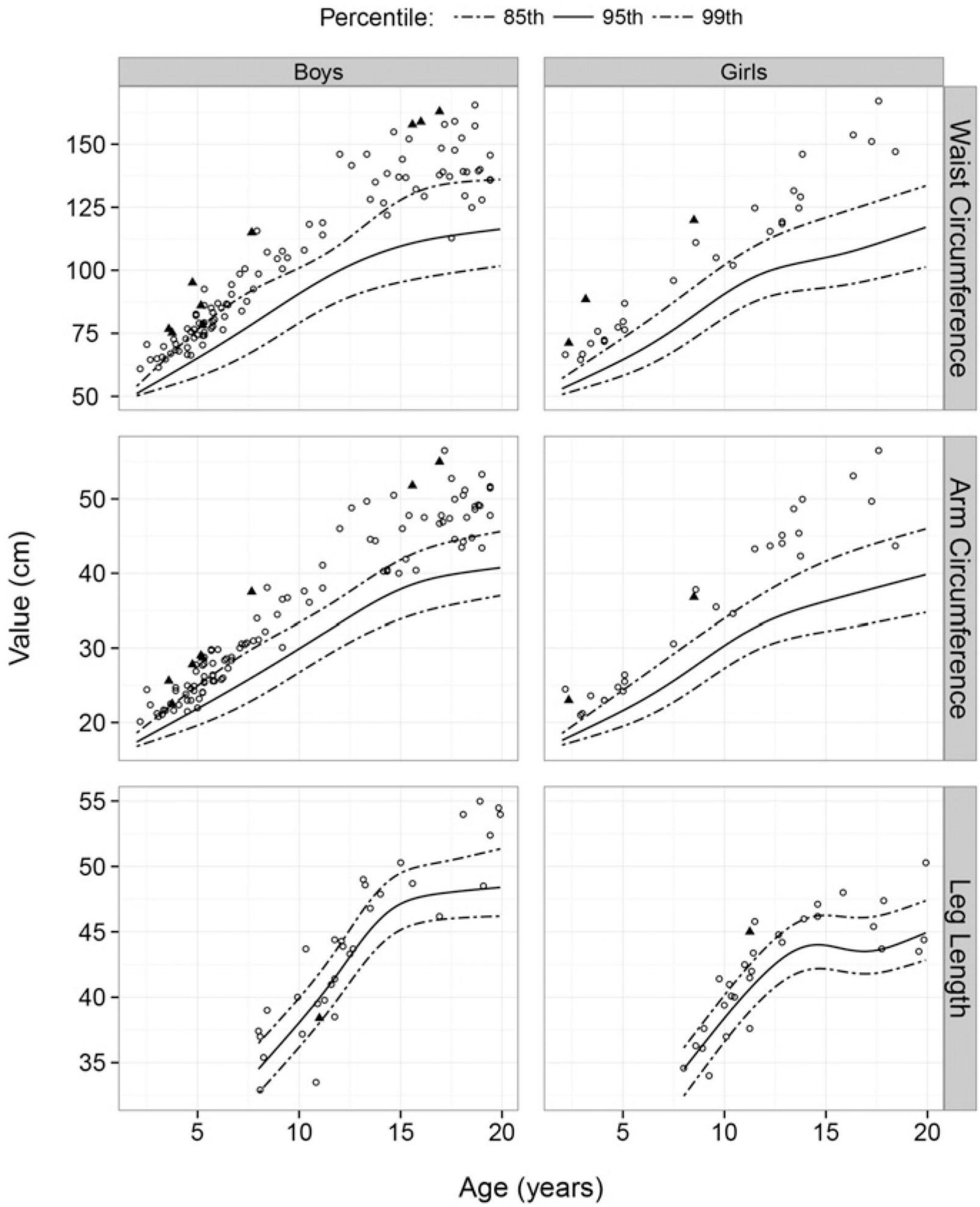

FIGURE 2.

Lines represent the weighted, smoothed 85th, 95th, and 99th percentiles of waist circumference (top panels), arm circumference (middle panels), and leg length (bottom panels) by sex (columns) and age for all 2- to 19-y-olds in the NHANES 1999–2012 as calculated with the use of quantile regression (35, 36). Points in the top and middle panels represent the waist and arm circumferences of subjects who had a BMI_{MZ} between 6 and 6.9; triangles represent BMI_{MZ} values ≥7.0. Points in the bottom panel represent leg lengths of subjects who had a $height_{MZ}$ ≥3.0. BIV, biologically implausible value; BMI_{MZ}, modified BMI *z* score; $height_{MZ}$, modified height *z* score.

TABLE 1

Prevalence of obesity and BIVs by sex, race-ethnicity, and age groups in the NHANES 1999–2000 to 2011–2012[1]

	Obesity(n = 4811)	**BIV(n = 277)**	**High weight BIV (n = 138)**	**High height BIV(n = 92)**	**High BMI BIV(n = 146)**
Overall (n = 26,480)	16.0 (15.2, 16.9)	0.86 (0.72, 1.016)	0.39 (0.30, 0.50)	0.37 (0.26, 0.51)	0.37 (0.29, 0.46)
Sex					
Boys (n = 13,506)	16.8 (15.9,17.8)*	1.17 (0.97, 1.40)**	0.56 (0.41, 0.74)**	0.44 (0.29, 0.63)**	0.58 (0.45, 0.73)**
Girls (n = 12,974)	15.3 (14.3, 16.3)	0.53 (0.38, 0.72)	0.22 (0.13, 0.34)	0.30 (0.19, 0.46)	0.15 (0.08, 0.26)
Race-ethnicity					
Whites (n = 7264)	13.9 (12.6, 15.2)**	0.59 (0.4, 0.84)**	0.23 (0.13, 0.38)**	0.35 (0.19, 0.58)	0.16 (0.08, 0.28)**
Non-Hispanic blacks (n = 7671)	20.3 (19.2, 21.4)	1.93 (1.60, 2.30)	1.10 (0.86, 1.38)	0.65 (0.48, 0.87)	0.92 (0.69, 1.19)
Mexican-American (n = 7919)	21.0 (19.8, 22.2)	0.89 (0.67, 1.15)	0.46 (0.30, 0.67)	0.19 (0.10, 0.31)	0.67 (0.47, 0.92)
Other (n = 3626)	16.0 (14.5, 17.5)	0.82 (0.46, 1.34)	—	—	—
Age group, y					
2–5.9 (n = 5919)	10.8 (9.8, 12.0)**	1.11 (0.80, 1.48)	0.42 (0.22, 0.71)	—	0.80 (0.55, 1.13)*
6–11.9 (n = 7987)	17.1 (16.0, 18.3)	0.96 (0.72, 1.25)	0.39 (0.26, 0.56)	0.58 (0.39, 0.84)*	0.25 (0.15, 0.37)
12–19.9 (n = 12,674)	17.7 (16.5, 18.8)	0.67 (0.49, 0.90)	0.38 (0.25, 0.58)	0.24 (0.13, 0.40)	0.26 (0.16, 0.40)

[1] All values are prevalences (%); 95% CIs in parentheses. Values and are not shown if the relative SE was >30%. Estimates of obesity did not exclude values considered to be BIVs. *P* values indicate whether there was a significant difference in levels of each column variables across sex, race-ethnicity, or age groups. These differences were assessed in ANOVA models that included race, sex, and age group as predictor variables.

* $P < 0.05$,

** $P < 0.001$.

BIV, biologically implausible value.

TABLE 2

Characteristics of selected children and adolescents who had a high BIV[1]

Sex	Age, y	BMI kg/m^2	BMI *z* score$_M$	Weight kg	Weight *z* score$_M$	Waist circumference cm	Waist circumference Percentile	Arm circumference cm	Arm circumference Percentile	Height cm	Height *z* score$_M$	Leg length cm	Leg length Percentile
Girl	8	27.1	3.3	61.6	5.1	82.7	96	28.6	97	150.8	3.7	—	—
Boy	14	37.7	3.8	127.6	5.4	115.3	97	37.3	96	184.0	2.5	—	—
Boy	17	43.2	4.5	154.8	5.5	140.0	99	41.2	96	189.4	1.9	—	—
Boy	5	23.9	5.1	28.7	3.1	74.5	98	22.0	95	109.6	0.1	—	—
Boy	18	46.6	5.2	154.2	5.4	112.8	94	52.8	99	181.9	0.9	—	—
Boy	5	23.3	5.2	24.4	2.4	66.6	97	21.5	95	102.4	−0.8	—	—
Boy	5	24.2	5.6	30.8	4.4	66.4	96	24.6	99	112.9	1.3	—	—
Boy	16	47.7	5.6	130.4	4.7	132.1	99	40.4	96	165.3	−1.0	—	—
Boy	16	60.2	8.1	191.7	8.6	158.9	99	—	—	178.5	0.7	—	—
Boy	17	60.9	8.2	215.3	9.5	163.0	99	55.0	99	188.1	1.8	—	—
Boy	16	62.7	8.7	181.3	8.2	157.8	99	51.8	99	170.0	−0.3	—	—
Boy	8	42.4	9.2	80.2	9.3	115.0	99	37.5	99	137.5	2.0	—	—
Girl	3	33.2	10.6	37.3	10.0	88.5	99	—	—	106.0	2.6	—	—
Boy	5	32.9	11.2	50.5	10.7	95.1	99	27.8	99	123.8	3.6	—	—
Boy	10	21.1	1.0	58.3	2.5	—	—	—	—	166.4	3.8	43.7	99
Girl	13	18.1	−0.2	60.6	1.1	—	—	—	—	182.9	3.9	44.8	99
Boy	8	20.2	1.4	46.2	3.2	—	—	—	—	151.4	3.9	37.4	99
Boy	13	34.6	3.3	123.2	5.7	—	—	—	—	188.7	3.9	49.0	99
Girl	9	27.2	3.0	66.3	4.9	—	—	—	—	156.1	3.9	36.3	97
Boy	18	19.9	−1.0	83.2	1.0	—	—	—	—	204.4	4.0	54.0	99
Boy	11	27.9	2.4	83.6	4.3	—	—	—	—	173.1	4.1	38.4	87
Girl	11	33.1	3.2	105.1	5.5	—	—	—	—	178.2	4.3	45.0	99

[1]Values are shown for 8 subjects (top rows) who had a weight$_{MZ}$ > 5 or a BMI$_{MZ}$ > 5 and at least one circumference that was less than the 97th percentile, for 6 subjects (middle rows) who had a BMI$_{MZ}$ ≥ 8 and a weight$_{MZ}$ > 8, and for 8 subjects (bottom rows) who had a height$_{MZ}$ > 3.75. Within each section, subjects are listed in ascending order of the modified *z* score. BIV, biologically implausible value; BMI$_{MZ}$, modified BMI *z* score; height$_{MZ}$, modified height *z* score; weight$_{MZ}$, modified weight *z* score.

TABLE 3

Minimum and maximum values of weight, height, and BMI by year of age in 2- to 19-y-olds in the NHANES 1999–2000 to 2011–2012[1]

		Weight, kg		Height, cm		BMI, kg/m^2	
Age, y	***n***	**Minimum**	**Maximum**	**Minimum**	**Maximum**	**Minimum**	**Maximum**
2	1774	8.9	27.5 (8.0)	79.0	105.3 (4.1)	11.5	29.5 (8.1)
3	1393	9.9	37.3 (10.0)	84.6	114.3 (3.4)	12.4	33.2 (10.6)
4	1461	11.1	50.5 (10.7)	89.7	135.2 (5.8)	8.0	32.9 (11.2)
5	1291	11.5	44.1 (6.9)	90.7	132.5 (3.6)	12.1	30.2 (8.5)
6	1316	14.5	53.0 (6.4)	99.0	139.2 (3.7)	12.1	30.9 (7.5)
7	1356	16.6	80.2 (9.3)	107.1	144.3 (3.5)	11.5	42.4 (9.2)
8	1360	17.1	88.5 (8.0)	105.5	156.1 (3.9)	12.1	46.1 (8.1)
9	1330	19.4	87.4 (6.0)	118.0	161.7 (3.5)	12.5	39.6 (6.4)
10	1280	20.3	104.0 (6.3)	122.0	167.5 (3.8)	12.3	40.7 (5.8)
11	1345	20.4	130.1 (7.2)	116.4	178.2 (4.3)	12.4	45.1 (6.3)
12	1609	24.0	143.6 (8.3)	129.3	182.9 (3.9)	12.6	54.4 (7.8)
13	1659	27.7	155.6 (7.9)	135.2	188.7 (3.9)	13.3	55.2 (7.5)
14	1623	28.4	165.0 (7.7)	138.5	190.8 (3.6)	13.4	57.2 (7.6)
15	1505	29.8	181.3 (8.2)	119.8	195.0 (3.2)	14.1	62.7 (8.7)
16	1644	34.0	215.3 (9.5)	134.8	198.3 (3.3)	15.3	60.9 (8.2)
17	1586	35.4	176.0 (6.9)	140.9	198.2 (3.7)	14.1	62.1 (7.7)
18	1485	33.7	201.5 (8.1)	133.0	204.4 (4.0)	15.5	57.1 (6.9)
19	1463	37.3	171.2 (6.2)	143.3	202.0 (3.5)	15.1	60.0 (7.6)

[1] Maximum modified weight *z* scores are shown in parentheses.