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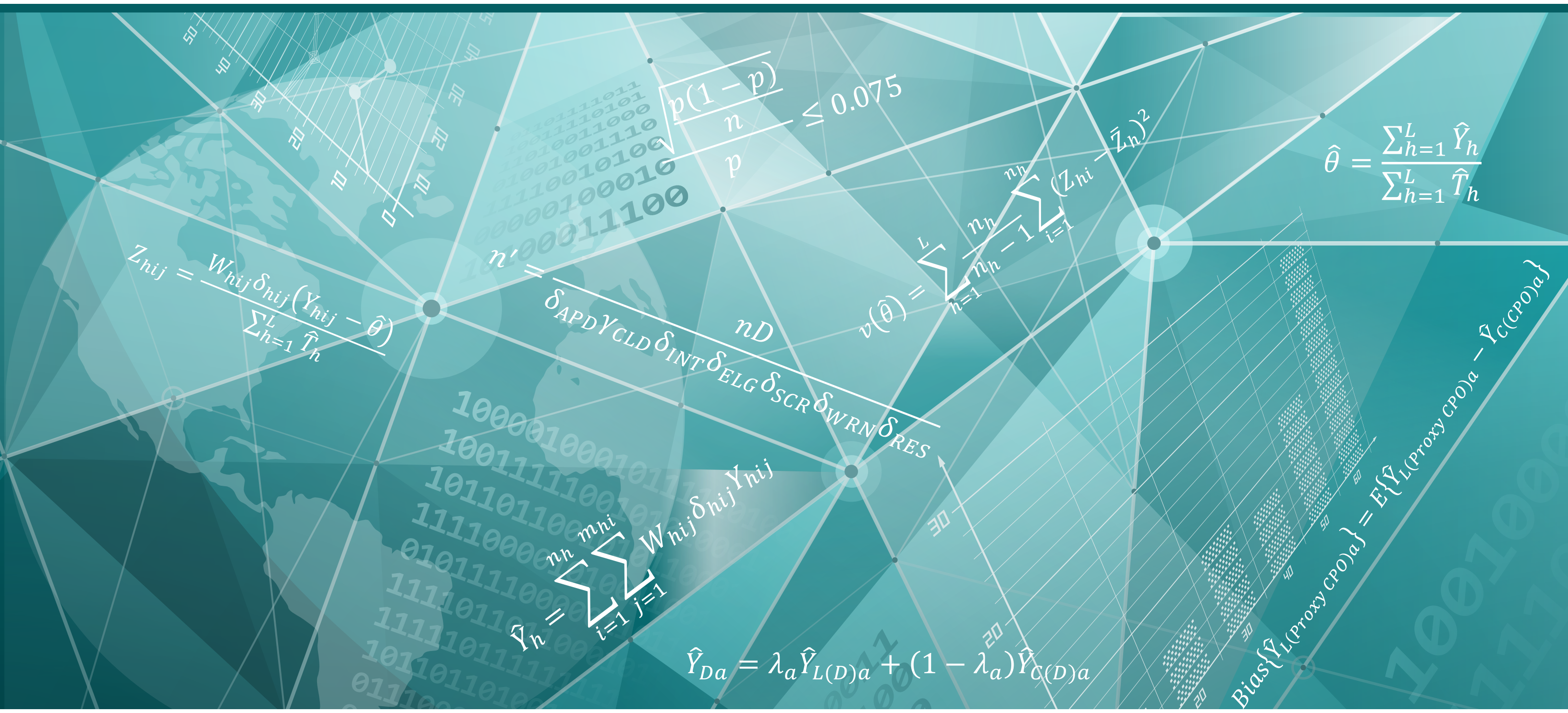

Evaluation of Alternative Body Mass Index (BMI) Metrics to Monitor Weight Status in Children and Adolescents With Extremely High BMI Using CDC BMI-for-age Growth Charts

Data Evaluation and Methods Research

U.S. DEPARTMENT OF HEALTH AND HUMAN SERVICES
Centers for Disease Control and Prevention
National Center for Health Statistics

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Data Evaluation and Methods Research

U.S. DEPARTMENT OF HEALTH AND HUMAN SERVICES
Centers for Disease Control and Prevention
National Center for Health Statistics

Hyattsville, Maryland
December 2022

National Center for Health Statistics

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Evaluation of Alternative Body Mass Index (BMI) Metrics to Monitor Weight Status in Children and Adolescents With Extremely High BMI Using CDC BMI-for-age Growth Charts

by Craig M. Hales, National Center for Health Statistics; David S. Freedman, National Center for Chronic Disease Prevention and Health Promotion; Lara Akinbami, Rong Wei, and Cynthia L. Ogden, National Center for Health Statistics

Abstract

Background

In the United States, obesity and severe obesity in children and adolescents are defined using threshold values from the 2000 Centers for Disease Control and Prevention (CDC) sex-specific body mass index (BMI)-for-age growth charts. BMI z-scores and percentiles from the 2000 CDC BMI-for-age growth charts are also used to monitor children's weight status over time and to evaluate obesity treatments. Parameters to calculate percentiles and corresponding z-scores (BMI*z*) were derived from selected percentiles between the 3rd and 97th. Use of the BMI-for-age growth charts for children and adolescents with extremely high BMI requires extrapolation beyond the 97th percentile, which leads to compression of BMIz values into a very narrow range and is not recommended. This report evaluates eight alternative BMI metrics for monitoring weight status in children and adolescents with extremely high BMI.

Methods

The following BMI metrics were evaluated based on ease of use and understanding in clinical and research settings and compatibility with current weight status categorizations: 1) untransformed BMI, 2) percent of the 95th percentile, 3) BMI units from the median, 4) adjusted BMI units from the median, 5) percent from the median, 6) adjusted percent from the median, 7) modified BMIz, and 8) extended BMIz.

Results

All eight alternatives offer a solution to the problem of compression at extreme BMI values. However, the extended method 1) improves the characterization of BMI distributions at very high values using additional data from the National Health and Nutrition Examination Survey (NHANES), 1999–2016 (instead of relying on extrapolation), and 2) preserves current CDC 2000 z-scores and percentiles below the 95th percentile, which allows seamless transitions among weight categories of obesity, overweight, and healthy weight.

Conclusion

To facilitate implementation of the extended method described above, the 95th percentile in research and clinical settings, extended z-scores and percentiles have been incorporated into CDC clinical growth charts and computer programs, available from: https://www.cdc.gov/growthcharts.

Keywords: obesity • overweight • National Health and Nutrition Examination Survey (NHANES)

Introduction

In the United States, obesity and severe obesity in children and adolescents are defined using threshold values from the 2000 Centers for Disease Control and Prevention (CDC) sex-specific body mass index (BMI, calculated as kg/m^2)-for-age growth charts (1–3). In addition to defining obesity, BMI z-scores and percentiles are used to monitor children's weight status over time and to evaluate obesity treatments in research settings. Because percentiles near the upper limit of 100% become less useful for detecting meaningful differences (for example, 99.99 compared with 99.999th percentile), percentiles can be converted to z-scores that indicate the number of standard deviations of a value from the mean. However, BMI z-scores (BMI*z*) and percentiles based on the 2000 BMI-for-age CDC growth charts (BMIz [CDC 2000] and BMI percentiles [CDC 2000]) were never meant to be used to monitor children with extremely high BMI values, and significant limitations exist when they are used to monitor children with severe obesity (2,4,5). Namely, BMIz (CDC 2000) values corresponding to extremely high BMI values are compressed into a very narrow range (5).

Studies on obesity prevalence, its impact, and the availability of effective treatment have highlighted the need for meaningful standardized measures to track extremely high values of BMI in clinical and research settings (5–8). The National Center for Health Statistics (NCHS) has been exploring alternative metrics to describe and monitor weight status in children and adolescents with extremely high BMI values (4,9). This report summarizes the limitations of BMIz (CDC 2000), presents the strengths and limitations of alternative BMI metrics, and recommends a BMI metric to describe and monitor the weight status of children with extremely high BMI values.

2000 CDC BMI-for-age Growth Charts

The 2000 CDC BMI-for-age growth charts serve as a reference for monitoring growth and development among children and adolescents aged 2 through 19 years in the United States (Figure 1). These charts were developed using nationally representative cross-sectional data from the National Health Examination Surveys II and III (1960s) and the National Health and Nutrition Examination Surveys (NHANES) I (1970–1973), II (1976–1980), and III (1988–1994, data from children aged 2 months through 6 years only). The BMI-for-age growth charts include percentiles between the 3rd and 97th percentiles that were smoothed using various methods (2,10). Because of sparse data on children and adolescents above the 97th percentile, reliable percentile curves above this percentile could not be generated.

Parameters that characterize the sex-specific BMI distribution at 1-month intervals for youth aged 2 through 19 years were estimated to enable the calculation of percentiles and z-scores between the smoothed curves. The L parameter is the Box–Cox power transformation required to correct for skewness, or lack of symmetry, in the distribution, while M represents the median BMI, and S is the coefficient of variation (standard deviation divided by median) indicating the dispersion of the BMI distribution (11,12). Although the 2000 CDC growth charts also present values of LMS parameters, these were not generated through use of the LMS method developed by Cole (11–14). In the original LMS method, LMS parameters are estimated from the data, smoothed, and then can be used to create any desired percentiles. In the method used for the 2000 CDC BMI-for-age growth charts, a set of preselected percentiles were estimated from the data and smoothed using a variety of statistical methods (2). LMS parameters for the CDC 2000 BMI-for-age growth charts were then estimated such that the resulting distribution matched the smoothed 3rd through 97th percentiles. No data beyond these levels were used. Thus, the CDC 2000 LMS parameters were not designed to generate any percentile values above the 97th percentile or below the 3rd percentile. Figure 2 Panels A–C show the sex- and age-specific values of the CDC L, M, and S parameters. Using the sex- and age-specific values of these parameters in the CDC BMI-for-age growth charts (11,12,14), the BMIz (CDC 2000) of any child or adolescent is defined as:

$$BMIz(CDC\ 2000) = \frac{(BMI/M)^L - 1}{L \bullet S} \qquad [1]$$

A direct correspondence between z-scores and percentiles exists; for example, a z-score of 1.645 is equal to the 95th percentile.

Limitations of BMI z-score (CDC 2000) for BMI Greater Than 97th Percentile

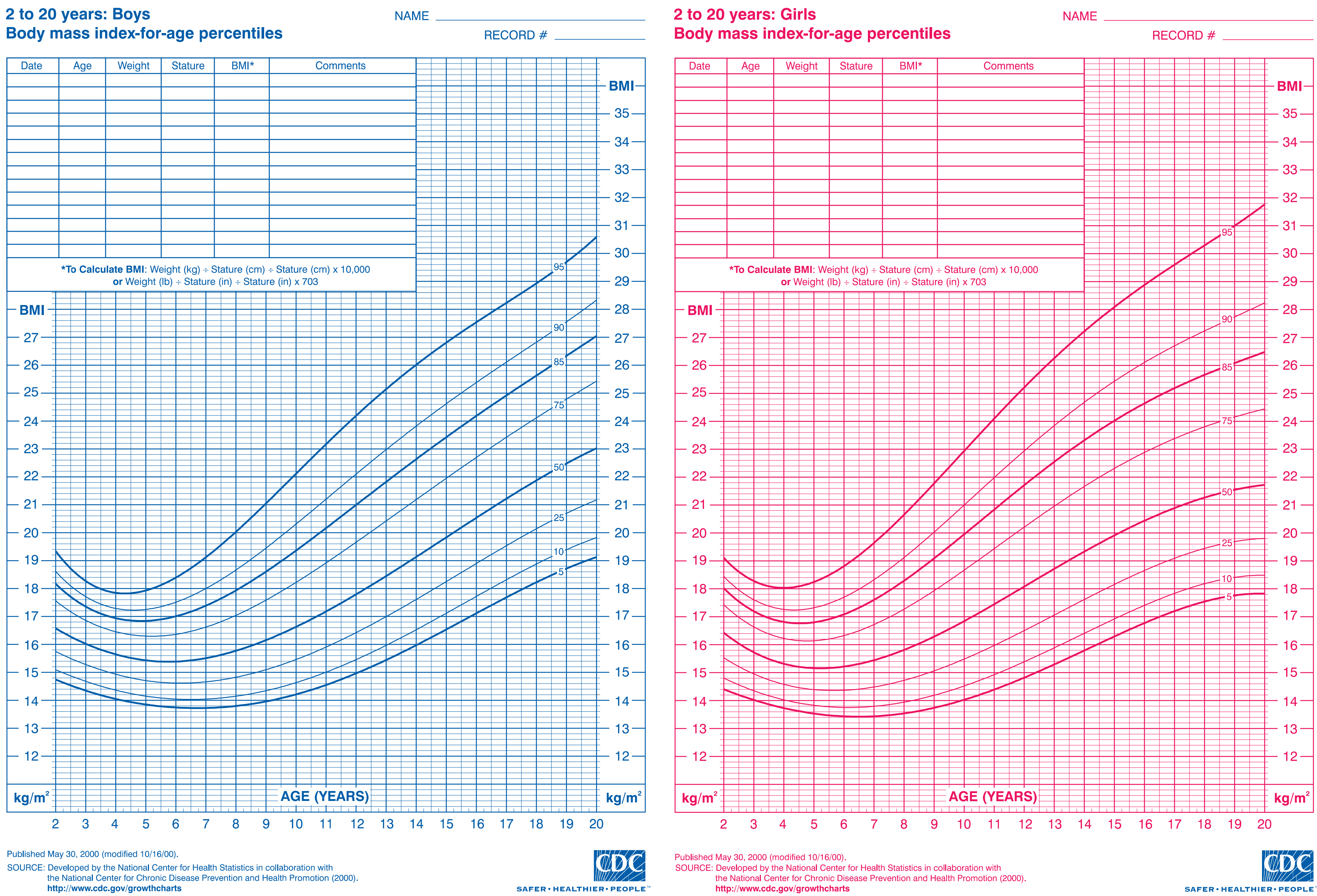
Because LMS parameters for calculating BMIz (CDC 2000) were based on selected (3rd, 5th, 10th, 25th, 50th, 75th, 85th, 90th, 95th, and 97th) smoothed percentiles, these parameters are valid only within this percentile range, and should not be used to extrapolate values above the 97th percentile (2,14). These LMS parameters should not be used to calculate z-scores outside this range because it often results in unusual and unexpected results. For example, Figure 3 shows that a BMIz (CDC 2000) of 4 does not exist after age 5.5 years for boys or after age 4 years for girls.

Equation [1] shows that as a child's BMI becomes very large relative to the median, $(BMI/M)^L$ would approach 0 because L is less than -1 at all ages and less than -2 at most ages (Figure 2 Panel A). Therefore, as BMI becomes very large, the maximum BMIz (CDC 2000) is defined only by the values of the sex- and age-specific values of the L and S parameters:

$$(-1)/(L \bullet S) \qquad [2]$$

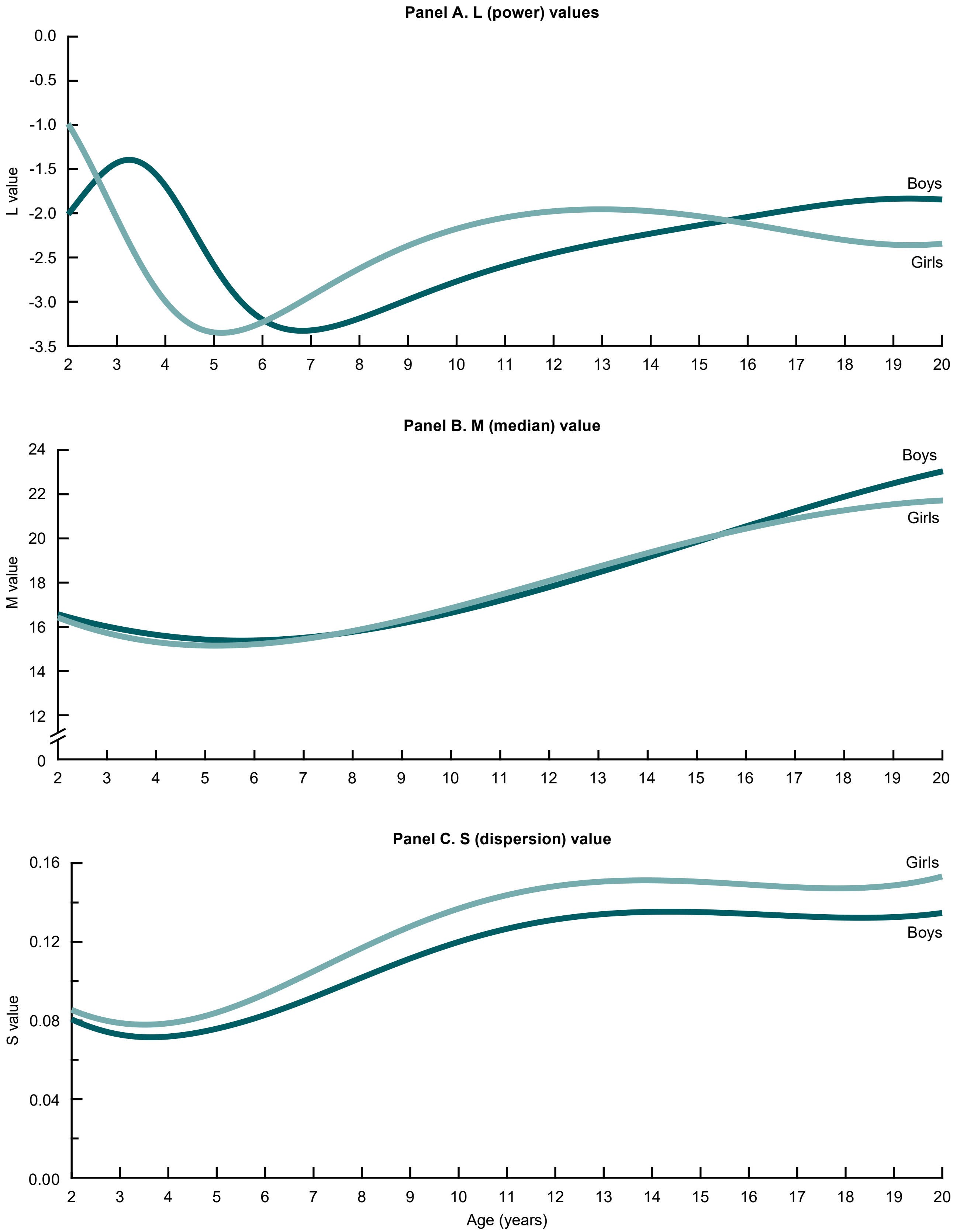
Given the sex- and age-specific values of L (Figure 2 Panel A) and S (Figure 2 Panel C) from age 2 through 19 years, the maximum value of BMIz (CDC 2000) among girls decreases from about +11.5 at age 2 years to below +2.8 at age 19 years (Figure 4). Because of these inconsistencies in the maximum value of BMIz (CDC 2000) by age, the z-score of a young child with an extremely high BMI can decrease by more than 1 unit or standard deviation even if there is a substantial increase in BMI over time (15). Also, at extremely high BMI values, the corresponding BMIz (CDC 2000) approaches a maximum value and becomes increasingly compressed such that very large changes in BMI correspond to very small changes in z-score. Figure 5 illustrates this among 3-, 9-, and 17-year-old boys and girls for the range of BMI values observed in NHANES, 2015–2018 (16). At lower BMI values, a small increase in BMI is associated with a large increase in BMIz (CDC 2000), while at higher BMI values, a large

Figure 1. Centers for Disease Control and Prevention 2000 body mass index-for-age growth charts for boys and girls



NOTE: BMI is body mass index.
SOURCE: Centers for Disease Control and Prevention.

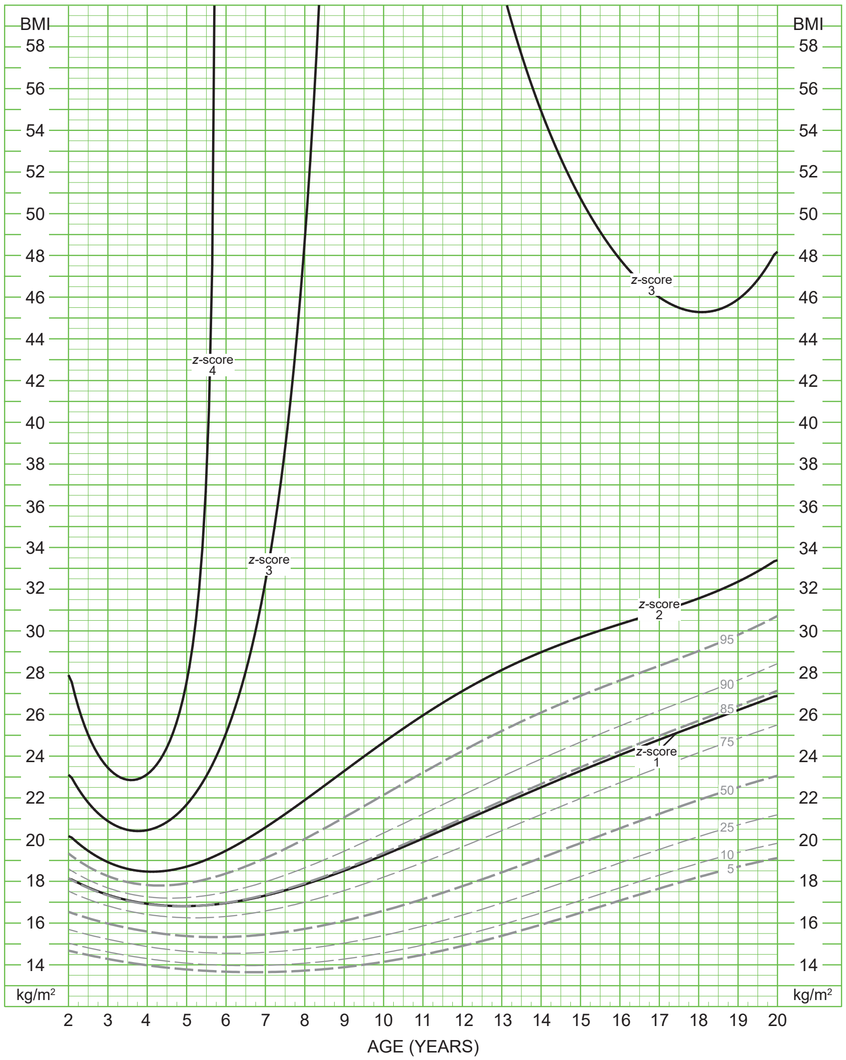
Figure 2. L (power), M (median), and S (dispersion) values for Centers for Disease Control and Prevention 2000 body mass index-for-age growth charts, by sex and age



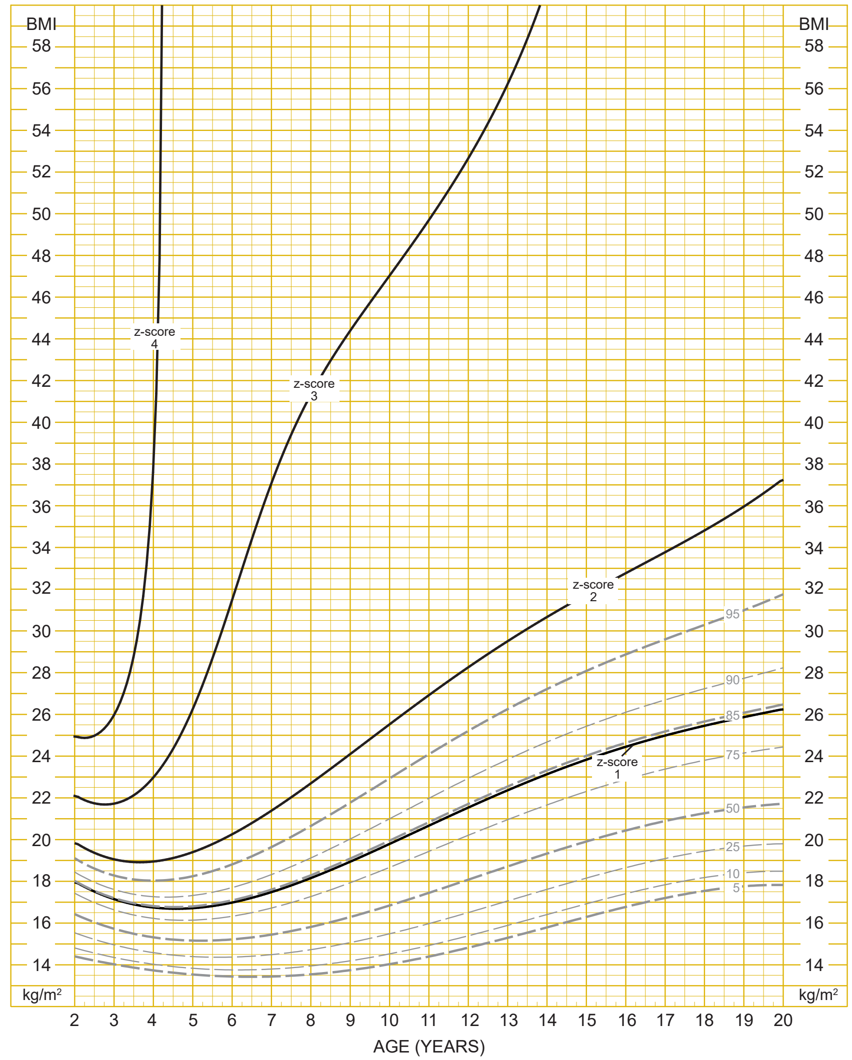
SOURCE: Centers for Disease Control and Prevention 2000 body mass index-for-age growth charts.

Figure 3. Centers for Disease Control and Prevention 2000 body mass index percentiles (5th–95th) and z-scores of 1, 2, 3, and 4

BMI z-score (CDC 2000): Boys

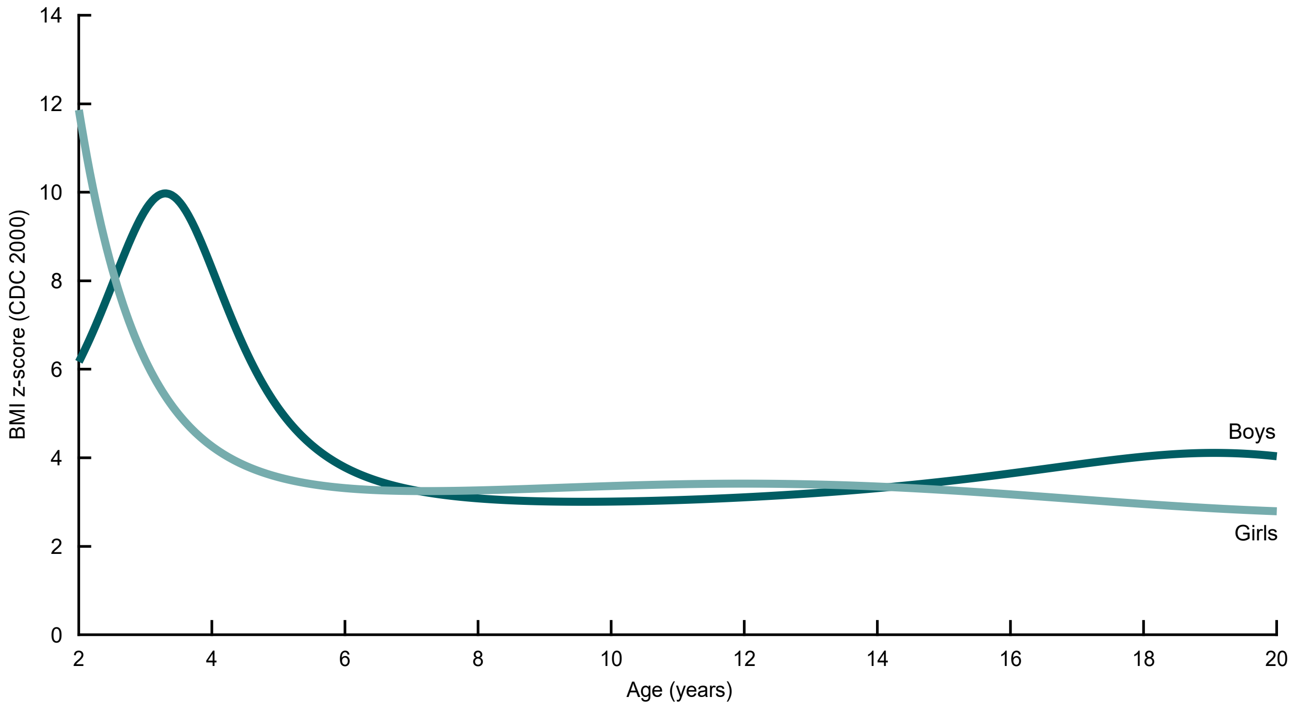


BMI z-score (CDC 2000): Girls



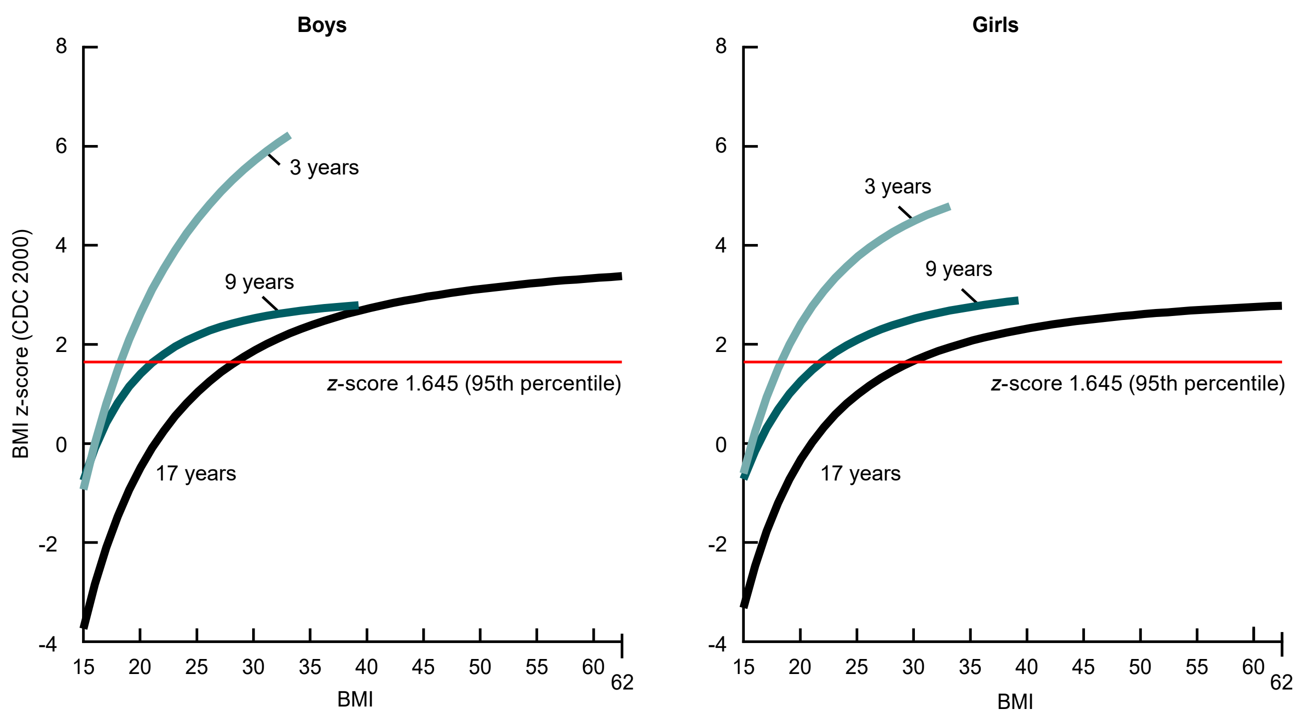
NOTES: BMI is body mass index. CDC is Centers for Disease Control and Prevention.
SOURCE: Centers for Disease Control and Prevention 2000 BMI-for-age growth charts.

Figure 4. Maximum possible values of BMI z-score (CDC 2000), by sex and age



NOTES: BMI is body mass index. CDC is Centers for Disease Control and Prevention.
SOURCE: Centers for Disease Control and Prevention 2000 BMI-for-age growth charts.

Figure 5. Relationship between BMI and BMI z-score (CDC 2000) for boys and girls aged 3, 9, and 17 years



NOTES: BMI is body mass index. CDC is Centers for Disease Control and Prevention.
SOURCE: Centers for Disease Control and Prevention 2000 BMI-for-age growth charts.

change in BMI is associated with only a small change in BMIz (CDC 2000). For example, compared with a 9-year-old boy with a BMI of 45, a 9-year-old boy with a BMI of 50 would have a BMIz (CDC 2000) that is only 0.04 units higher (2.91 compared with 2.87). Furthermore, the amount of variability in BMIz (CDC 2000) at extremely high BMI values differs by age, making this metric an inconsistent measure to track BMI change over time (17).

Using the CDC BMI-for-age Growth Charts to Identify Biologically Implausible Values

Because of these known issues, when the 2000 CDC BMI-for-age growth charts were released, caution was advised about extrapolating beyond the 97th percentile (2). However, a metric or analytic tool was needed to identify implausibly high or low body size measures (that may be a result of errors in data entry or measurement). To identify biologically implausible values, CDC developed a modified z-score (BMIz [modified]) (18) that does not have an upper limit. While BMIz (modified) addressed the issue of compressed z-score values at extremely high BMI values, this measure was designed only for assessing data quality, not for monitoring extremely high BMI values in clinical, community, or public health contexts.

Using the CDC BMI-for-age Growth Charts to Define Weight Status

In the United States, obesity in children and adolescents is defined as BMI at or above the 95th percentile of sex-specific BMI-for-age, overweight is defined as between the 85th and 95th percentiles, and healthy weight is defined as between the 5th and 85th percentiles (1). Because the 97th percentile was the highest percentile in the CDC BMI-for-age growth charts used to estimate values of L, M, and S, using these percentiles or z-scores to define severe obesity has proved challenging. An early suggestion for a threshold for severe obesity was the extrapolated 99th percentile, equivalent to BMIz (CDC 2000) of 2.326 (19,20). Flegal et al (4) proposed using a percentage of the sex-specific 95th percentile to describe children with extremely high BMI values because 120% of the 95th percentile is a better approximation of the empirical 99th percentile at most ages than is the LMS-extrapolated 99th percentile. Thus, the threshold of 120% of the 95th percentile or BMI greater than or equal to 35 (the threshold for class II obesity in adults) (3) or just 120% of the 95th percentile (21,22) has been increasingly used in classifying severe obesity in children and adolescents.

Alternative BMI Metrics for Assessing and Monitoring Weight Status of Children and Adolescents With Extremely High BMI Values

BMI z-scores derived from the LMS parameters associated with the 2000 CDC BMI-for-age growth charts (BMIz [CDC 2000]) have been used widely in the literature to monitor the weight status of children and to evaluate the impact of obesity interventions (22–26). As described previously, large differences between extremely high BMI values result in small differences in BMIz (CDC 2000) because BMIz (CDC 2000) values are compressed near the upper bound (5). Several alternative metrics to the BMIz (CDC 2000) have been proposed in the literature (6,15,27–30). In response to the need for a uniform standard, NCHS published a Federal Register notice in January 2018 suggesting adding curves for various percentages of the 95th percentile to CDC BMI-for-age growth charts (9). Public feedback resulted in many supportive comments but also a recognition that percent of the 95th percentile, although currently used in some clinical settings, still presented some limitations.

To launch discussions of alternative metrics, NCHS convened a workshop on February 21–22, 2018, with about 30 participants from CDC, the National Institutes of Health, and academia. The goals were to discuss alternatives to the 2000 CDC BMI z-score (BMIz [CDC 2000]) and how best to evaluate these alternative metrics. Most workshop participants agreed on the following desirable characteristics of a BMI metric: 1) be easy to use and understand in clinical settings as well as for research evaluating obesity treatments; 2) preserve existing definitions of overweight and obesity based on 2000 CDC BMI-for-age growth chart percentiles; and 3) reflect the mean and dispersion of BMI distribution by sex and age.

Eight alternatives to BMIz (CDC 2000) (Table A) were discussed at the workshop and are described below. Although the alternative metrics were proposed for use in children with extremely high BMI values, these metrics can also be calculated for BMI values below the 95th percentile. Figures 6–13 show each metric superimposed on CDC BMI-for-age percentiles from the 5th through the 95th percentile with an expanded BMI range on the y axis.

Alternative Metric 1: BMI (untransformed)

The first alternative is simply BMI itself, untransformed with respect to a reference or standard population. Charts with a higher BMI limit on the y axis (Figure 6) would allow children with extremely high BMI values to be plotted well above the existing percentile curves.

BMI (untransformed) has some strengths as an alternative to BMIz (CDC 2000). BMI is already understood by the clinical

Table A. Alternative metrics for extreme body mass index values

Metric	Description
1. BMI (untransformed)	BMI without transformation to account for sex- and age-specific BMI distribution from a reference population.
2. Percent of the 95th percentile	BMI expressed as a percentage of the 95th percentile from the CDC 2000 growth chart.
3. BMI units from the median	BMI expressed as kg/m^2 from the sex- and age-specific median from the CDC 2000 growth chart.
4. Percent from the median	BMI expressed as a percentage from the sex- and age-specific median from the CDC 2000 growth chart.
5. Adjusted BMI units from the median	BMI units from the median (Metric 3) standardized to values of S (dispersion) and M (median) at a reference age (see Appendix).
6. Adjusted percent from the median	Percent from the median (Metric 4) standardized to values of S (dispersion) at a reference age (see Appendix).
7. Modified BMI z-scores and percentiles	BMI expressed as a z-score or percentile based on the CDC 2000 growth chart, except the BMI distribution is characterized by an arbitrary value for dispersion.
8. Extended BMI z-scores and percentiles	BMI expressed as a z-score or percentile equivalent to the CDC 2000 BMI z-scores and percentiles up to the 95th percentile. Above the 95th percentile, extended z-scores are based on BMI distributions of children and adolescents with obesity from the CDC 2000 growth chart reference population; NHANES III, 1988–1994; and NHANES, 1999–2016.

NOTES: BMI is body mass index. CDC is Centers for Disease Control and Prevention.

SOURCE: National Center for Health Statistics, Centers for Disease Control and Prevention 2000 BMI-for-age growth charts.

and public health communities because BMI threshold values define overweight and obesity in adults, and percent BMI change is used to evaluate responses to weight loss interventions in children, adolescents, and adults (31,32). BMI transformation may not be needed in short-term studies during which only small changes in BMI due to normal growth and development are expected. Using BMI (untransformed) avoids the compression problem with BMIz (CDC 2000) at extremely high BMI values.

There are also limitations to using untransformed BMI. Untransformed BMI does not account for sex- and age-specific differences in BMI distributions due to normal growth and development (for example, changes in body composition throughout childhood and adolescence). In addition, changes in absolute or percent BMI can indicate vastly different types of change in weight status in older compared with younger children. Finally, untransformed BMI is not typically used for monitoring change over time in children without obesity, so it would be unsuitable in a mixed cohort of children with and without obesity.

Alternative Metric 2: Percent of the 95th Percentile

Percent of the 95th percentile was proposed as an alternative to BMI percentiles and z-scores (CDC 2000) for BMI values above the 97th percentile. Specifically, 120% of the 95th percentile was recommended as the cut point for defining severe obesity in children and adolescents because it approximates the empirical 99th percentile of the 2000 CDC BMI-for-age growth chart reference population (3). The use of a percentage of the 95th percentile for values beyond 120% has been suggested as a convenient way to characterize weight status at extremely high BMI values (6,33). Figure 7 shows 80%, 100%, 120%, 140%, 160%, and 180% of the 95th percentile superimposed on the CDC BMI-for-age growth charts.

A strength of this metric is its familiarity given the use of 120% of the 95th percentile for defining severe obesity (3). It has been widely used in the research and clinical settings, including in analyses of large cohorts in the peer-reviewed literature (34), and publicly available "severe obesity growth charts" (6) are now incorporated into several electronic health record systems. Also, percent of the 95th percentile does not show compression at extreme BMI values.

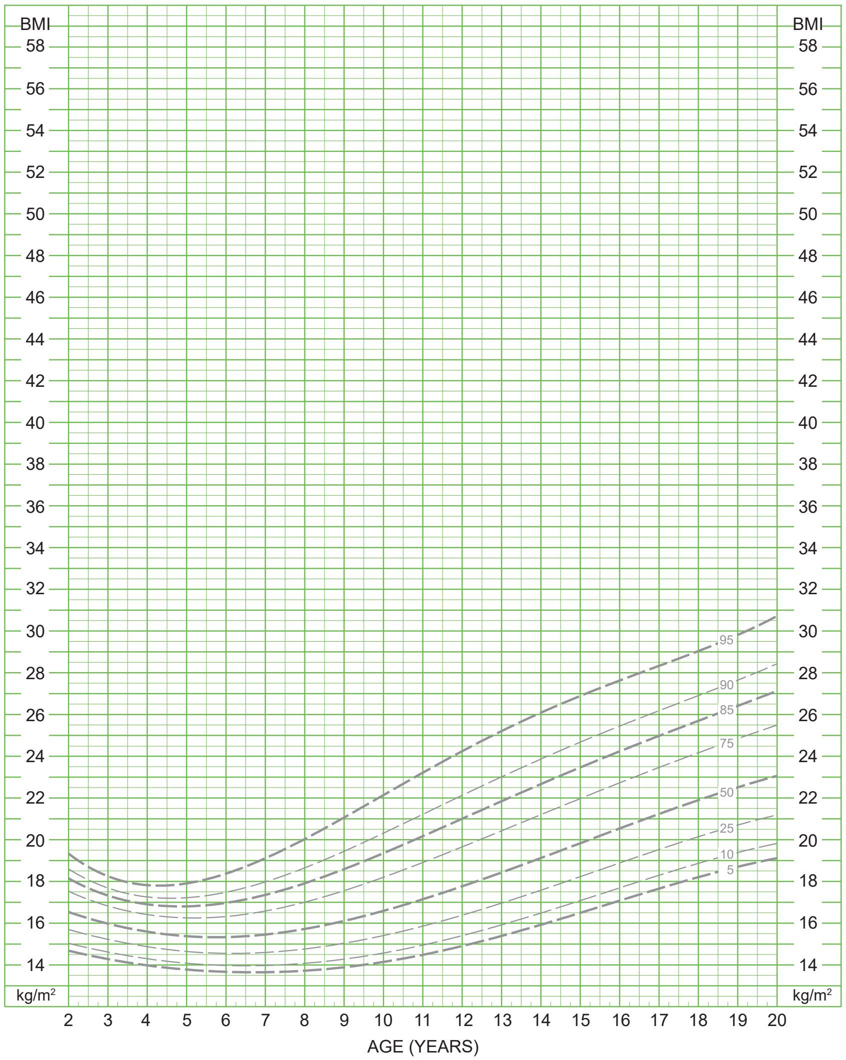
There are limitations in expressing BMI as a percentage of the 95th percentile. Percent of the 95th percentile only partly accounts for sex- and age-specific dispersion of BMI distributions. While the 95th percentile curve itself does account for BMI dispersion, BMI intervals above 120% of the 95th percentile are constant multiples of the 95th percentile at all ages and do not reflect the age-specific dispersion of BMI distributions in the higher range of BMI values. As a result, for Figure 7, the curves at and above 120% of the 95th percentile are approximately equidistant from one to the next. In contrast, the distances between the 3rd and 97th percentile curves vary with age, being much closer together for younger children than for older children and adolescents. Another consequence of only partial accounting for dispersion at younger ages is that the percent of the 95th percentile does not align with the definition of overweight (85th percentile).

Alternative Metrics 3 and 4: BMI Units From the Median and Percent From the Median

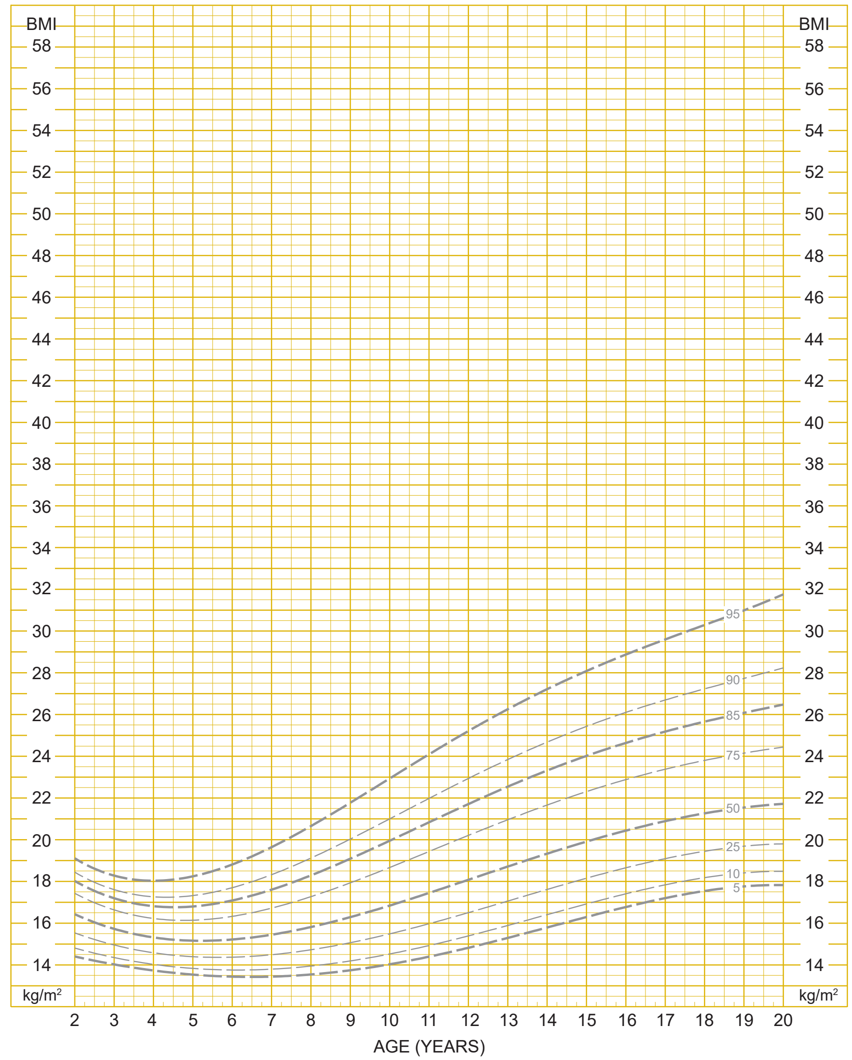
BMI units from the median (also called distance from median BMI) (Figure 8) and percent from the median (also called percent distance from the median BMI) (Figure 9) characterize a child's BMI relative to the sex- and age-specific median BMI (35). For example, the median BMI for 14-year-old girls in the CDC BMI-for-age growth charts is 19.4. If a 14-year-old girl had a BMI of 25, her BMI units from

Figure 6. Alternative metric 1: BMI (untransformed)

BMI (untransformed): Boys

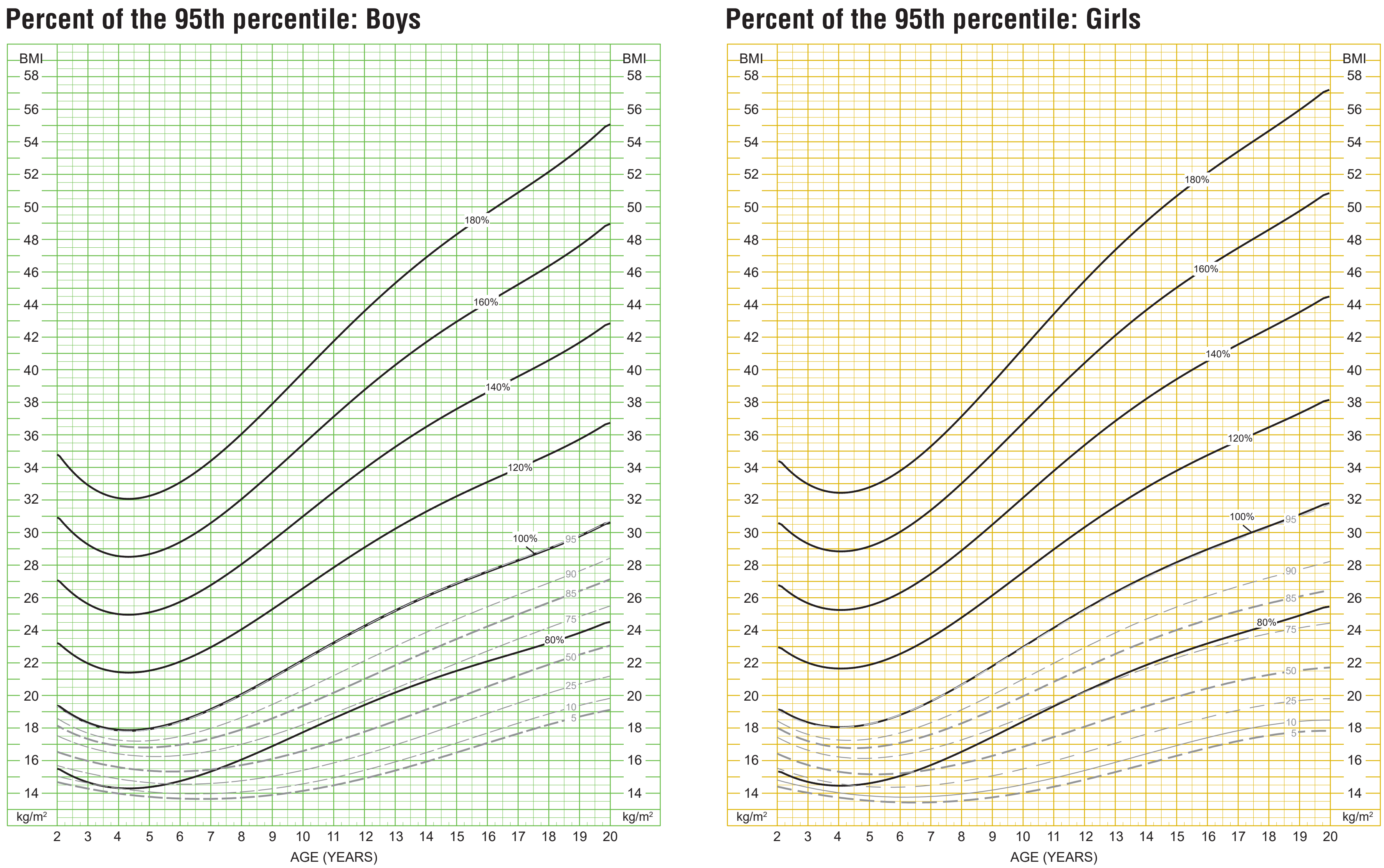


BMI (untransformed): Girls



NOTE: BMI is body mass index.
SOURCE: National Center for Health Statistics, Centers for Disease Control and Prevention 2000 BMI-for-age growth charts.

Figure 7. Alternative metric 2: Percent of the 95th percentile



NOTE: BMI is body mass index.
SOURCE: National Center for Health Statistics, Centers for Disease Control and Prevention 2000 body mass index-for-age growth charts.

the median would be 5.6 (25.0 minus 19.4), and her percent from the median would be 5.6 divided by 19.4, which equals 28.9%. If another 14-year-old girl had a BMI of 17, her BMI units from the median would be -2.4 (17 minus 19.4), and her percent from the median would be -2.4 divided by 19.4, which equals -12.4%. Percentages from the median are expressed as positive or negative values, with a BMI at the median having a value of 0 for both metrics.

The strengths of these metrics are that they: 1) account for sex and age differences in median BMI, and 2) are not compressed at extremely high BMI values. In addition, percent from an expected value has been used in studies of malnutrition in children (36,37), so there is precedent for using this unit of measurement.

These two metrics have some limitations. First, although they do account for sex- and age-specific median BMI, they do not account for the age-specific dispersion of BMI. As a result, any given BMI unit or percent from the median would have substantially different implications for younger children than for adolescents. Second, these metrics do not align with the current definitions of overweight and obesity. Third, except for studies of malnutrition, BMI units from the median and percent from the median are not commonly used for children and adolescents below the 95th percentile, so they would be an unfamiliar metric in most settings.

Alternative Metrics 5 and 6: Adjusted BMI Units From the Median and Percent From the Median

Adjusted BMI units from the median and percent distance from the median (Figures 10 and 11) transform BMI to account for not only median BMI but also for sex- and age-specific dispersion of BMI distributions. BMI units from the median and percent from the median were adjusted to allow comparison across childhood and adolescence, as they are standardized to values of S (both metrics) and M (BMI units from the median only) at a reference age (curves in Figures 10 and 11 were calculated using age 20 years [240 months] as the reference). The Appendix describes their calculation (35).

The shapes of the M and S curves (Figure 2 Panels B and C) indicate that the effect of adjusting BMI units from the median and percent from the median vary by age. Because values of S differ only slightly between ages 12 and 19 years, the adjusted percent from the median will be very close to the unadjusted percent from the median for this age range. Therefore, if cross-sectional or longitudinal associations using the unadjusted and adjusted metrics were compared in a study of 12- through 19-year-olds, the results would likely be very similar. It is only when comparisons are made across a wide range of ages that the advantages of adjusting BMI units from the median and percent from the median will be evident.

Adjusted BMI units and percent from the median have some advantages. As mentioned previously, these metrics adjust for differences in not only median BMI but also the dispersion of BMI across age and by sex. Also, the general shape of the curves for adjusted BMI units from the median and adjusted percent from median more closely resemble the shape of CDC BMI-for-age growth chart percentiles, especially for children over age 4 years. Another strength of these two metrics is the lack of compression seen with BMIz (CDC 2000) at extremely high BMI values.

These adjusted metrics also have some limitations. First, the values of S (dispersion) used in the adjustments were estimated from selected smoothed percentiles between the 3rd and 97th in the CDC BMI-for-age growth charts rather than from all the data. It is not certain how this influenced the estimates of the S parameter at various ages. Second, these adjusted metrics based on BMI units or percent from the median have rarely been used in research, clinical, and public health settings (35) and may be more difficult to understand and apply than many of the other metrics. Third, this scale does not align with the CDC cut points for overweight and obesity.

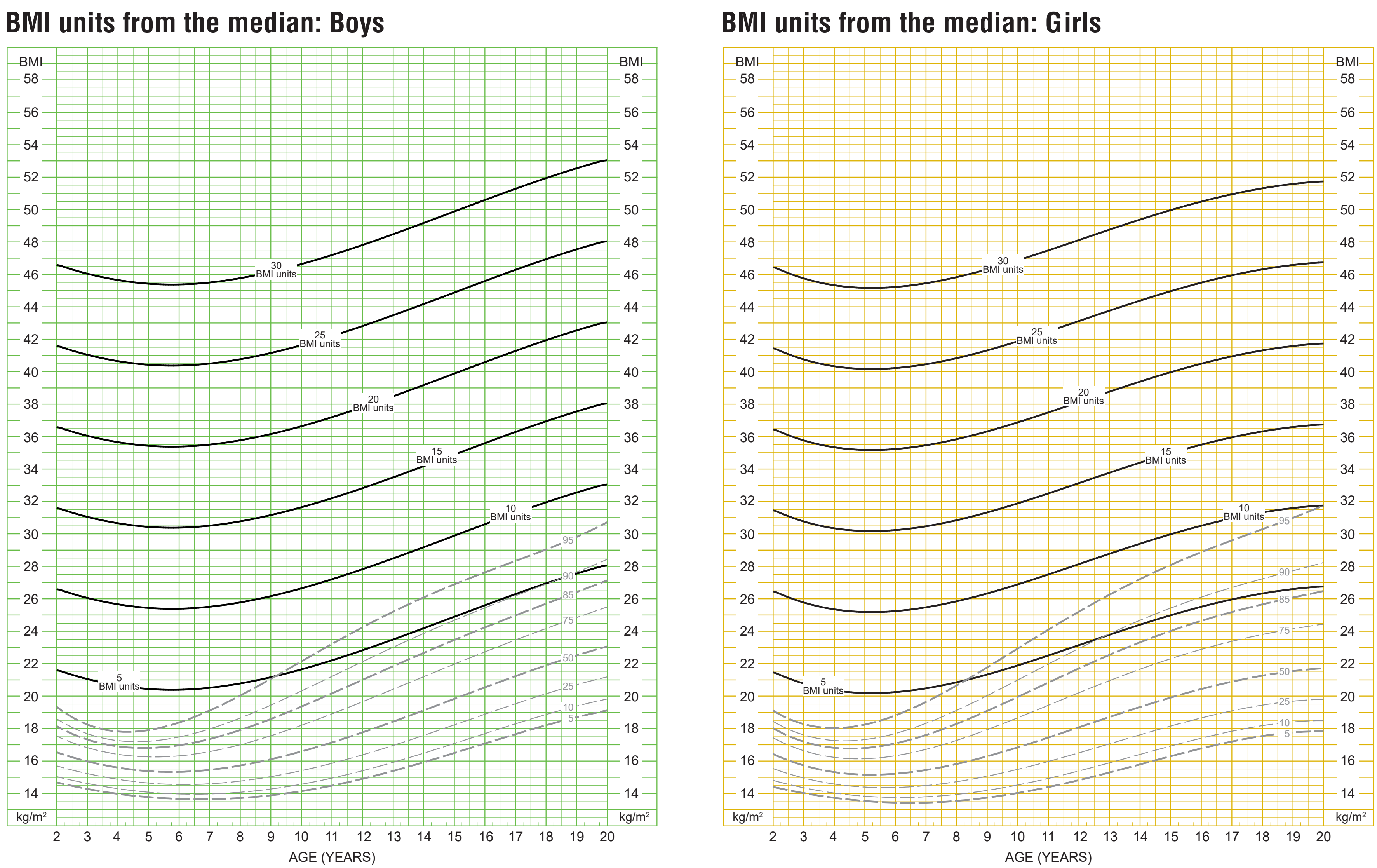
Alternative Metric 7: BMI z-scores and Percentiles (modified)

As described previously, CDC created modified BMI z-scores solely to identify outliers or biologically implausible values (18). BMIz (modified) was constructed by extrapolating one-half the distance (kg/m^2) between z-scores of 0 and +2 to the extremely high values, thereby removing the upper bound created by the LMS transformation. Although not created for tracking extremely high BMI values, some studies have nonetheless used BMIz (modified) to track children with severe obesity, and it has been suggested that this metric could be used to characterize the weight status of all children, not just those with extremely high BMIs (15,30). Figure 12 shows BMI values corresponding to BMIz (modified) values of +2, +3, +4, and +5 superimposed on the percentiles from the CDC BMI-for-age growth charts.

The strengths of BMIz (modified) are that it continues to use the familiar concept of z-scores and has been publicly available in the CDC growth charts SAS program (38). In addition, BMIz (modified) is characterized by increasing dispersion of BMI with increasing age and is not compressed at extremely high BMI values.

The main limitation of BMIz (modified) is the arbitrary assumption that one-half of the distance between z-scores of 0 and +2 can accurately characterize BMI distribution at extremely high BMI values. This assumption is likely to be wrong because it implies that the BMI distance between z-scores of 0 and +1 is similar to the distance between z-scores of +1 and +2, z-scores of +5 and +6, etc. For example, for 19-year-old females, the BMI difference between z-scores 0 and +1 is 4.3 BMI units, while the distance

Figure 8. Alternative metric 3: BMI units from the median

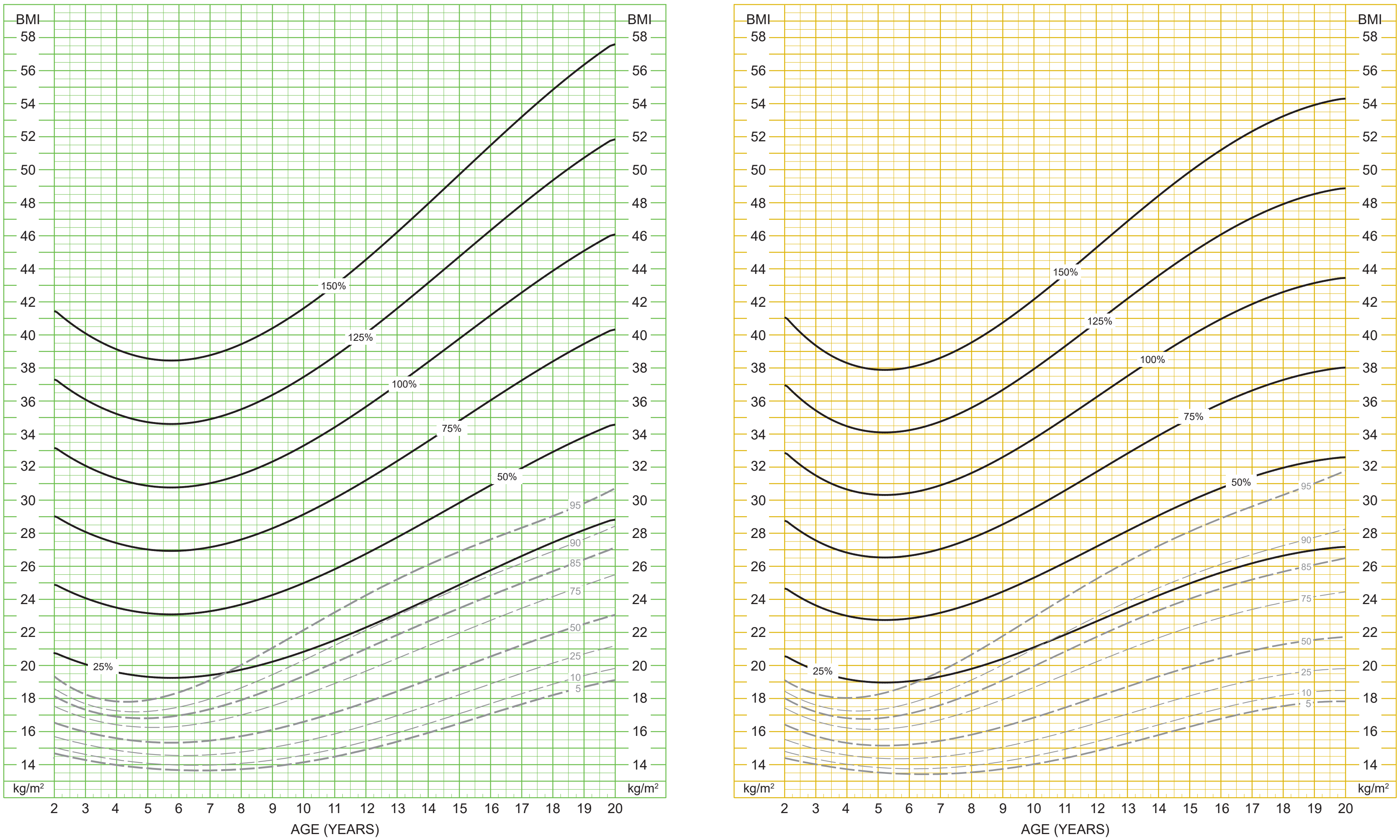


NOTE: BMI is body mass index.
SOURCE: National Center for Health Statistics, Centers for Disease Control and Prevention 2000 BMI-for-age growth charts.

Figure 9. Alternative metric 4: Percent distance from the median

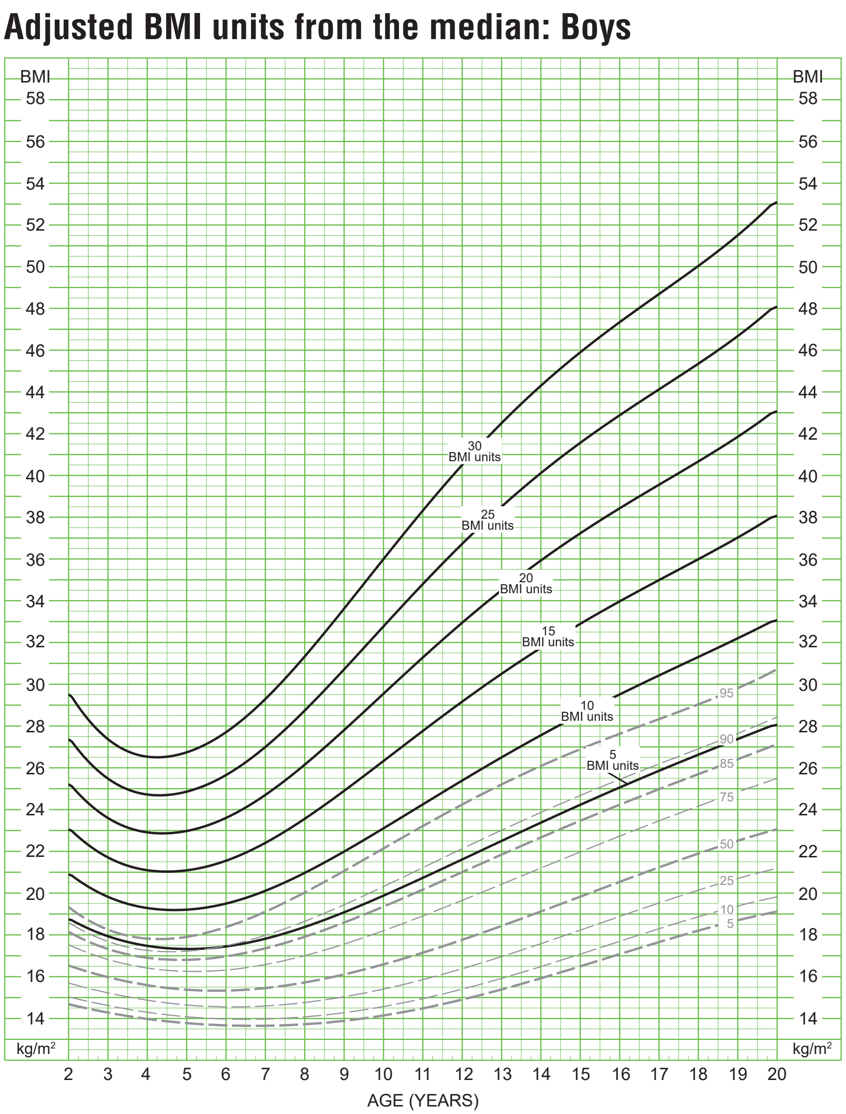
Percent distance from the median: Boys

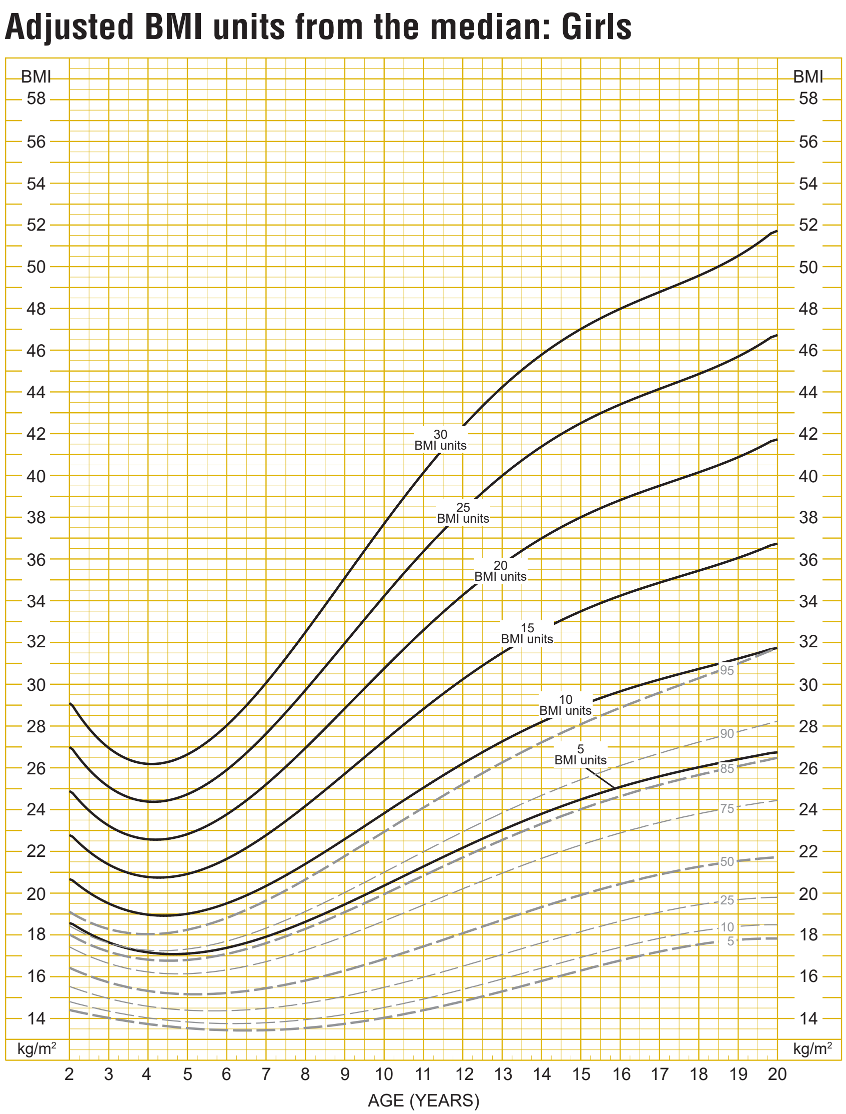
Percent distance from the median: Girls



NOTE: BMI is body mass index.
SOURCE: National Center for Health Statistics, Centers for Disease Control and Prevention 2000 BMI-for-age growth charts.

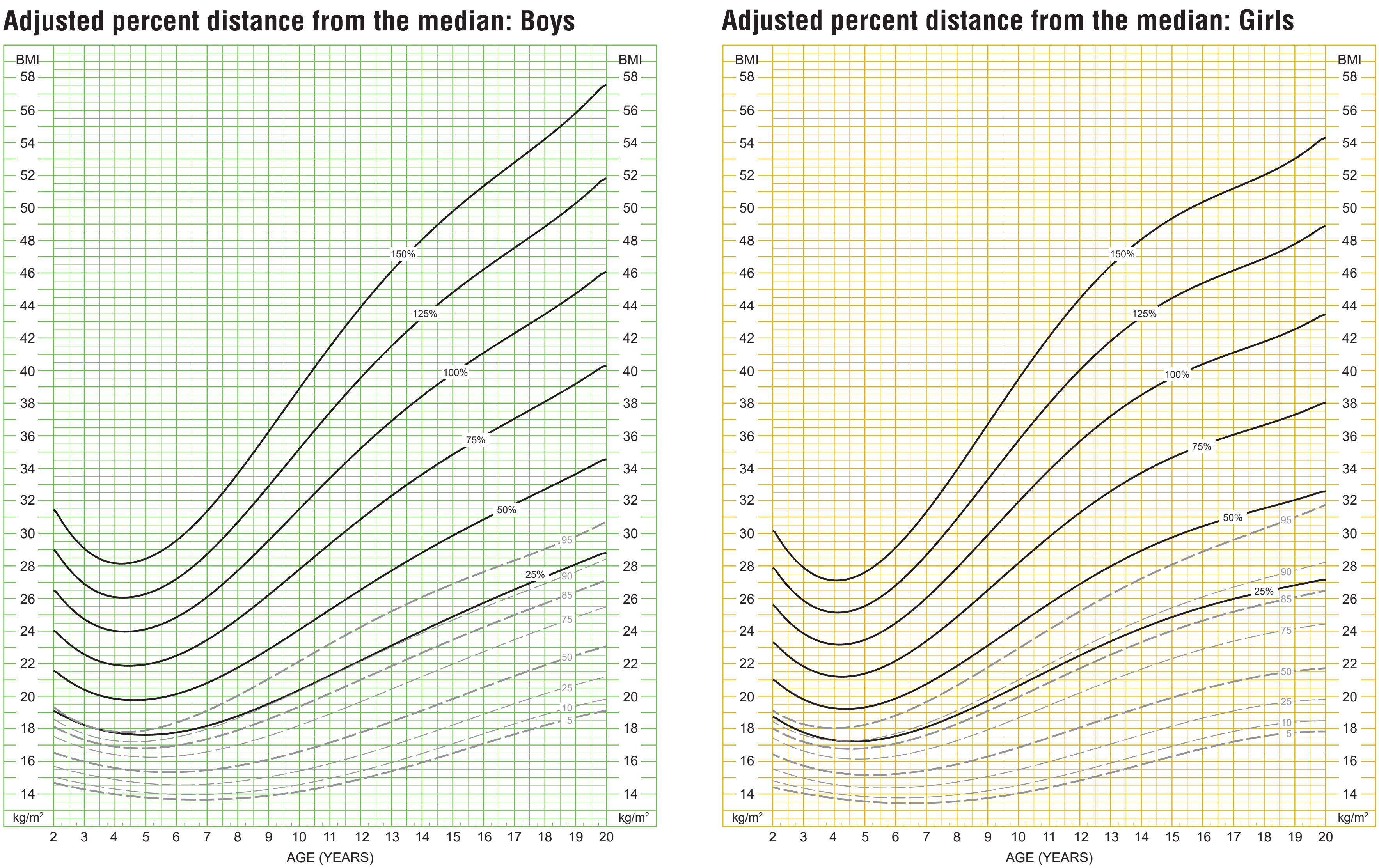
Figure 10. Alternative metric 5: Adjusted BMI units from the median





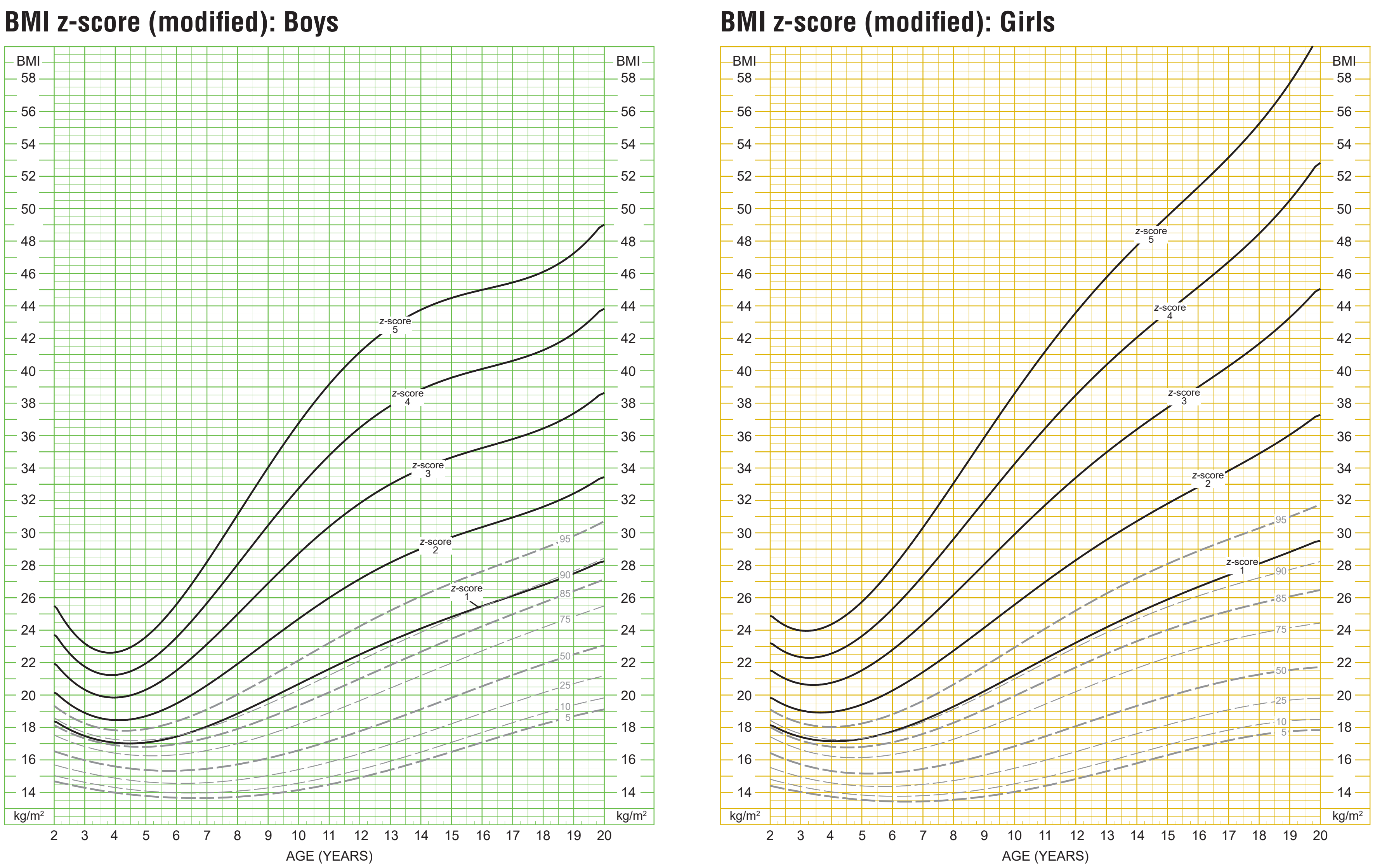
NOTE: BMI is body mass index.
SOURCE: National Center for Health Statistics, Centers for Disease Control and Prevention 2000 BMI-for-age growth charts.

Figure 11. Alternative metric 6: Adjusted percent distance from the median



NOTE: BMI is body mass index.
SOURCE: National Center for Health Statistics, Centers for Disease Control and Prevention 2000 BMI-for-age growth charts.

Figure 12. Alternative metric 7: Body mass index z-scores (modified)



NOTE: BMI is body mass index.
SOURCE: National Center for Health Statistics, Centers for Disease Control and Prevention 2000 BMI-for-age growth charts.

between z-scores +1 and +2 is 10.1 units. A second limitation is that BMIz (modified) does not align with BMIz (CDC 2000) below the 97th percentile, which could cause confusion when evaluating a child for overweight or obesity. Third, a BMIz (CDC 2000) of +2, which is one of the two points on which BMIz (modified) is based, is beyond the range of BMI percentile curves (3rd to 97th percentiles or z-scores of -1.88 to +1.88) used to estimate the L, M, and S parameters.

Alternative Metric 8: BMI z-scores and Percentiles (extended)

A new method for calculating BMI percentiles and z-scores for children with extremely high BMI values addresses the previously mentioned limitations by adding data for children and adolescents with obesity from more recent NHANES surveys (NHANES III and NHANES, 1999–2016) (39,40). This "extended" method generates a conditional distribution that retains the same BMI distribution up to the 95th percentiles the 2000 CDC growth charts. Therefore, BMIz (extended) values are equivalent to BMIz (CDC 2000) for children and adolescents up to the 95th percentile. Incorporating more recent NHANES cycles increases the sample size and allows for better characterization of the BMI distribution above the 95th percentile without the compression that occurs for BMIz (CDC 2000).

BMIz (extended) values above the 95th percentile are based on a data set of 8,777 children and adolescents with obesity (1,814 [21%] from the 2000 CDC growth chart reference population and 6,963 [79%] from NHANES III and NHANES, 1999–2016). These data were used to model BMI distribution above the 95th percentile as half-normal distributions by sex and within 6-month age groups. This method does not compress high BMI values into a narrow range and allows for the calculation of BMI percentiles and z-scores for any BMI above the 95th percentile and forms a single continuous and uninterrupted metric with BMI percentiles and z-scores below the 95th percentile. BMIz (extended) thus "extends" BMI percentiles and z-scores beyond the limits of BMIz (CDC 2000), resulting in curves above the 95th percentile that reflect age-related changes in BMI dispersion consistent with the dispersion below the 95th percentile (Figure 13).

Although CDC 2000 percentiles are considered valid up to the 97th percentile, BMIz (extended) values are slightly lower than BMIz (CDC 2000) for BMI values between the 95th and 97th percentiles (CDC 2000). For example, for a 4-year-old boy with a BMI of 18.2, BMIz (CDC 2000) equals 1.86 (96.9th percentile), but BMIz (extended) equals 1.71 (95.6th percentile). This discrepancy occurs because BMIz (extended) above the 95th percentile was constructed using a population made up mostly of children and adolescents from more recent NHANES data, who are heavier than children and adolescents with obesity from the CDC 2000 growth chart reference population. BMI values of 14- through 19-year-olds with obesity in NHANES 1999–2000 through 2015–2016 were 1.5 (boys) and 1.0 (girls) kg/m^2 higher than the mean BMI values of 14- to 19-year-olds with obesity in the 2000 CDC growth chart reference population.

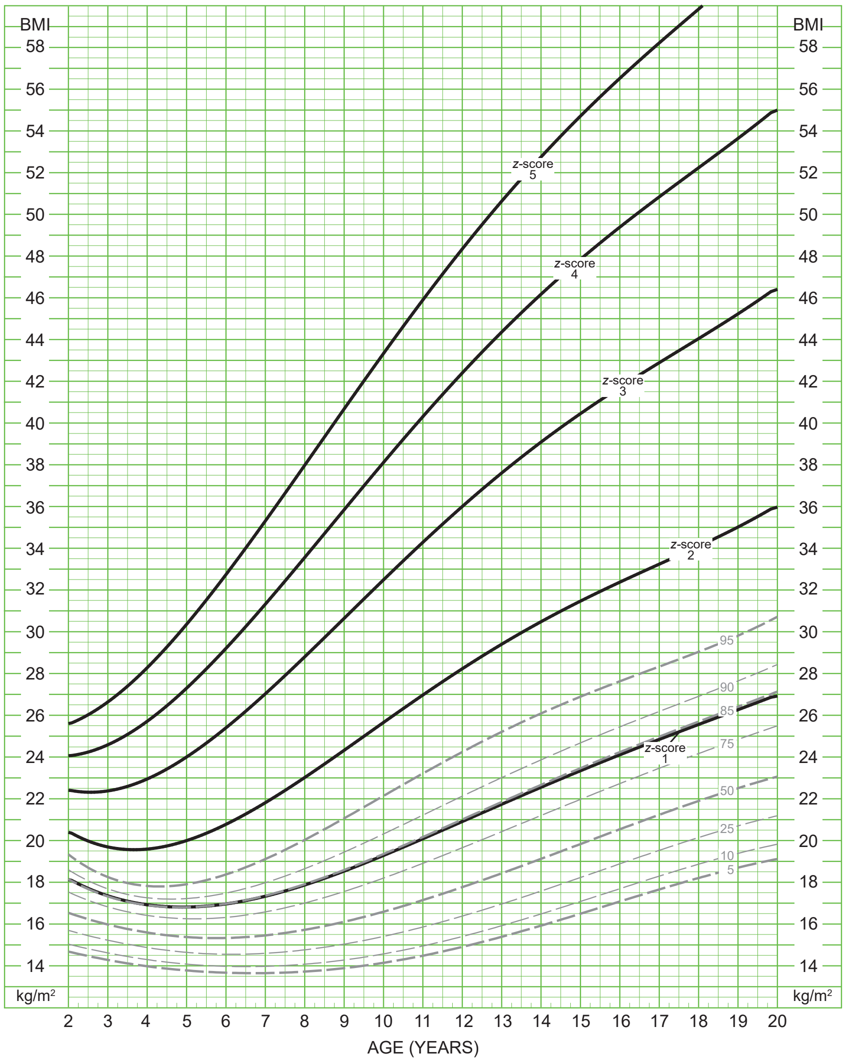
Figure 14 Panels A–D show the distribution of BMIz (CDC 2000) and BMIz (extended) in children and adolescents aged 2 through 19 years from NHANES, 2015–2018 (16); the 95th percentile is indicated with a vertical red line. BMIz (extended) was constructed to preserve BMIz (CDC 2000) up to the 95th percentile, and this can be seen in Figure 14 Panel A (girls) and Panel C (boys) as complete overlap of histograms for BMIz (extended) and BMIz (CDC 2000) in this range. Compression of BMIz (CDC 2000) above the 95th percentile is evident as a steeper drop-off in the distribution at z-scores greater than 2. By contrast, the distribution of BMIz (extended) shows a longer right tail that reflects extremely high BMI values in the population that are not subject to the same compression phenomenon. Figure 14 Panel B (girls) and Figure 14 Panel D (boys) show the same distributions using local polynomial smoothing. Whereas the histograms with a cut point at the 95th percentile demonstrate the clear boundary between the two underlying BMI distributions above and below this cut point, smoothing procedures blend densities across both sides, producing a second smaller peak at the 95th percentile.

The extended method has several advantages. First, using nationally representative data to characterize weight status in children and adolescents with extremely high BMI distinguishes BMIz (extended) from other BMI metrics that rely, in various ways, on extrapolation using the L, M, and S parameters from the CDC 2000 growth chart reference population. Another consequence of better characterization of BMI distribution above the 95th percentile is mitigating the compression of BMIz (CDC 2000) at extremely high BMI values. Figure 15 shows how the relationship between BMI and BMIz diverges above the 95th percentile, with BMIz (CDC 2000) flattening out at higher BMI values and BMIz (extended) continuing in an upward trajectory. Second, because BMIz (extended) preserves BMIz (CDC 2000) values up to the 95th percentile, it forms a single continuous metric for BMI percentiles and z-scores above and below the 95th percentile.

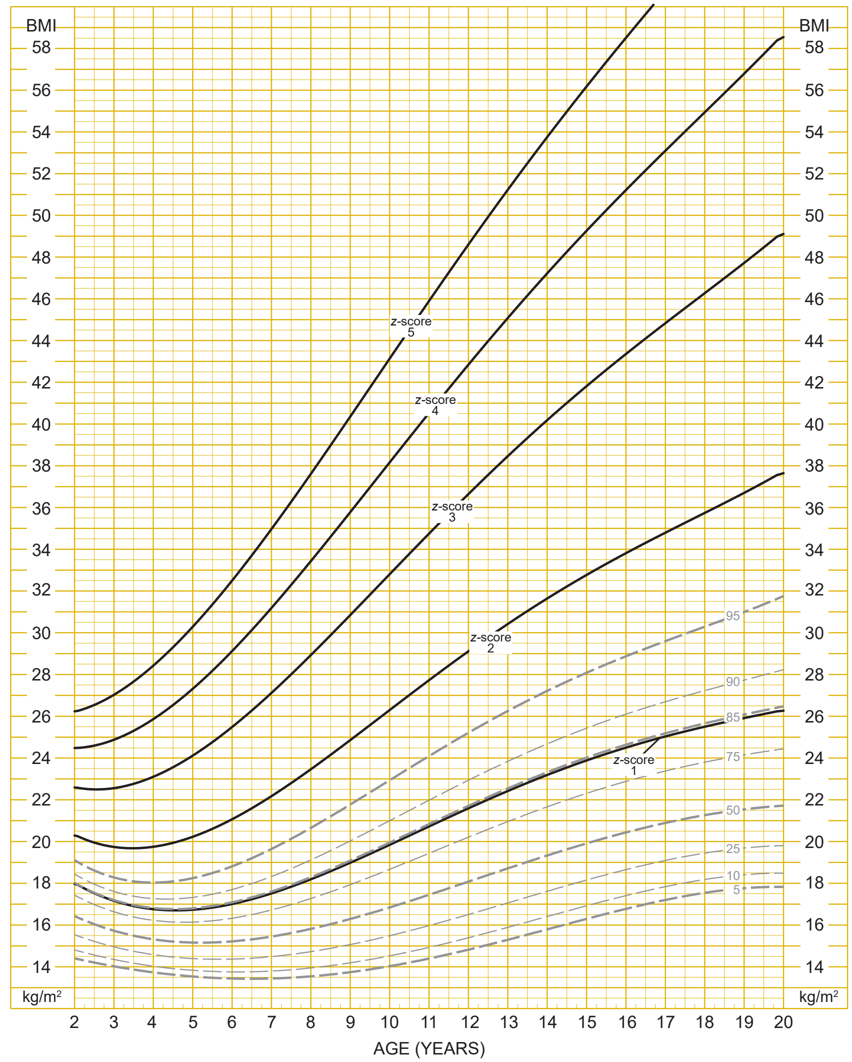
BMIz (extended) has some limitations. First, although BMIz (extended) preserves BMIz (CDC 2000) for BMI values up to and including the 95th percentile, visualizing smoothed BMIz (extended) densities produces a second peak at the 95th percentile resulting from the abrupt transition between the two underlying BMI distributions. Second, BMIz (extended) has a maximum value of 8.21 for boys and girls across all ages resulting from the limitations of floating-point arithmetic in converting percentiles that are very close to 100, such as 99 followed by 14 9s after the decimal point, into a corresponding z-score. BMIz (extended) of 8.21 in boys corresponds to BMI values of 33.0 at age 3 years, 55.2 at age 9 years, and 80.2 at age 17. The comparable age-specific BMI values among girls are 33.3, 54.7, and 82.0. BMI values this high are extremely rare.

Figure 13. Alternative metric 8: Body mass index z-scores (extended)

BMI z-score (extended): Boys

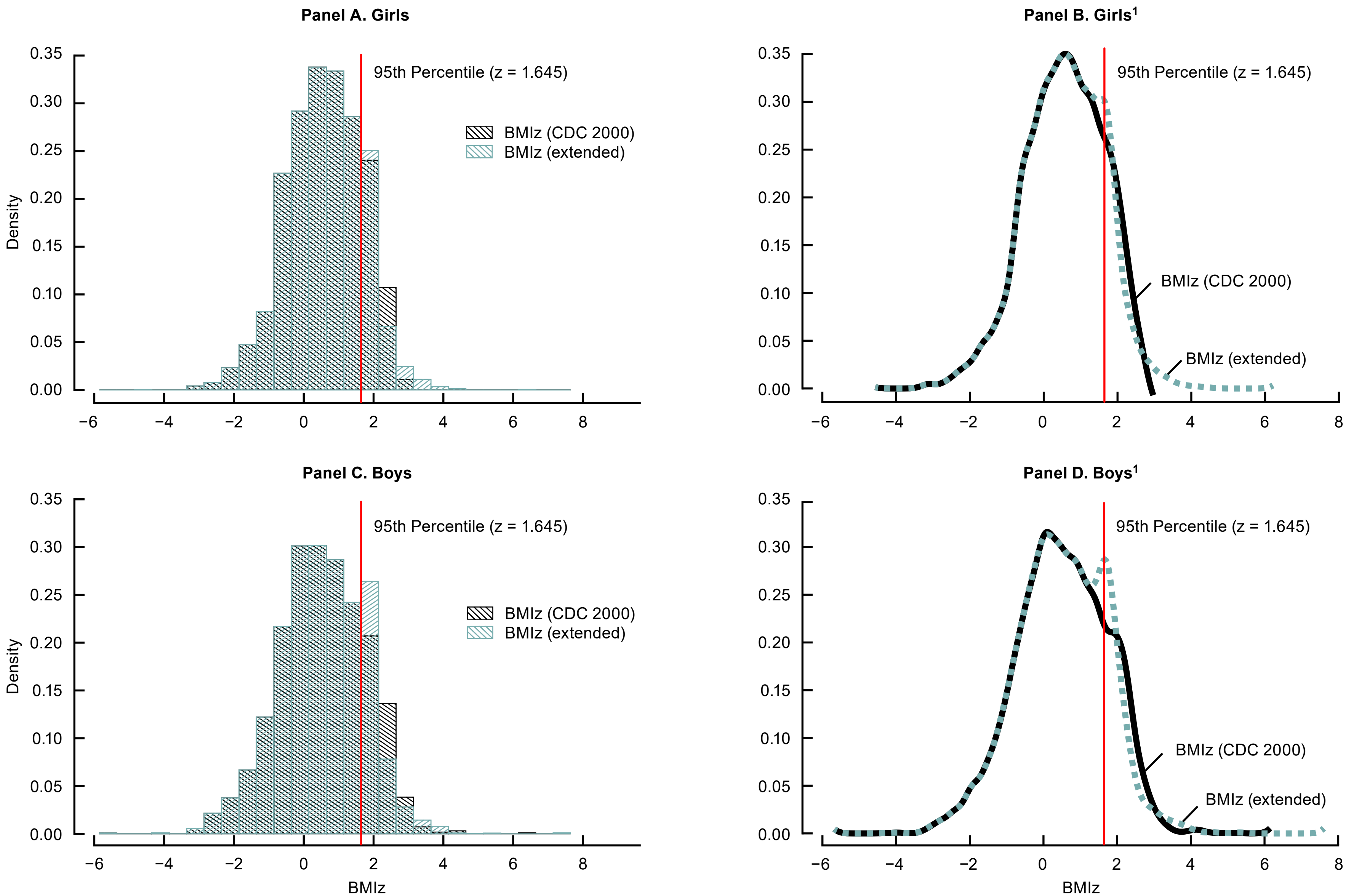


BMI z-score (extended): Girls



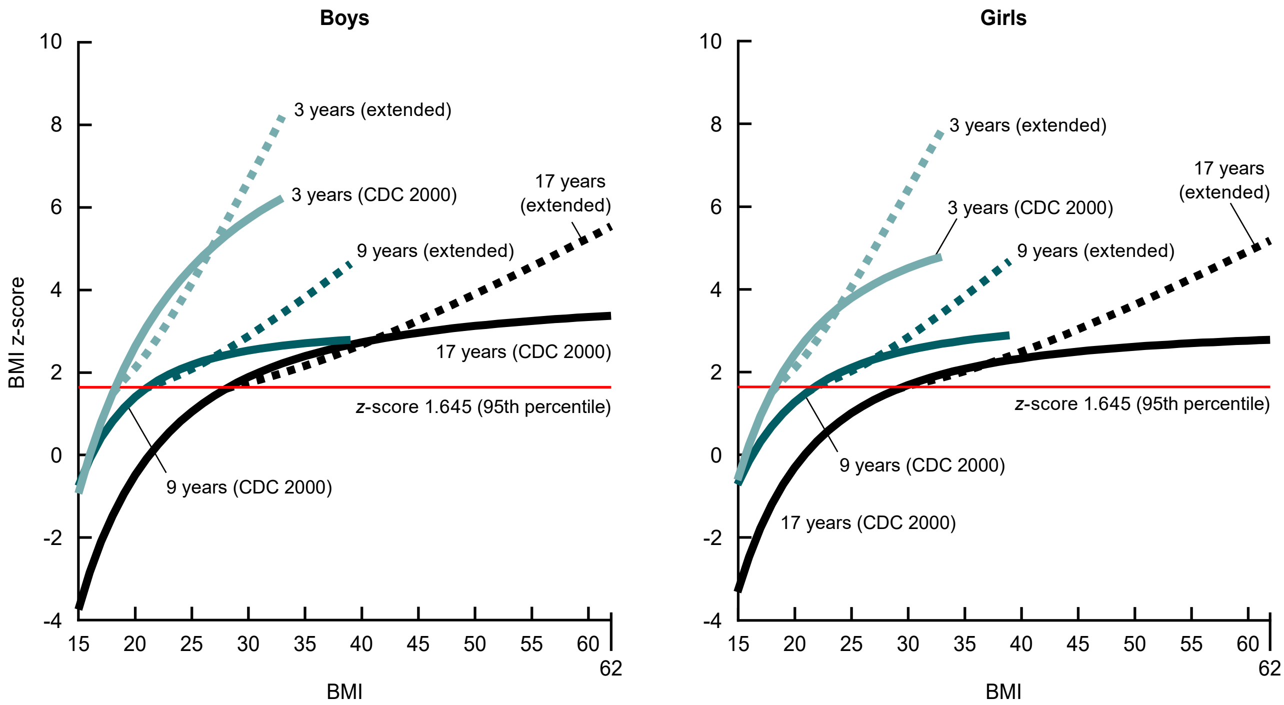
NOTE: BMI is body mass index.
SOURCE: National Center for Health Statistics, Centers for Disease Control and Prevention 2000 BMI-for-age growth charts.

Figure 14. Distribution of BMI z-score (CDC 2000) and BMI z-score (extended) in children and adolescents aged 2–19 years: United States, 2015–2018



[1]Smoothed densities calculated using local polynomials.
NOTES: BMI is body mass index. BMIz is BMI z-score. CDC is Centers for Disease Control and Prevention.
SOURCE: National Center for Health Statistics, National Health and Nutrition Examination Survey, 2015–2018.

Figure 15. Relationship between BMI and BMI z-score (CDC 2000) and BMI z-score (extended) for boys and girls aged 3, 9, and 17 years



NOTES: BMI is body mass index. CDC is Centers for Disease Control and Prevention.
SOURCE: National Center for Health Statistics, Centers for Disease Control and Prevention 2000 BMI-for-age growth charts.

Using Alternative BMI Metrics

Assessing Weight Status

In clinical settings, the American Academy of Pediatrics (AAP) and the U. S. Preventive Services Task Force recommend assessing weight status and diagnosing obesity in children and adolescents (22,41). In children and adolescents—unlike adults—overweight, obesity, and severe obesity are defined relative to the CDC 2000 growth chart reference population to account for growth and development. Of the alternative BMI metrics, only BMI z-scores and percentiles (extended) preserve BMI z-scores and percentiles (CDC 2000) below the 95th percentile and therefore have the same threshold for overweight (z = 1.036 or 85th percentile) and obesity (z = 1.645 or 95th percentile) for boys and girls across the entire age range. While percent of the 95th percentile has a fixed threshold for obesity (100% of the 95th percentile) and severe obesity (120% of 95th percentile), its thresholds for overweight vary by sex and age.

Monitoring Weight Status Over Time

Qualitative evaluation of a child's BMI trajectory by visual inspection of the BMI-for-age growth charts is part of routine clinical practice. AAP frames obesity treatment targets for certain children and adolescents with obesity as weight maintenance or loss until BMI is less than the 85th percentile. For children and adolescents with BMI values above the 97th percentile, reference curves using a separate BMI metric, such as the percent of the 95th percentile, are often used to help clinicians determine if weight status is improving, worsening, or is stable. Ideally, a single BMI metric could indicate clinically relevant shifts in weight status relative to a reference population from age 2 through 19 years across weight categories of healthy weight, overweight, and classes of obesity.

To show the behavior of the eight BMI metrics for tracking weight status, two children with severe obesity and longitudinal follow-up were selected from the IQVIA Ambulatory Electronic Medical Record Database to demonstrate actual BMI trajectories that could be seen in clinical settings (42). This database contained clinical data on approximately 76 million patients from all 50 states treated by about 100,000 health care providers affiliated with approximately 800 ambulatory sites.

Table B and Figure 16 Panels A–H show the BMI trajectory of a girl whose weight status transitions from overweight to obesity and then to severe obesity before reverting to obesity and then overweight from age 3 to 14 years using the alternative BMI metrics. At age 3 years, this girl has a healthy weight, with a BMI of 16.9 or the 83.8th percentile (CDC 2000). By age 5 years, she has developed obesity (greater than or equal to the 95th percentile [CDC 2000]), with a BMI of 19.4. Her BMI percentile (extended) of 96.4

indicates that she has crossed the obesity threshold because extended percentiles preserve the CDC 2000 percentiles up to the 95th percentile. Her percent of 95th percentile of 105% indicates that she has crossed the obesity threshold. In contrast, the values for BMI percentile (modified) (97.1), BMI units from the median (4.2), percent from the median (27.7), adjusted BMI units from the median (10.7), and adjusted percent from the median (49.0) require knowledge of the obesity thresholds in terms of these metrics (92.5, 3.3, 21.5, 8.2, and 37.9, respectively) to determine her change in weight status.

By age 6 years, the girl has crossed the severe obesity threshold (greater than 120% of the 95th percentile), with a percent of the 95th percentile of 134%. This girl's BMI continues to increase to a maximum of 31.5 at age 9 years. All BMI metrics for this girl also reach their maximum at this age.

After age 9 years, her BMI decreases until converting back to overweight by age 13 years (or 163 months) with a BMI of 26.3 or 94.2nd percentile (CDC 2000). BMI percentile (extended) also indicated this conversion from 158 months to 163 months, going from 95.3 to 94.2. At 158 months, her BMI percentile (modified) is 92.9th, which may be misconstrued as in the overweight range when, in fact, the obesity threshold for BMI percentile (modified) is the 91.9th percentile for a girl of this age. Percent of the 95th percentile also indicates this conversion from obesity to overweight, with values going from 101% to 98% of the 95th percentile.

Table B and Figure 17 Panels A–H show the BMI trajectory of a boy with severe obesity, whose BMI stays relatively stable from age 4 to 12 years—increasing only from 27.8 to 30.8—using the alternative BMI metrics. BMI trajectories plotted in units of the alternative metrics on the y axis are shown in Figure 18. While BMI (untransformed) shows a leveling off from age 9 to 12 (Figure 18 Panel C), all the other BMI metrics account for age-specific changes in median BMI with age and show a decrease, reflecting that the boy's BMI is decreasing relative to increasing median BMI over this age range. From age 4 to 9, different patterns appear among the metrics, reflecting differences in assumed underlying BMI distributions. BMI units from the median and percent from the median, which account for age-specific changes in median only, show increases from age 4 to 9 years, reflecting the increased BMI over a period where the median BMI is stable. Adjusted BMI units from the median, adjusted percent from the median, and percent from the 95th percentile all show an initial increase from age 4 to 6, and then a decline thereafter, whereas BMIz (extended) and BMIz (modified) show a decreasing pattern across the entire period. These differences appear because of differences in how the metrics characterize the dispersion of the BMI distribution below about age 6 years. Adjusted BMI units from the median, adjusted percent from the median, and percent from the 95th percentile have approximately constant dispersion between age 4 and 6 (as can be seen by the constant distance between reference curves in this age range in Figure 17 Panels D, G, and H), while BMIz (modified) and BMIz (extended) have increasing dispersion between age 4 and 6 (as can be seen by the increasing distance between the reference curves in this age range in Figure 17 Panels A and B). The increase in BMI from age 4 to 6 results in an increase in the three metrics where the median and

Table B. Monitoring weight status over time using alternative metrics: Two examples

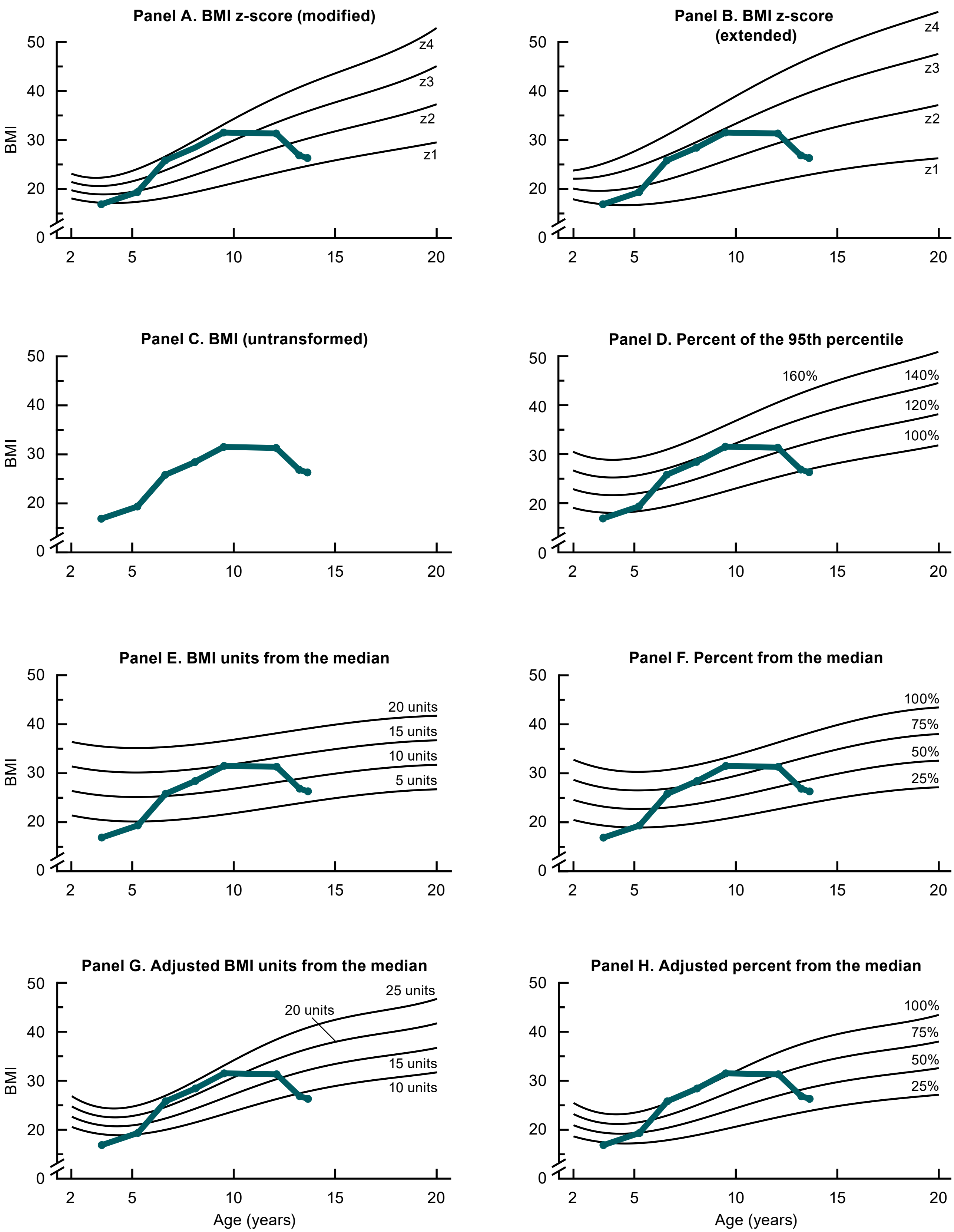
Age (years)	Age (months)	BMI percentile (modified)	BMI z-score (modified)	BMI percentile (extended)[1]	BMI z-score (extended)[1]	BMI (untransformed)	Percent of 95th percentile	BMI units from median	Percent from median	Adjusted BMI units from median	Adjusted percent from median
Example 1, Girl:											
3	41	79.15	0.81	83.77	0.99	16.9	93	1.4	8.9	3.8	17.5
5	63	97.11	1.90	96.41	1.80	19.4	105	4.2	27.7	10.7	49.3
6	79	99.99	3.74	99.78	2.84	25.8	134	10.5	68.3	22.6	104.1
8	97	99.98	3.61	99.79	2.87	28.4	137	12.6	79.4	22.4	103.2
9	114	99.99	3.62	99.84	2.95	31.5	141	15.0	90.4	22.7	104.3
12	145	99.51	2.58	98.78	2.25	31.3	124	13.2	72.7	16.3	74.9
13	158	92.90	1.47	95.27	1.67	26.9	101	8.0	42.5	9.3	43.0
13	163	90.24	1.30	94.19	1.57	26.3	98	7.2	37.7	8.3	38.2
14	177	88.78	1.22	93.54	1.52	26.9	96	7.1	35.9	7.9	36.4
Example 2, Boy:											
4	48	> 99.99	8.69	> 99.99	4.77	27.8	156	12.2	78.1	33.6	146.1
5	61	> 99.99	8.30	> 99.99	4.57	29.3	163	13.8	89.8	36.4	158.3
7	87	> 99.99	5.25	99.97	3.48	29.6	153	14.1	90.4	29.7	128.8
9	112	99.99	3.87	99.82	2.91	30.8	144	14.4	88.5	23.9	103.9
11	133	99.91	3.14	99.40	2.51	31.1	133	13.8	80.2	19.6	85.0
12	145	99.72	2.77	98.89	2.29	30.8	127	13.0	72.5	17.1	74.1

[1]BMI percentile (extended) and BMI z-score (extended) preserve Centers for Disease Control and Prevention 2000 BMI percentiles and z-scores up to the 95th percentile.

NOTE: BMI is body mass index.

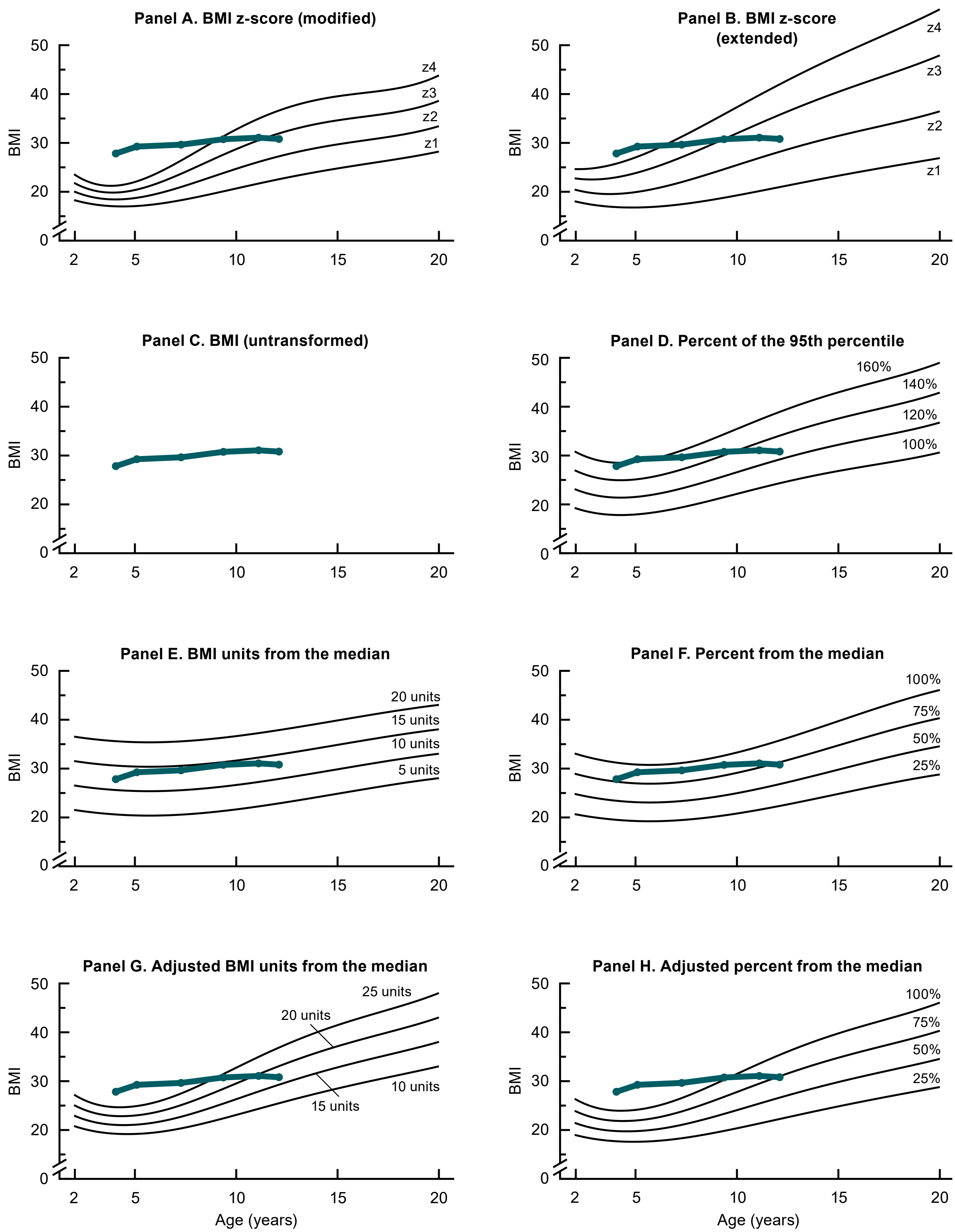
SOURCE: National Center for Health Statistics, Centers for Disease Control and Prevention 2000 BMI-for-age growth charts and IQVIA Ambulatory Electronic Medical Record Database.

Figure 16. Monitoring weight status over time using alternative metric reference curves—Example 1 (girl)



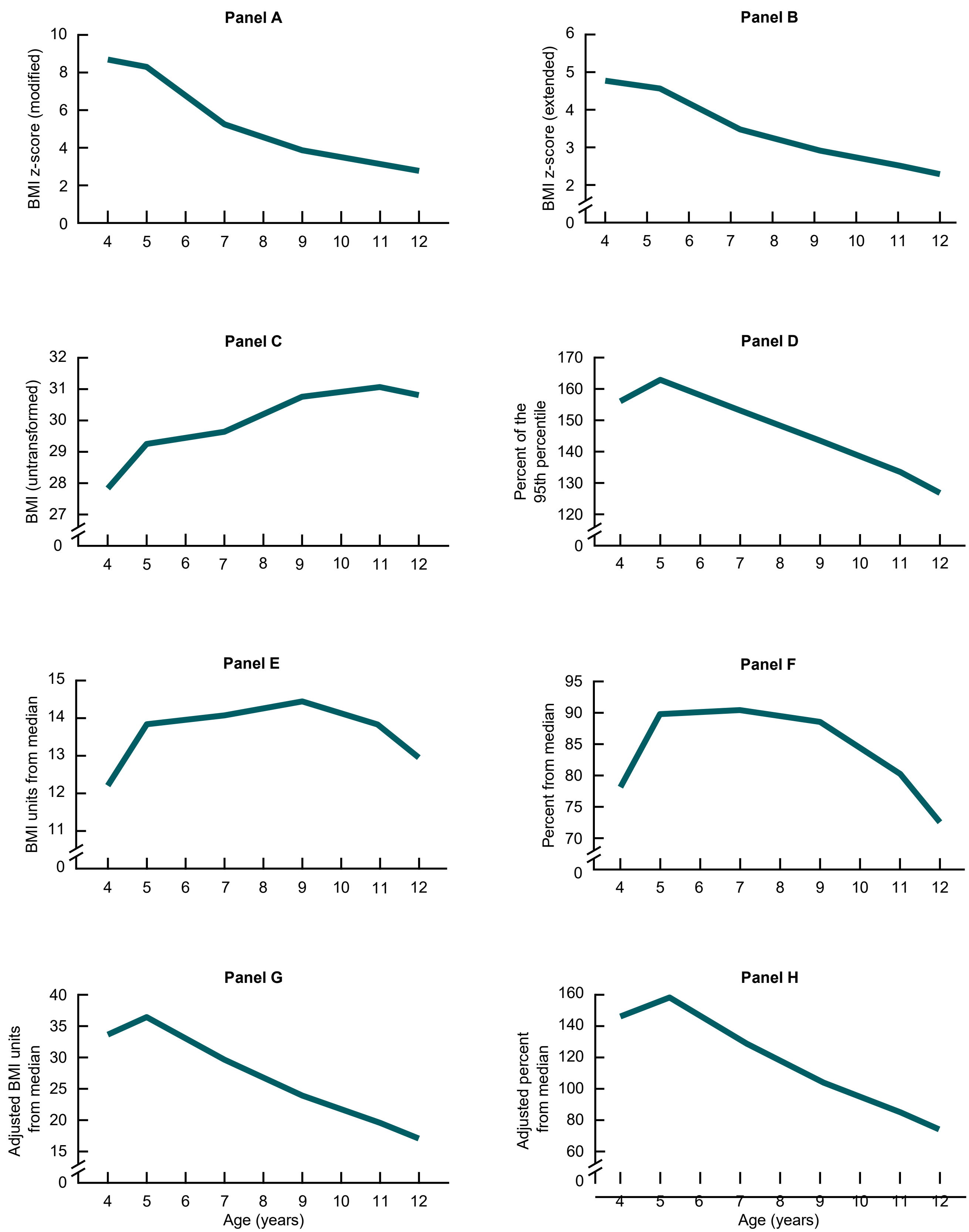
NOTE: BMI is body mass index.
SOURCES: National Center for Health Statistics, Centers for Disease Control and Prevention 2000 BMI-for-age growth charts and IQVIA Ambulatory Electronic Medical Record Database.

Figure 17. Monitoring weight status over time using alternative metric reference curves—Example 2 (boy)



NOTE: BMI is body mass index.
SOURCES: National Center for Health Statistics, Centers for Disease Control and Prevention 2000 BMI-for-age growth charts and IQVIA Ambulatory Electronic Medical Record Database.

Figure 18. Monitoring weight status over time in units of alternative metrics—Example 2 (boy)



NOTES: BMI is body mass index; y axis limits vary to accomodate minimum and maximum values for each metric.
SOURCES: National Center for Health Statistics, Centers for Disease Control and Prevention 2000 BMI-for-age growth charts and IQVIA Ambulatory Electronic Medical Record Database.

dispersion are constant but results in a decrease in BMIz (modified) and BMIz (extended) because this increase is less than what would be expected given the increase in dispersion.

Evaluating Obesity Treatment

In routine clinical settings, changes in weight status can be monitored qualitatively by visual inspection of the BMI trajectory on the BMI-for-age growth chart. However, evaluating individual-level obesity treatments or interventions, such as lifestyle modification counseling, pharmacotherapy, and bariatric surgery, requires more precise quantification of weight status changes. For adults, clinical trials use percent weight change (equal to percent BMI change in adults whose height is constant) for evaluating the efficacy of weight loss interventions. There is currently no widely accepted single standard for children and adolescents, so outcomes are usually framed in terms of change in some BMI metric. Change in a BMI metric that reflects consistent clinical changes in boys and girls across childhood and adolescence and for a broad range of initial BMI values, would allow meaningful comparisons between individuals and within groups of different sexes and ages.

For pediatric clinical trials, the Food and Drug Administration recommends mean change in BMI and the proportion of patients who lose greater than or equal to 5% of baseline BMI to account for changes in linear growth (43). In contrast, the European Medicines Agency (EMA) recommends change in BMIz as the primary endpoint of anti-obesity medication clinical trials in children but that change in percent of the median also be assessed (44). EMA did not specify which growth chart or reference population to use when calculating BMIz. Many behavioral interventions and clinical trials among children and adolescents have focused on change in BMIz (26,45), whereas both percent excess weight loss (46) and BMI change (8) have been used as the outcome in studies of bariatric surgery among adolescents.

A limitation of using BMI change to evaluate obesity treatment is the lack of adjustment for expected sex- and age-specific BMI changes over the study period. Accounting for such changes may impact observational study results when follow-up occurs over a long period (for example, greater than 3 years) or during ages of rapid expected BMI change, or when the study subjects span a wide age range. Conversely, adjustment would have little impact in studies with a 1-year follow-up of children or adolescents with a narrow age range.

An underlying assumption is that the expected value of the BMI metric at the end of an observation period is the same as at the beginning, without any intervention and no regression to the mean. For example, without any intervention and no regression to the mean (47), a child with a BMIz (CDC 2000) of 1.5 is expected to grow along this BMIz curve until the end of follow-up, ending with a BMIz (CDC 2000) of 1.5, even though the child's BMI changes. Because of differences in the methods used to construct the alternative BMI metrics, each metric produces a different expected change over an observation period without any intervention. Therefore, the effect of an intervention over the observation period will also vary depending on the BMI metric.

Several investigators have recommended against using BMIz (CDC 2000) to assess efficacy in clinical trials (17,27–29,45) because of compression at high BMI values and the curvilinear relation of BMI to BMIz (CDC 2000). BMIz (extended) mitigates this compression by incorporating data on children and adolescents with obesity from more recent surveys, the relationship between BMIz (extended) and clinically relevant endpoints has not yet been determined. Other recommendations include BMI (untransformed), BMI units from the median, or percent from the median on a log scale (17,27,29).

Further research may help determine which BMI metric is most suitable for studies of weight status change. To further understanding of how various metrics perform in intervention studies, investigators can report results using several BMI metrics (45).

Assessing the Relationship Between BMI Metrics and Body Fat

A few studies have examined changes in levels of body fatness in relation to changes in various BMI metrics over 1- to 2-year periods (48–50). These studies have consistently found that changes in body fatness are less strongly correlated with changes in BMIz (CDC 2000) compared with other BMI metrics, such as BMI units from the median, percent from the median (on either the arithmetic or log scale), percent of the 95th percentile, and BMI (untransformed). Kakinami et al (48) also noted that correlations between body fat and various BMI metrics depend on the adiposity metric, such as fat mass, percent body fat, or fat mass index (fat mass divided by height squared).

Strengths and Limitations of Alternative BMI Metrics

Table C summarizes the strengths and limitations of the alternative BMI metrics.

Comparability with the current CDC 2000 BMI-for-age growth charts and weight status thresholds will help with a smoother transition to an alternative BMI metric. A BMI metric that has the same BMI percentiles and z-scores as the CDC 2000 BMI-for-age growth chart up to the 95th percentile is preferred because it allows for the same metric to be applied across the weight status spectrum. Because BMI z-scores and percentiles (extended) are the only BMI metrics with this property, it is also the only one with a single cut point that aligns with the current definition of overweight.

Table C. Characteristics of alternative body mass index metrics

Characteristic	BMI (untransformed)	BMI z-scores and percentiles (modified)	BMI z-scores and percentiles (extended)	Percent of 95th percentile	BMI units or percent from median	Adjusted BMI units or percent from median
Strengths						
Equivalent to CDC 2000 growth chart BMI distributions below the 95th percentile	No	No	Yes	No	No	No
Has a single cut point that aligns with current definition of overweight	No	No	Yes	No	No	No
Has a single cut point that aligns with current definition of obesity	No	No	Yes	Yes	No	No
Has a single cut point that aligns with current definition of severe obesity	No	No	No	Yes	No	No
Currently used in clinical settings for children and adolescents with obesity	Yes	No	No	Yes	No	No
Currently used in research settings for children and adolescents with obesity or severe obesity	Yes	No	No	Yes	No	No
Adjusts for sex- and age-specific median BMI distributions	No	Yes	Yes	Yes	Yes	Yes
Adjusts for sex- and age-specific dispersion of BMI distributions	No	Partial[1]	Yes	Partial[2]	No	Yes
Limitations						
Exhibits compression at extremely high BMI values	No	No	No	No	No	No
Makes assumptions for BMI distributions at extremely high BMI values derived from reference population with very sparse data in this range	No	Yes	No	Yes	Yes	Yes
Has an upper limit or maximum value	No	Yes[3]	Yes[3]	No	No	No

[1]An arbitrary standard deviation equal to one-half the distance between z-scores 0 and 2 is applied, which distorts the original adjustment for dispersion.
[2]While the 95th percentile adjusts for dispersion, percentages of the 95th percentile do not.
[3]Percentiles have a maximum value of 100 but calculation of z-scores is limited only by floating point arithmetic.

NOTES: BMI is body mass index. CDC is Centers for Disease Control and Prevention.

SOURCE: National Center for Health Statistics, Centers for Disease Control and Prevention 2000 BMI-for-age growth charts.

The current definition of obesity can be expressed as single values for BMI z-scores and percentiles (extended) (1.645 and 95th percentile, respectively) and percent of the 95th percentile (100%). Having a single threshold value is useful when presenting weight status distributions such as in Figure 14 because a vertical reference line can be drawn at the obesity threshold regardless of sex or age to aid interpretation.

Familiarity with the unit of measurement will also help ease the transition to using a new method. Of the alternative BMI metrics, only BMI (untransformed) and percent of the 95th percentile are used in clinical and research settings for U.S. children and adolescents with obesity. Although the modified method is not commonly used in clinical or research settings and the extended method was only recently developed, z-scores and percentiles are very familiar from decades of use in growth charts for other anthropometric measures such as height, weight, and head circumference.

Alternative BMI metrics are also characterized by whether they adjust for the sex- and age-specific BMI median and dispersion of the reference population. BMI (untransformed) is unadjusted, but all other metrics adjust for sex- and age-specific median BMI. All alternative BMI metrics adjust for sex- and age-specific dispersion of BMI distributions except BMI (untransformed), BMI units from the median, and percent from the median. Lack of adjustment for dispersion is particularly noticeable at younger ages when BMI dispersion is smallest and can be seen in the patterns of a boy's weight status trajectory in Figures 17 and 18 Panels C, E, and F.

None of the alternative BMI metrics suffer from the problem of compression at extreme BMI values that is seen with BMIz (CDC 2000).

All alternative BMI metrics except BMI z-scores and percentiles (extended) and BMI (untransformed) characterize BMI distributions at extremely high BMI values based on extrapolation beyond the 2000 CDC growth charts reference population data. BMIz (extended) was developed expressly to resolve this limitation. Instead of relying on the CDC 2000 historical growth chart reference population, it is enriched with data from children and adolescents with obesity in more recent NHANES surveys to better characterize the BMI distribution at extremely high BMI values. Differences in growth chart reference curves among the alternative BMI metrics are particularly noticeable for children aged 2 to about 7 years. Percent of the 95th percentile (Figure 7) and the unadjusted BMI units and percent from the median

(Figures 8 and 9) assume that BMI-for-age growth chart reference curves above the 95th percentile are equidistant from either the 95th percentile or from the median and give rise to a marked shift in patterns above the 95th percentile compared with those below. The most obvious example is the pattern of BMI percentile curve nadirs, which occur at younger and younger ages as BMI percentile (CDC 2000) curves increase from 5th to 95th. Only BMIz and percentile (extended) curves above the 95th percentile continue this pattern of nadirs occurring at younger and younger ages, with no appreciable nadir at z-scores 4 and 5 (Figure 13 Panels A and B). BMI percentile curves (modified) (Figure 12) do show decreasing age at BMI nadir, but the age decrease between nadirs from a given z-score curve to the next higher one is smaller compared with the pattern below the 95th percentile.

BMI percentiles approach 100% with increasing BMI values, including those calculated using the extended method. Fortunately, percentiles are readily converted to z-scores using statistical tables or software and are favored when quantitative analysis is required. Printable BMI-for-age growth charts for boys and girls with an expanded BMI range on the y axis and extended BMI percentiles are shown in Figure 19 to aid interpretation of BMI trajectories. The threshold for severe obesity at 120% of the 95th percentile is superimposed for reference.

While the curve indicating 120% of the 95th percentile remains about equidistant from the 95th percentile from age 2 through 19 and shows a nadir at the same age as for the 95th percentile, the 98th, 99th, 99.9th, and 99.99th percentiles (extended) based on data from children with obesity from 1963 to 2016 show a different pattern, especially in children under about 8 years. In longitudinal studies, using the extended method, some children may cross the threshold for severe obesity (120% of the 95th percentile) despite moving along the same percentile.

Finally, the relationships of BMI metrics with clinical and physiological measures associated with excess weight, including sensitivity to change in response to interventions, were not included when evaluating strengths and limitations. Reporting results of previously completed and future studies using multiple BMI metrics will further understanding of these relationships.

Conclusions

Increases in the prevalence of obesity and the increasing severity of obesity in children and adolescents with obesity have led to the development of additional tools for evaluating and monitoring weight status in clinical and research settings. Eight alternative BMI metrics have been described in this report. None of these metrics have the problem of compression at extremely high BMI values, but all have limitations, especially when applied across the weight status spectrum and a wide range of ages. This report evaluated alternative BMI metrics based on their mathematical properties, familiarity, and compatibility with current practice.

The extended method for calculating z-scores and percentiles stands out among the alternatives. First, the extended method improves the characterization of BMI distributions at very high values using nationally representative data from more recent NHANES cycles, whereas all other BMI metrics that refer to a reference population (all alternative metrics except untransformed BMI) rely on extrapolating beyond this reference population. Second, below the 95th percentile, extended BMI z-scores and percentiles preserve CDC 2000 z-scores and percentiles that are currently in use, which allows seamless transitions from the current CDC z-scores and percentiles below the 95th percentile to extended z-scores and percentiles above the 95th percentile. A drawback of BMIz (extended) is the abrupt transition between the two underlying BMI distributions that appears as a second peak at the 95th percentile when visualizing smoothed BMIz (extended) densities.

Alternative BMI metrics other than extended BMIz and percentiles may be appropriate for use in certain scenarios, such as during adolescence when differences among the metrics are less pronounced, when transitions to or from obesity are minimal, or for monitoring BMI changes over short periods when adjusting for expected growth and development is less critical.

The application of the extended BMI percentiles and z-scores in various clinical and research settings will expand understanding of its performance, including its association with other anthropometric measurements, risk factors, and health outcomes. Clinical growth charts, computer programs, and other tools to aid in implementing extended z-scores and percentiles for children with extremely high BMI are available from: https://www.cdc.gov/growthcharts.

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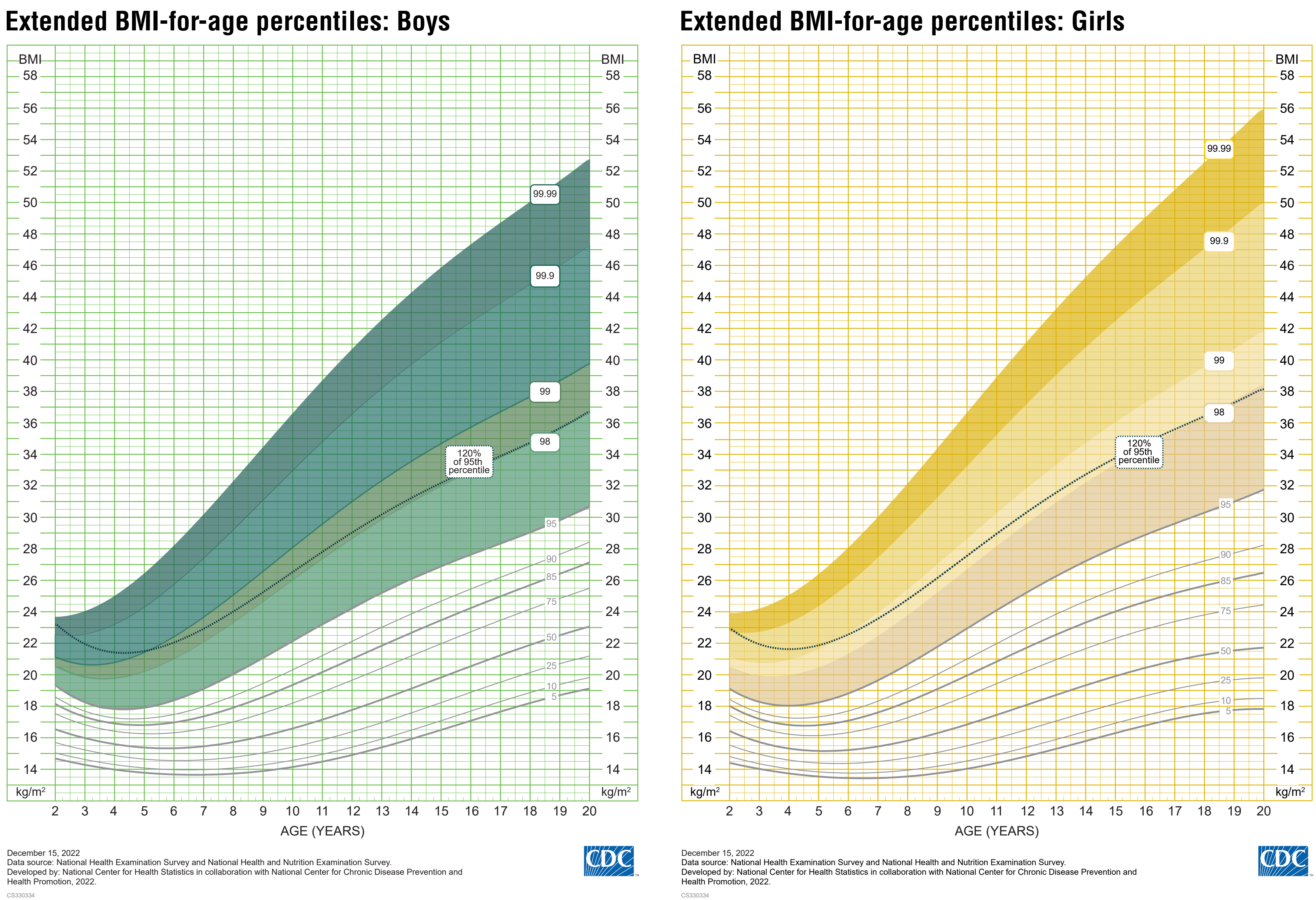
Figure 19. Centers for Disease Control and Prevention growth charts with extended body mass index percentiles



NOTE: BMI is body mass index.
SOURCE: National Center for Health Statistics, Centers for Disease Control and Prevention.

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Appendix

Adjustment of Body Mass Index (BMI) Units From the Median and Percent From the Median for Differences by Sex and Age

As can be seen in Figure 2 Panels B and C, both the median BMI (M) and the dispersion of BMI (S) vary substantially with age in the Centers for Disease Control and Prevention (CDC) growth charts. The S parameter among girls, for example, increases from about 0.08 at age 2 years to about 0.15 by age 12 years and remains relatively constant through age 19 years. The increases in M and S with age indicate that BMI units and percent from the median cannot be interpreted similarly at all ages.

The distance from the median can be adjusted for differences in M and S by scaling the distance by values of M and S at the reference age. Percent from the median can be adjusted for differences in S by scaling by the value of S at the reference age. Any reference age can be used, but the M and S values at 240 months of age are used here. The scaling is done separately for boys and girls.

The LMS transformation to calculate the BMI z-score of a child is

$$BMIz(CDC\ 2000) = \frac{(BMI/M)^L - 1}{L \bullet S} \qquad [1]$$

in which L is the power transformation for normality, M is the median BMI, and S is the coefficient of variation (standard deviation divided by the median) or dispersion in the CDC growth charts. L, M, and S parameters are specific for each sex and age in months. For the adjustment of distance from the median and percent from the median, L is set to a fixed value and a value of 1 is used here.

The LMS formula for BMIz with L = 1 is

$$\frac{\frac{BMI}{M} - 1}{S} \qquad [2]$$

Multiplying this by $\frac{M}{M}$ yields

$$\frac{BMI - M}{M \bullet S} \qquad [3]$$

in which the numerator represents the distance from the median for that sex and age.

The numerator of equation [3] can be adjusted for age differences in the M and S parameters by scaling the numerator distance (*BMI* − *M*) by the ratios (*Sref* / *S*) and (*Mref* / *M*) to yield

$$(BMI - M) \bullet \frac{Mref \bullet Sref}{M \bullet S} \qquad [4]$$

This represents the adjusted distance from the median, with the distance from the median adjusted to reference values for M and S at age 20. Equation [4] is also equation [3] multiplied by reference values for M and S.

For the adjustment of percent from the median, both the numerator and denominator of equation [2] can by multiplied by 100 to yield

$$\frac{100 \bullet \frac{BMI}{M} - 100}{100 \bullet S} \qquad [5]$$

in which the numerator represents the percent from the median.

This percent from the median can be adjusted for differences in the values of the S parameter across ages by scaling the numerator by (*Sref* / *S*) to yield

$$(100 \bullet \frac{BMI}{M} - 100) \bullet \frac{Sref}{S} \qquad [6]$$

This represents the adjusted percent from the median, with the percent adjusted for the difference between the values of the S parameter at a specific age and its reference value at 240 months. It should also be noted that equation [6] is simply equation [5] multiplied by 100 • *Sref*

The reference values for a 20-year-old (240 months) girl, for example, are 21.7 (*Mref*) and 0.153 (*Sref*) (51). A 24-month-old girl with a BMI at the 95th percentile (19.1) has a BMI units from the median of 2.7 kg/m^2 and, at this sex and age, M is 16.4 and S is 0.085 (51). Using equation [4], this girl's adjusted BMI units from the median is

$$(19.1 - 16.4) \bullet \frac{21.7 \bullet 0.153}{16.4 \bullet 0.085}$$

This girl's adjusted BMI units from the median is therefore 6.4 kg/m^2. Conceptually, this reflects what this girl's BMI units from the median would be if the girl was 240 months rather than 24 months of age.

The adjustment for the percent from the median metric involves only the S parameter. The adjusted percent from median would be the child's percent from the median multiplied by the dispersion ratio

$$\frac{Sref}{S}$$

so that this child's adjusted percent from the median is

$$(100 \bullet \frac{19.1}{16.4} - 100) \bullet \frac{0.153}{0.085} = 29.6\%$$

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