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# Not so implausible: impact of longitudinal assessment of implausible anthropometric measures on obesity prevalence and weight change in children and adolescents

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## Abstract

**Purpose:** Implausible anthropometric measures are typically identified using population outlier definitions, which conflate implausible and extreme measures. We determined the impact of a longitudinal outlier approach on estimated prevalence of body mass index (BMI) categories and mean change in anthropometric measures in pediatric electronic health record data.

**Methods:** We examined 996,131 observations from 147,375 children (10–18 years) in the ADVANCE Clinical Data Research Network, a national network of community health centers. Sex-stratified, mixed effects, linear spline regression modeled weight, height, and BMI as a function of age. Longitudinal outliers were defined as observations with studentized residual>|6|; population outliers were defined by Centers for Disease Control-defined z-score thresholds.

**Results:** At least 99.7% of anthropometric measures were not extreme by longitudinal or population definitions (agreement≥0.995). Prevalence of BMI categories after excluding longitudinal or population outliers differed by <0.1%. Among children >85$^{th}$ percentile at baseline, annual mean changes in anthropometric measures were larger in data that excluded longitudinal (girls: 1.28 inches, 12.45 pounds, 1.55 kg/m$^2$; boys: 2.36, 14.65, 1.07) versus population outliers (girls: 0.53 inches, 8.07 pounds, 0.76 kg/m$^2$; boys: 1.45, 11.25, 1.44).

**Conclusions:** Longitudinal outlier methods may reduce underestimation of weight, height, and BMI change in children with elevated baseline values.

### Keywords

Longitudinal; Youth; Biologically implausible values; Outliers; Anthropometry; Body Mass Index; Obesity

## INTRODUCTION

Electronic health record (EHR) data is increasingly used for pediatric obesity research, surveillance, and screening [1]. Weight and height measured in clinical settings may contain more error than in research settings, but there is no standard method for identifying implausible measures among pediatric anthropometric EHR data [2].

A common approach for identifying implausible anthropometric measures in U.S. children identifies biologically implausible values relative to the Centers for Disease Control and Prevention (CDC) growth curves [3]. This approach assumes that extreme measures - those that exceed predefined z-score cutoffs based on a reference population - are biologically implausible and erroneous; we refer to these measures as *population outliers*. This assumption has been challenged in the context of increasing prevalence and severity of pediatric obesity in the U.S. [4]. Evidence based on children 2–4 years of age with high body mass index (BMI) values at two measurement occasions suggests that population outliers include valid values, underestimating obesity prevalence by 1% [5]. Moreover, population outlier definitions do not consider implausible change over time, and may truncate estimates of anthropometric change among the heaviest children as their weights increase beyond "biologically implausible" thresholds. Importantly, children who are racial/ethnic minorities or of low socioeconomic status have a higher burden of obesity relative to more affluent White children [6,7], and are thus particularly vulnerable to misclassification when population outlier methods are applied.

Recent work has proposed longitudinal methods for identifying implausible values in pediatric anthropometric data. In contrast to population outlier methods, *longitudinal outlier* methods are child-specific; they use repeated measures for each child to inform the validity of any given measure. However, these methods vary with regard to the requisite number of measures per child, the dependence on the validity of first observation, and the extent to which data from the full study population is incorporated. Methods include a jackknife residual method for growth data from birth to 24 months of age [8], conditional growth percentiles for birth to 6.5 years of age [9], and a data cleaning method for EHR data based on deviation from the weighted moving average for each child 1–21 years of age [1]. Welch and colleagues used mixed effects models to identify longitudinal outliers in clinical data on a predominately adult patient population [10], which accommodates the substantial variability in number and spacing of anthropometric measures, as well as in age of first observation found in clinical data.

In this study, we extend Welch's approach to accommodate the nonlinear growth patterns typically observed in pediatric populations. We develop and test this method in 147,375 low-income children receiving care in community health centers in the 23 states participating in the ADVANCE Clinical Data Research Network. The extensive longitudinal measures and high burden of severe childhood obesity in our study population enabled examination of the extent to which exclusion of population outliers might bias the estimates of weight, height, and BMI change over time in the heaviest children as their weights increase beyond the population outlier cutpoints. Our objectives were to (a) demonstrate a mixed effects model-based method for identifying longitudinal implausible anthropometric measures in pediatric EHR data, (b) compare classification of and level of agreement between population outliers and longitudinal outliers and (c) determine the impact of outlier identification approach on the estimated values for (i) prevalence of BMI categories and (ii) change in anthropometric measures.

# METHODS

## Study population

We used data from the ADVANCE Clinical Data Research Network, a national network of Federally-Qualified Health Centers serving >4.3 million safety net patients across the U.S. [11]. ADVANCE is a multi-center collaborative led by OCHIN, Inc. (not an acronym) health information network in partnership with Health Choice Network (HCN) and Fenway Health. Together, these systems have outpatient clinical data from >130 community health centers with > 1,100 clinics. ADVANCE includes pediatric and adult patients with ≥1 office visit on or after 1/1/2012 across OCHIN, HCN, and Fenway Health networks, and their historical records, dating back as far as 2005.

This study examines anthropometric data for children 10–18 years of age from OCHIN and HCN networks. Fenway data were excluded because the network does not include pediatric clinics. We focused on middle childhood through adolescence as critical life stages in which obesity often develops; however, the proposed methodology could be adapted for other ages. EHR data were extracted from clinical encounters from 01/01/2012 through 12/31/2015 (354,614 children, 1,270,278 encounters). Initial data screening at the encounter-level excluded (1) 1,455 encounters with height ≤25 inches or ≥100 inches and (2) 123 encounters with weight of ≤5 or ≥1000 pounds. This initial exclusion of biologically impossible values was required to achieve model convergence; selected cutpoints were well beyond the 1st and 99th percentiles of the original distributions for weight (62 and 280 pounds) and height (51.7 and 73.3 inches), respectively. We then excluded 207,036 children with <3 remaining height, weight, and body mass index (BMI) measures. Our final analytic sample included 147,375 children randomly assigned to training or test datasets. 73,599 children were selected for the training dataset; the remaining 73,776 were retained for the test dataset. Mean weight, height, and BMI for included versus excluded children were generally within 0.1 z-scores (Appendix Table A.1.)

## Study variables

Dependent variables included time-varying weight, height, and BMI. Weight and height were ascertained from clinical encounter records. BMI was calculated from weight and height measured on the same day. For descriptive analysis, BMI was converted to age- and sex-specific BMI z-scores and percentiles using the CDC 2000 growth curves [12], then classified into underweight (<5th percentile), normal weight (≥5th, <85th), overweight (≥85th, <95th), obesity (≥95th to <20% higher than the 95th percentile), and severe obesity (≥20% higher than the 95th percentile) [13].

Independent variables included time-varying age (continuous) and time-constant sex (male, female) and race/ethnicity (Asian, Native Hawaiian/Pacific Islander, Black/African, American Indian/Alaska Native, White, Multiple Race, Other/Unknown, and Hispanic). Sex, date of birth, and race/ethnicity were recorded by clinical staff and are non-missing for the majority of patients because most community health centers are required to report these data to the US Health Resources and Services Administration.

## Statistical analysis

Weight, height, and BMI trajectories were modeled using linear spline mixed effects regression models. We built on previous work proposing similar methods to identify longitudinal outliers in clinical data on a predominately adult patient population, accounting for clustering of multiple observations per patient over time [10]. We extended this model to account for nonlinear growth in youth by incorporating piecewise regression over age [14]. Statistical analysis was conducted in SAS Version 9.4 (SAS Institute, Cary, NC). Each of the following steps were performed first in the training dataset (n=73,599), then repeated in the test dataset (n=73,776).

First, mixed effects regression modeled weight, height, and BMI as a function of age, specifying random intercept and slopes for subjects, and fixed effects for race/ethnicity.

Analyses were stratified by sex to accommodate sex-specific growth patterns. Piecewise trajectories were fit by including spline terms for age; the number and placement of knots were determined by inflection points identified in loess plots, stratified by sex and race/ethnicity in order to address potential racial/ethnic differences in growth trajectories. Graphically-identified inflection points within the age range of the study (10–18 years) for weight, height, and BMI were 12.5 years for girls and 15 years for boys. Racial/ethnic groups had different intercepts, but similar inflection points; therefore final models were stratified by sex and included race/ethnicity as a covariate:

$$\text{Girls: } Y_{it} = \beta_0 + \beta_1 * Age + \beta_2 Age\_after12.5 + \beta_x X_i + b_{0i} + b_{1t} Age + b_{2t} Age\_after12.5 + \varepsilon_{it}$$
$$\text{Boys: } Y_{it} = \beta_0 + \beta_1 * Age + \beta_2 Age\_after15 + \beta_x X_i + b_{0i} + b_{1t} Age + b_{2t} Age\_after15 + \varepsilon_{it}$$

Where $Y_{it}$ denotes weight, height, or BMI for patient *i* at time *t*. Continuous *Age* was centered at ten years, with additional spline variable for years after age 12.5 and 15 for girls (*Age_after12.5*) and boys (*Age_after15*), respectively. $X_i$ was race/ethnicity. $b_{0i}$ enabled patient variability at age 10. $b_{1t}$ enabled different patient-level growth trajectories from age 10–12.5 for girls and age 10–15 for boys. $b_{2t}$ enabled different patient-level growth trajectories from age 12.5–18 for girls and age 15–18 for boys. Model coefficients are presented in Appendix Tables A.2-3.

Second, after fitting the sex-stratified longitudinal models, we calculated studentized residuals for each measurement, representing the difference between the measurement at any given encounter relative to the expected value from the child's specific growth curve, standardized by their estimated standard error. Longitudinal encounter-level outliers were defined as measurements with studentized residuals >|6|. Population outliers were defined based on modified z-scores as described by the CDC: weight z-score <−5 or >8, height z-score <−5 or >4, BMI z-score <−4 or >8, relative to the CDC 2000 growth curves [15].

Third, we assessed agreement between population and longitudinal outliers by computing percent agreement and prevalence-adjusted bias-adjusted kappa (PABAK) statistics. PABAK was selected over Cohen's Kappa, which can yield paradoxical results when the prevalence of the outcome is not evenly distributed across categories of interest [16].

Fourth, we determined the impact of outlier identification approach on prevalence of BMI categories and change in anthropometric measures. Within two analytic subsamples – one excluding population outliers, the other excluding longitudinal outliers – we calculated prevalence of BMI categories and mean change in weight, height, and BMI from the first to the last observed measurements $\left(\frac{Last\ Measurement_i - First\ Measurement_i}{Years_i}\right)$.

## RESULTS

Study characteristics were similar in the training and test samples (Table 1). Both were composed of 57% females and a large proportion of Hispanic (43%) and non-Hispanic white (36%) children. Among the first observed encounters for each child, mean age was 13.6 years; mean height, weight, and BMI z-scores were 0.1, 0.7, and 0.8, respectively. Among the last observed encounters for each child, mean age was 15.7 years, mean height z-score was smaller (−0.08), and mean weight and BMI remained elevated (mean z-score 0.7 and 0.7, respectively). Children had a median of 4 height and BMI measures and 5 weight measures, although number of measurements per child varied; 10% had only 3 measures, 10% had ≥10 measures.

In mixed effects models (Appendix Table A.2-3), weight, height, and BMI increased at faster rate prior to the first inflection point (girls: 12.5 years; boys: 15 years), compared to after. Relative to white children, children of color were generally shorter and heavier at baseline, with the exception of Asian children who were shorter and lighter.

Overall, few outliers were identified using either longitudinal and population definitions in the test dataset; ≥99.7% of weight, height, and BMI measurements were not extreme by either definition in both girls and boys (Agreement and PABAK ≥0.995; Table 2). Among population outliers, the proportion also classified as longitudinal outliers varied. For example, most *low* weight and height population outliers were also classified as longitudinal outliers in girls (weight: 89.3%; height: 67.1%) and boys (weight: 88.2%; height: 74.6%). For low BMI, agreement was lower: few of the population outliers were longitudinally-defined outliers (6.8% in girls, 17.3% in boys). *High* population outliers were typically also longitudinal outliers in girls (weight: 100%; height: 84.6%; BMI: 83.7%), but less so in boys (weight: 18.4%; height: 50.6%; BMI: 48.8%).

Exclusion of population or longitudinal BMI outliers had negligible impact on the prevalence of BMI categories; estimated prevalences were within 0.1 percentage point (Table 3). Prevalence estimates were also similar if height and weight outliers were omitted from calculated BMI values (as opposed to excluding BMI outliers).

Annualized mean change in height and BMI was similar upon removing longitudinal outliers, compared to removing population outliers (Table 4). However, among children who were >85$^{th}$ percentile at baseline, mean changes in height, weight, and BMI were consistently and substantially higher in data screened for longitudinal outliers (girls: 1.24 inches, 12.39 pounds, 1.53 kg/m$^2$; boys: 2.34, 14.08, 1.07), compared to population outliers (girls: 0.61 inches, 8.22 pounds, 0.75 kg/m$^2$; boys: 1.53, 11.61, 0.48).

The comparison of longitudinal and population outliers with regard to prevalence, agreement, BMI category prevalence, and change over time were similar in the training and test datasets (Appendix Tables A.4-A.6).

## DISCUSSION

In this study, we demonstrated a longitudinal method for assessing weight, height, and BMI outliers in a large population of low-income children. Overall, outliers were uncommon and agreement between population and longitudinal outlier definitions was high. The method used to identify outliers had negligible impact on the estimated prevalence of BMI categories. However, within children with elevated height, weight or BMI at baseline (>85$^{th}$ percentile), exclusion of population outliers resulted in smaller estimates of mean change in weight, height, and BMI over time, compared to exclusion based on longitudinal outliers.

This latter finding indicates that population-based outlier exclusion criteria may limit the accuracy of growth trajectory estimation for high-risk children, for whom growth tracking has high clinical relevance.

Despite concerns about error in weight and height in clinical data, <0.3% of pediatric weight, height, and BMI measurements in our analytic sample were classified as outliers by either definition. This finding is consistent with a recent review, in which the prevalence of implausible height, weight, or BMI values ranged from 0.03% to 4.5% using variable, largely cross-sectional definitions in large study populations. Yang and Hutcheon's longitudinal outlier approach identified 0.3% of weight measures in young children as potential outliers in an intervention trial [9]. Among studies using EHR data, Daymont et al reported that 3.8% of weight and 4.5% of height measures were implausible; or 0.3% of weights and 1% of heights implausible for reasons other than values "carried forward" [1], which were not explicitly identified in our study. In previous work using EHR data, BMI among children 2–17 years was highly reliable over time (ICC 0.97) [17], and childhood obesity prevalence was consistent with NHANES [18]. In short, high quality anthropometric measurements are available from EHR data, even in the lower-resourced setting of safety net providers. This would be anticipated, given the clinical importance of accurate measurements for medication dosing and other clinical decisions.

Correspondingly, the outlier identification method had negligible impact on the estimated prevalence of BMI categories. This result contrasts with findings from Freedman et al., who found that inclusion of valid but extreme BMI measures resulted in a 1 percentage point difference in obesity prevalence in predominately low-income children 0–5 years of age [5]. The small impact of excluding potentially valid but extreme anthropometry measures on overall obesity prevalence in our EHR-based sample of older children is encouraging, particularly for studies that focus on overall obesity prevalence in cross-sectional populations.

Yet pediatric obesity research increasingly focuses on weight and BMI changes over time, temporal growth patterning, or, as severe obesity becomes more common, children in the upper ranges of weight and BMI. Indeed, we found that the estimates of mean change in weight, height, and BMI over time were smaller in analyses that excluded population outliers in children who were >85$^{th}$ percentile at baseline. These findings suggest that longitudinal outlier approaches are valuable in analyses that focus on weight change among the highest risk children.

## Strengths and limitations

This study should be interpreted with several limitations in mind. Similar to most prior studies, classification as a longitudinal or population outlier was not validated against a gold standard. Yet we contributed evidence about agreement between approaches and their impact on estimates of BMI classification prevalence and BMI change. While we did not test alternative thresholds for the longitudinal residual values, we recommend this as an important next step in future research. Third, linear splines for age adequately captured the growth trajectory in our study population from 10–18 years of age while remaining feasible in our large, complex database, but other functional forms should be explored in studies using different age ranges. Fourth, determining the extent to which our findings are generalizable to children of higher socioeconomic status requires replication in middle and higher income study populations. Other study populations may exhibit different patterns of health care utilization and, therefore, timing of measures; however, measurements were consistent with the well-child visit schedule observed in most clinical populations. Balancing these limitations is our feasible and reproducible approach for identifying implausible values in a large, multi-state study population of under-represented and vulnerable low-income children.

### Recommendations for identifying potentially invalid weight, height, and BMI values in pediatric EHR data

We offer several recommendations for defining and excluding potentially implausible weight, height, and BMI values in pediatric EHR data. First, population-based definitions are well-defined and easy to implement in any research context. They are the primary option for cross-sectional studies; and likely sufficient for longitudinal studies that examine mean BMI or obesity prevalence at specific points in time and do not focus on children with weight or BMI above the 85$^{th}$ percentile.

Second, our findings suggest that longitudinal approaches are important for studies that examine changes in weight or BMI over time or among children with elevated weight or BMI. The development of longitudinal approaches is an evolving area, with several proposed approaches [1,8,9]. This paper contributes a regression-based approach for identifying longitudinal anthropometric outliers in exceptionally large sample of older children with highly variable time points found in EHR data. Advancement of longitudinal methods requires more validation against a gold standard, such as expert clinician review as described by Daymont et al [1].

Third, our longitudinal approach can be applied to weight, height, and calculated BMI. We found that excluding extreme weight and heights from BMI calculations produced similar BMI category prevalences as excluding extreme calculated BMI. Yet we recommend outlier assessment of weight and height because it aligns with the underlying data error mechanism. At a minimum, the approach should be explicitly reported to support research reproducibility.

## Conclusion

We describe a longitudinal method for identifying weight, height, or BMI outliers that can be easily implemented and reproduced in EHR-based pediatric study populations. In our low-income clinical study population, less than 0.3% of anthropometry measures were potential outliers and prevalence of BMI classifications were robust to outlier identification method. Yet our findings suggest that longitudinal outlier identification methods are needed for unbiased estimation of weight, height, and BMI change in children with elevated values at baseline.

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## Appendix A. Supplemental Tables

### Table A1.

Characteristics of children aged 10 to 18 years in the ADVANCE Weight Cohort[a]

| | Analytic Sample | Excluded |
|---|---|---|
| Total (n) | 147,375 | 207,242 |
| Sex [%] | | |
| Female | 57.42 | 51.60 |
| Male | 42.58 | 48.40 |
| Race/Ethnicity [%] | | |
| American Indian or Alaskan Native | 0.45 | 0.39 |
| Asian | 2.70 | 2.81 |
| Black or African American | 14.58 | 17.88 |
| Multiple Race | 1.28 | 1.10 |
| Native Hawaiian or Other Pacific Islander | 0.48 | 0.59 |
| White | 36.16 | 31.73 |
| No Information/Unknown | 1.57 | 3.30 |
| Hispanic | 42.79 | 42.19 |
| First observed visit [median ($10^{th}$, $90^{th}$ Percentile)] | | |
| Age (years) | 13.39 (10.27,17.25) | 14.41 (10.56,18.23) |
| Height z-score | 0.07 (−1.30,1.48) | 0.03 (−1.33,1.45) |
| Weight z-score | 0.55 (−0.95,2.46) | 0.45 (−1.02,2.26) |
| BMI z-score | 0.60 (−0.82,2.43) | 0.47 (−0.93,2.21) |
| Last observed visit [median ($10^{th}$, $90^{th}$ Percentile)] | | |
| Age (years) | 16.16 (12.04,18.73) | 14.86 (11.08,18.47) |
| Time since first visit (years) | 1.85 (0.37,4.37) | 0.38 (0.04,1.94) |
| Height z-score | −0.09 (−1.44,1.31) | −0.01 (−1.37,1.41) |
| Weight z-score | 0.54 (−0.97,2.48) | 0.48 (−1.02,2.33) |
| BMI z-score | 0.58 (−0.85,2.45) | 0.50 (−0.92,2.28) |
| Number of measures per child [median ($10^{th}$, $90^{th}$ Percentile)] | | |
| Height | 4 (3, 10) | 1 (1, 2) |
| Weight | 5 (3, 13) | 1 (1, 2) |
| BMI | 4 (3, 10) | 1 (1, 2) |

BMI, body mass index; SD, standard deviation; HCN, Health Care Network

[a]OCHIN and HCN patients who, between 1/1/2012 and 12/31/2015, were 10–18 years of age

## Table A.2.

Mixed model regression results: **Test** dataset[a]

| | Girls | | Boys | |
|---|---|---|---|---|
| | **Full** | **Outliers Removed** | **Full** | **Outliers Removed** |
| | β (95% Confidence Interval) | | | |
| **Weight** | | | | |
| Intercept | 88.32 (87.70, 88.93) | 87.97 (87.36, 88.58) | 84.04 (83.31, 84.76) | 83.94 (83.23, 84.65) |
| Age1[b] | 14.85 (14.71, 15.00) | 14.81 (14.67, 14.95) | 14.11 (14.00, 14.22) | 14.09 (13.99, 14.19) |
| Age2[c] | −9.58 (−9.77, −9.39) | −9.35 (−9.54, −9.17) | −7.84 (−8.07, −7.60) | −7.79 (−8.00, −7.57) |
| Asian | −18.59 (−20.71, −16.47) | −18.29 (−20.41, −16.17) | −9.89 (−12.39, −7.38) | −9.56 (−12.04, −7.07) |
| NHPI | 8.78 (3.91, 13.65) | 8.28 (3.41, 13.14) | 15.55 (9.79, 21.3) | 15.21 (9.52, 20.89) |
| Black | 7.84 (6.80, 8.88) | 7.43 (6.39, 8.47) | 0.52 (−0.79, 1.83) | 0.86 (−0.44, 2.16) |
| AI/AN | 5.57 (0.81, 10.33) | 5.25 (0.48, 10.02) | 2.18 (−4.26, 8.62) | 2.53 (−3.85, 8.91) |
| Multiple race | 7.05 (4.15, 9.96) | 6.55 (3.64, 9.46) | 0.68 (−3.41, 4.76) | 0.73 (−3.31, 4.76) |
| Other race | 0.58 (−2.29, 3.45) | 0.89 (−1.98, 3.77) | 1.62 (−1.78, 5.01) | 1.57 (−1.79, 4.94) |
| Hispanic | 0.11 (−0.65, 0.87) | −0.01 (−0.78, 0.75) | 5.69 (4.77, 6.61) | 5.95 (5.03, 6.86) |
| **Height** | | | | |
| Intercept | 56.39 (56.31, 56.46) | 56.54 (56.47, 56.61) | 55.44 (55.36, 55.52) | 55.50 (55.43, 55.58) |
| Age1[b] | 2.50 (2.48, 2.52) | 2.48 (2.46, 2.5) | 2.49 (2.48, 2.500) | 2.48 (2.47, 2.49) |
| Age2[c] | −2.18 (−2.21, −2.16) | −2.16 (−2.18, −2.14) | −2.02 (−2.04, −2.00) | −2.01 (−2.03, −1.98) |
| Asian | −2.03 (−2.22, −1.85) | −2.05 (−2.23, −1.87) | −1.68 (−1.91, −1.45) | −1.66 (−1.90, −1.43) |
| NHPI | −0.75 (−1.16, −0.33) | −0.78 (−1.18, −0.37) | −0.06 (−0.60, 0.48) | 0.00 (−0.55, 0.54) |
| Black | −0.01 (−0.09, 0.08) | 0.01 (−0.08, 0.09) | −0.03 (−0.15, 0.09) | −0.01 (−0.13, 0.11) |
| AI/AN | 0.11 (−0.29, 0.51) | 0.07 (−0.32, 0.46) | 0.18 (−0.43, 0.78) | 0.15 (−0.46, 0.76) |
| Multiple race | 0.26 (0.01, 0.50) | 0.23 (−0.01, 0.47) | −0.08 (−0.45, 0.29) | −0.10 (−0.47, 0.28) |
| Other race | −0.19 (−0.44, 0.06) | −0.19 (−0.44, 0.06) | −0.45 (−0.77, −0.13) | −0.44 (−0.76, −0.11) |
| Hispanic | −1.45 (−1.52, −1.39) | −1.47 (−1.53, −1.40) | −0.92 (−1.00, −0.83) | −0.89 (−0.98, −0.81) |
| **BMI** | | | | |
| Intercept | 19.71 (19.56, 19.86) | 19.68 (19.56, 19.8) | 19.86 (19.73, 20.00) | 19.85 (19.72, 19.97) |
| Age1[b] | 1.22 (1.16, 1.27) | 1.16 (1.13, 1.18) | 0.80 (0.78, 0.82) | 0.80 (0.79, 0.82) |
| Age2[c] | −0.60 (−0.67, −0.53) | −0.47 (−0.51, −0.43) | −0.27 (−0.32, −0.21) | −0.22 (−0.26, −0.19) |
| Asian | −2.16 (−2.59, −1.72) | −2.08 (−2.48, −1.68) | −0.88 (−1.32, −0.44) | −0.95 (−1.38, −0.52) |
| NHPI | 1.50 (0.52, 2.48) | 1.33 (0.43, 2.23) | 2.81 (1.80, 3.82) | 2.83 (1.86, 3.81) |
| Black | 1.49 (1.29, 1.7) | 1.26 (1.07, 1.45) | −0.09 (−0.31, 0.13) | −0.1 (−0.32, 0.11) |
| AI/AN | 0.99 (0.04, 1.94) | 1.01 (0.13, 1.89) | 0.10 (−1.01, 1.21) | 0.12 (−0.97, 1.22) |
| Multiple race | 1.22 (0.64, 1.81) | 1.27 (0.73, 1.81) | 0.32 (−0.37, 1.01) | 0.24 (−0.44, 0.91) |
| Other race | −0.08 (−0.68, 0.52) | 0.07 (−0.48, 0.62) | 0.29 (−0.32, 0.90) | 0.31 (−0.28, 0.90) |
| Hispanic | 0.90 (0.74, 1.05) | 0.82 (0.68, 0.97) | 1.48 (1.32, 1.64) | 1.43 (1.28, 1.58) |

AI/AN, American Indian/Alaskan Native; BMI, body mass index; NHPI, Native Hawaiian or Pacific Islander

[a]Children 10–18 years of age in the ADVANCE Weight Cohort (n=73,776)

[b]Age1 corresponds to age in years from age 10 to 12.5 for girls and from age 10 to 15 in boys.

[c]Age2 corresponds to age in years from age 12.5 to 18 for girls and from age 15 to 18 in boys.

### Table A.3.

Mixed model regression results: **Training** dataset[a]

| | Girls | | Boys | |
|---|---|---|---|---|
| | **Full** | **Outliers Removed** | **Full** | **Outliers Removed** |
| | β (95% Confidence Interval) | | | |
| **Weight** | | | | |
| Intercept | 88.04 (87.43, 88.65) | 87.85 (87.24, 88.46) | 84.34 (83.62, 85.07) | 83.96 (83.26, 84.67) |
| Age1[b] | 14.73 (14.59, 14.87) | 14.62 (14.49, 14.76) | 14.03 (13.92, 14.14) | 14.03 (13.93, 14.13) |
| Age2[c] | −9.33 (−9.51, −9.14) | −9.03 (−9.21, −8.84) | −7.58 (−7.81, −7.35) | −7.54 (−7.75, −7.32) |
| Asian | −15.93 (−18.17, −13.68) | −15.85 (−18.11, −13.58) | −12.26 (−14.86, −9.67) | −11.66 (−14.21, −9.1) |
| NHPI | 10.16 (5.15, 15.17) | 10.27 (5.24, 15.3) | 11.88 (5.66, 18.1) | 11.5 (5.38, 17.62) |
| Black | 7.99 (6.95, 9.03) | 7.64 (6.6, 8.68) | 0.49 (−0.83, 1.81) | 0.74 (−0.56, 2.04) |
| AI/AN | 7.62 (2.74, 12.5) | 7.42 (2.51, 12.33) | 8.54 (1.28, 15.8) | 8.66 (1.53, 15.8) |
| Multiple race | 7.58 (4.65, 10.51) | 7.37 (4.43, 10.32) | 3.08 (−0.88, 7.04) | 2.54 (−1.36, 6.44) |
| Other race | −1.78 (−4.63, 1.07) | −1.87 (−4.74, 1) | 0.42 (−2.95, 3.79) | −0.56 (−3.89, 2.76) |
| Hispanic | 0.02 (−0.74, 0.78) | −0.17 (−0.93, 0.6) | 5.36 (4.44, 6.29) | 5.94 (5.03, 6.85) |
| **Height** | | | | |
| Intercept | 56.42 (56.35, 56.49) | 56.54 (56.47, 56.61) | 55.47 (55.4, 55.55) | 55.55 (55.47, 55.63) |
| Age1[b] | 2.5 (2.48, 2.53) | 2.49 (2.47, 2.52) | 2.49 (2.48, 2.5) | 2.48 (2.47, 2.49) |
| Age2[c] | −2.19 (−2.21, −2.16) | −2.17 (−2.2, −2.15) | −2.02 (−2.05, −2) | −2 (−2.02, −1.98) |
| Asian | −1.98 (−2.18, −1.79) | −2.03 (−2.21, −1.84) | −1.92 (−2.16, −1.68) | −1.88 (−2.12, −1.64) |
| NHPI | −0.63 (−1.05, −0.21) | −0.68 (−1.1, −0.27) | −0.61 (−1.19, −0.03) | −0.47 (−1.06, 0.11) |
| Black | −0.05 (−0.13, 0.04) | 0 (−0.09, 0.08) | −0.07 (−0.19, 0.05) | −0.06 (−0.18, 0.06) |
| AI/AN | 0.07 (−0.34, 0.48) | 0.06 (−0.35, 0.46) | −0.11 (−0.77, 0.55) | −0.15 (−0.81, 0.52) |
| Multiple race | 0.04 (−0.21, 0.29) | 0.02 (−0.23, 0.26) | −0.12 (−0.48, 0.24) | −0.13 (−0.5, 0.23) |
| Other race | −0.29 (−0.55, −0.04) | −0.34 (−0.59, −0.09) | −0.31 (−0.63, 0.01) | −0.28 (−0.6, 0.05) |
| Hispanic | −1.51 (−1.57, −1.44) | −1.52 (−1.58, −1.46) | −0.99 (−1.07, −0.9) | −0.98 (−1.06, −0.89) |
| **BMI** | | | | |
| Intercept | 19.53 (19.38, 19.67) | 19.56 (19.45, 19.68) | 19.9 (19.77, 20.03) | 19.88 (19.75, 20) |
| Age1[b] | 1.23 (1.18, 1.28) | 1.16 (1.13, 1.19) | 0.77 (0.75, 0.8) | 0.78 (0.76, 0.79) |
| Age2[c] | −0.59 (−0.65, −0.53) | −0.46 (−0.5, −0.42) | −0.15 (−0.21, −0.1) | −0.16 (−0.19, −0.12) |
| Asian | −1.78 (−2.24, −1.33) | −1.74 (−2.15, −1.32) | −1.15 (−1.59, −0.7) | −1.19 (−1.63, −0.75) |
| NHPI | 2.13 (1.15, 3.12) | 2.12 (1.21, 3.02) | 2.6 (1.55, 3.65) | 2.31 (1.26, 3.36) |
| Black | 1.52 (1.32, 1.73) | 1.22 (1.03, 1.4) | −0.06 (−0.28, 0.16) | −0.08 (−0.3, 0.13) |
| AI/AN | 1.14 (0.16, 2.12) | 1.2 (0.3, 2.1) | 1.23 (0.01, 2.45) | 1.31 (0.1, 2.51) |
| Multiple race | 1.37 (0.78, 1.96) | 1.29 (0.74, 1.83) | 0.77 (0.11, 1.43) | 0.81 (0.16, 1.47) |
| Other race | −0.18 (−0.78, 0.42) | −0.16 (−0.71, 0.4) | 0.24 (−0.35, 0.82) | 0.3 (−0.28, 0.88) |
| Hispanic | 0.96 (0.81, 1.12) | 0.88 (0.74, 1.02) | 1.45 (1.3, 1.6) | 1.43 (1.28, 1.59) |

AI/AN, American Indian/Alaskan Native; BMI, body mass index; NHPI, Native Hawaiian or Pacific Islander

[a]Children 10–18 years of age in the ADVANCE Weight Cohort (n=73,599)

[b]Age1 corresponds to age in years from age 10 to 12.5 for girls and from age 10 to 15 in boys.

[c]Age2 corresponds to age in years from age 12.5 to 18 for girls and from age 15 to 18 in boys.

**Table A.4.**

Agreement between population and longitudinal outliers: **Training** dataset[a]

| Longitudinal outliers[b] | | Population outliers[c] [n (column %)] | | | Percent Agreement | Prevalence-Adjusted Bias-Adjusted Kappa |
|---|---|---|---|---|---|---|
| | | Low | Not extreme | High | | |
| **Girls** | | | | | | |
| Weight | | | | | 0.9982 | 0.9974 |
| | Low | 55 (87.3) | 313 (0.1) | 0 (0.0) | | |
| | Not extreme | 8 (12.7) | 301,602 (99.8) | 3 (7.3) | | |
| | High | 0 (0.0) | 205 (0.1) | 38 (92.7) | | |
| Height | | | | | 0.997 | 0.9955 |
| | Low | 150 (79.8) | 288 (0.2) | 0 (0.0) | | |
| | Not extreme | 38 (20.2) | 189,824 (99.7) | 47 (47.5) | | |
| | High | 0 (0.0) | 198 (0.1) | 52 (52.5) | | |
| BMI | | | | | 0.9988 | 0.9983 |
| | Low | 3 (4.2) | 112 (0.1) | 0 (0.0) | | |
| | Not extreme | 68 (95.8) | 189,166 (99.9) | 10 (9.4) | | |
| | High | 0 (0.0) | 28 (0.0) | 96 (90.6) | | |
| **Boys** | | | | | | |
| Weight | | | | | 0.9975 | 0.9963 |
| | Low | 34 (56.7) | 208 (0.1) | 0 (0.0) | | |
| | Not extreme | 26 (43.3) | 192,484 (99.8) | 96 (86.5) | | |
| | High | 0 (0.0) | 151 (0.1) | 15 (13.5) | | |
| Height | | | | | 0.9968 | 0.9951 |
| | Low | 64 (57.1) | 228 (0.2) | 0 (0.0) | | |
| | Not extreme | 48 (42.9) | 137,612 (99.8) | 57 (57.6) | | |
| | High | 0 (0.0) | 116 (0.1) | 42 (42.4) | | |
| BMI | | | | | 0.9985 | 0.9977 |
| | Low | 15 (17.9) | 74 (0.1) | 0 (0.0) | | |
| | Not extreme | 69 (82.1) | 137,251 (99.9) | 38 (46.9) | | |
| | High | 0 (0.0) | 26 (0.0) | 43 (53.1) | | |

BMI, body mass index

[a]Children 10–18 years of age in the ADVANCE Weight Cohort (n=73,599)

[b]Studentized residual >|6| from sex-stratified, linear spline, mixed effects regression

[c]Weight z-score <−5 or >8, height z-score <−5 or >4, BMI z-score <−4 or >8, relative to the CDC 2000 growth curves

**Table A.5.**

BMI Category[a] Prevalence (child-level): **Training** Dataset[b]

| | Girls | | Boys | |
|---|---|---|---|---|
| | Population outlier approach | Longitudinal outlier approach | Population outlier approach | Longitudinal outlier approach |
| Height and weight outliers excluded | n=33,345 | n=33,214 | n=25,666 | n=25,585 |

| | Girls | | Boys | |
|---|---|---|---|---|
| | Population outlier approach | Longitudinal outlier approach | Population outlier approach | Longitudinal outlier approach |
| Underweight | 1.99 | 1.98 | 2.91 | 2.89 |
| Normal BMI | 51.82 | 51.90 | 52.21 | 52.26 |
| Overweight | 21.39 | 21.45 | 16.91 | 16.93 |
| Obese | 15.41 | 15.38 | 16.70 | 16.65 |
| Severe obesity | 9.40 | 9.30 | 11.28 | 11.27 |
| BMI outliers excluded | n=33,364 | n=33,342 | n=25,686 | n=25,683 |
| Underweight | 1.98 | 2.00 | 2.90 | 2.92 |
| Normal BMI | 51.80 | 51.80 | 52.19 | 52.16 |
| Overweight | 21.39 | 21.39 | 16.90 | 16.91 |
| Obese | 15.41 | 15.41 | 16.70 | 16.68 |
| Severe obesity | 9.41 | 9.40 | 11.31 | 11.32 |

BMI, body mass index

[a]BMI percentiles were classified according to Centers for Disease Control 2000 growth curves: underweight (<5th percentile), normal weight (5th to <85th), overweight (85th to <95th), obese (95th to <20% higher than the 95th percentile), and severe obese (≥20% higher than the 95th percentile).

[b]Children 10–18 years of age in the ADVANCE Weight Cohort. Children were classified based on last observed BMI measure, after omission of height and weight or BMI outliers, according to the population or longitudinal outlier approach.

## Table A.6.

Annualized change in anthropometry (child level): **Training** dataset[a]

| | Girls | | Boys | |
|---|---|---|---|---|
| | Population outlier approach | Longitudinal outlier approach | Population outlier approach | Longitudinal outlier approach |
| **Height change**[b] | | | | |
| Full sample | n=33,492 | n=33,439 | n=25,798 | n=25,769 |
| Mean (SD) | 0.78 (3.79) | 0.71 (10.07) | 1.71 (5.77) | 1.65 (5.78) |
| Median (10th, 90th percentile) | 0.43 (−0.34,2.57) | 0.41 (−0.42,2.65) | 1.80 (0.00,3.34) | 1.77 (0.00,3.42) |
| >85th percentile at baseline | n=5,839 | n=4,545 | n=5,383 | n=4,606 |
| Mean (SD) | 0.53 (5.92) | 1.28 (6.74) | 1.45 (5.66) | 2.36 (7.32) |
| Median (10th,90th percentile) | 0.53 (−0.44,2.38) | 0.73 (−0.13,3.26) | 1.65 (0.00,3.25) | 2.39 (0.00,4.04) |
| **Weight change**[b] | | | | |
| Full sample | n=42,254 | n=42,194 | n=31,195 | n=31,166 |
| Mean (SD) | 8.07 (22.78) | 8.34 (37.82) | 10.71 (21.60) | 10.93 (40.46) |
| Median (10th, 90th percentile) | 6.91 (−4.27,21.47) | 6.89 (−5.75,23.48) | 10.50 (−0.22,23.18) | 10.46 (−1.64,24.33) |
| >85th percentile at baseline | n=16,873 | n=17,398 | n=13,385 | n=12,961 |
| Mean (SD) | 8.07 (27.95) | 12.45 (44.52) | 11.25 (24.09) | 14.65 (50.88) |
| Median (10th,90th percentile) | 7.89 (−7.12,24.35) | 10.63 (−4.91,30.42) | 12.12 (−3.64,26.61) | 14.80 (−1.60,29.87) |
| **BMI change**[b] | | | | |
| Full sample | n=33,310 | n=33,345 | n=25,558 | n=25,682 |
| Mean (SD) | 0.89 (4.48) | 0.90 (8.27) | 0.68 (5.27) | 0.63 (15.11) |
| Median (10th, 90th percentile) | 0.72 (−1.06,2.99) | 0.72 (−1.41,3.37) | 0.66 (−1.01,2.50) | 0.66 (−1.26,2.79) |
| >85th percentile at baseline | n=14,973 | n=15,389 | n=11,938 | n=11,565 |

| | Girls | | Boys | |
|---|---|---|---|---|
| | Population outlier approach | Longitudinal outlier approach | Population outlier approach | Longitudinal outlier approach |
| Mean (SD) | 0.76 (4.97) | 1.55 (10.51) | 0.44 (6.58) | 1.07 (10.25) |
| Median (10th, 90th percentile) | 0.80 (−1.64,3.33) | 1.24 (−1.40,4.46) | 0.64 (−1.66,2.82) | 1.09 (−1.44,3.67) |

BMI, body mass index; SD, standard deviation

[a]Children 10–18 years of age in the ADVANCE Weight Cohort.

[b]Annualized change calculated as (last measure – first measurement)/number of years, after omission of height and weight or BMI outliers, according to the population or longitudinal outlier approach.

## List of Abbreviations/Acronyms:

| | |
|---|---|
| **BMI** | Body mass index |
| **EHR** | Electronic Health Record |
| **PABAK** | Prevalence-Adjusted Bias-Adjusted Kappa |

## REFERENCES

[1]. Daymont C, Ross ME, Russell Localio A, Fiks AG, Wasserman RC, Grundmeier RW. Automated identification of implausible values in growth data from pediatric electronic health records. J Am Med Inform Assoc 2017;24:1080–7. doi:10.1093/jamia/ocx037. [PubMed: 28453637]

[2]. Lawman HG, Ogden CL, Hassink S, Mallya G, Vander Veur S, Foster GD. Comparing Methods for Identifying Biologically Implausible Values in Height, Weight, and Body Mass Index Among Youth. Am J Epidemiol 2015;182:359–65. doi:10.1093/aje/kwv057. [PubMed: 26182944]

[3]. Centers for Disease Control and Prevention. Modified z-scores in the CDC growth charts n.d

[4]. Skinner AC, Ravanbakht SN, Skelton JA, Perrin EM, Armstrong SC. Prevalence of Obesity and Severe Obesity in US Children, 1999–2016. Pediatrics 2018. doi:10.1542/peds.2017-3459.

[5]. Freedman DS, Lawman HG, Pan L, Skinner AC, Allison DB, McGuire LC, et al. The prevalence and validity of high, biologically implausible values of weight, height, and BMI among 8.8 million children. Obesity (Silver Spring) 2016;24:1132–9. doi:10.1002/oby.21446. [PubMed: 26991694]

[6]. Isong IA, Richmond T, Avendaño M, Kawachi I. Racial/Ethnic Disparities: a Longitudinal Study of Growth Trajectories Among US Kindergarten Children. J Racial Ethn Health Disparities 2018;5:875–84. doi:10.1007/s40615-017-0434-1. [PubMed: 29124684]

[7]. Clarke P, O'Malley PM, Johnston LD, Schulenberg JE. Social disparities in BMI trajectories across adulthood by gender, race/ethnicity and lifetime socio-economic position: 1986–2004. Int J Epidemiol 2009;38:499–509. doi:10.1093/ije/dyn214. [PubMed: 18835869]

[8]. Shi J, Korsiak J, Roth DE. New approach for the identification of implausible values and outliers in longitudinal childhood anthropometric data. Annals of Epidemiology 2018;28:204–211.e3. doi:10.1016/j.annepidem.2018.01.007. [PubMed: 29398298]

[9]. Yang S, Hutcheon JA. Identifying outliers and implausible values in growth trajectory data. Annals of Epidemiology 2016;26:77–80.e2. doi:10.1016/j.annepidem.2015.10.002. [PubMed: 26590476]

[10]. Welch C, Petersen I, Walters K, Morris RW, Nazareth I, Kalaitzaki E, et al. Two-stage method to remove population- and individual-level outliers from longitudinal data in a primary care database. Pharmacoepidemiol Drug Saf 2012;21:725–32. doi:10.1002/pds.2270. [PubMed: 22052713]

[11]. DeVoe JE, Gold R, Cottrell E, Bauer V, Brickman A, Puro J, et al. The ADVANCE network: accelerating data value across a national community health center network. J Am Med Inform Assoc 2014;21:591–5. doi:10.1136/amiajnl-2014-002744. [PubMed: 24821740]

[12]. Kuczmarski RJ, Ogden CL, Guo SS, Grummer-Strawn LM, Flegal KM, Mei Z, et al. 2000 CDC Growth Charts for the United States: methods and development. Vital Health Stat 11 2002:1–190.

[13]. Division of Nutrition, Physical Activity, and Obesity, National Center for Chronic Disease Prevention and Health Promotion. Defining Childhood Obesity. 2016.

[14]. Howe LD, Tilling K, Matijasevich A, Petherick ES, Santos AC, Fairley L, et al. Linear spline multilevel models for summarising childhood growth trajectories: A guide to their application using examples from five birth cohorts. Stat Methods Med Res 2016;25:1854–74. doi: 10.1177/0962280213503925. [PubMed: 24108269]

[15]. Division of Nutrition, Physical Activity, and Obesity, National Center for Chronic Disease Prevention and Health Promotion. A SAS Program for the 2000 CDC Growth Charts (ages 0 to <20 years). Growth Chart Training 2016 https://www.cdc.gov/nccdphp/dnpao/growthcharts/resources/sas.htm (accessed July 12, 2018).

[16]. Byrt T, Bishop J, Carlin JB. Bias, prevalence and kappa. J Clin Epidemiol 1993;46:423–9. [PubMed: 8501467]

[17]. Bailey LC, Milov DE, Kelleher K, Kahn MG, Beccaro MD, Yu F, et al. Multi-Institutional Sharing of Electronic Health Record Data to Assess Childhood Obesity. PLOS ONE 2013;8:e66192. doi:10.1371/journal.pone.0066192. [PubMed: 23823186]

[18]. Flood TL, Zhao Y-Q, Tomayko EJ, Tandias A, Carrel AL, Hanrahan LP. Electronic Health Records and Community Health Surveillance of Childhood Obesity. American Journal of Preventive Medicine 2015;48:234–40. doi:10.1016/j.amepre.2014.10.020. [PubMed: 25599907]

## Highlights

- Improved methods for identifying anthropometric outliers in children are needed.
- Population outlier methods underestimate growth in high-risk children.
- Longitudinal outlier methods reduce underestimation of growth in high-risk children.

**Table 1.**

Characteristics of children aged 10 to 18 years in the ADVANCE Weight Cohort[a]

| | Training Dataset | Test Dataset |
|---|---|---|
| Total (n) | 73,599 | 73,776 |
| Sex [n (%)] | | |
| Female | 42,319 (57.5) | 42,306 (57.3) |
| Male | 31,280 (42.5) | 31,470 (42.7) |
| Race/Ethnicity [n (%)] | | |
| American Indian or Alaskan Native | 316 (0.4) | 346 (0.5) |
| Asian | 1,882 (2.3) | 2,103 (2.9) |
| Black or African American | 10,722 (14.6) | 10,770 (14.6) |
| Multiple Race | 939 (1.3) | 940 (1.3) |
| Native Hawaiian or Other Pacific Islander | 340 (0.5) | 363 (0.5) |
| White | 26,699 (36.3) | 26,587 (36.0) |
| No Information/Unknown | 1,154 (1.6) | 1,157 (1.6) |
| Hispanic | 31,547 (42.9) | 31,510 (42.7) |
| First observed visit [mean (SD)] | | |
| Age (years) | 13.58 (2.59) | 13.57 (2.58) |
| Height z-score | 0.07 (1.17) | 0.07 (1.17) |
| Weight z-score | 0.70 (1.38) | 0.70 (1.39) |
| BMI z-score | 0.75 (1.50) | 0.76 (1.46) |
| Last observed visit [mean (SD)][b] | | |
| Age (years) | 15.73 (2.47) | 15.72 (2.48) |
| Time since first visit (years) | 2.15 (1.57) | 2.15 (1.57) |
| Height z-score | −0.08 (1.12) | −0.08 (1.12) |
| Weight z-score | 0.69 (1.38) | 0.69 (1.39) |
| BMI z-score | 0.74 (1.47) | 0.74 (1.38) |
| Number of measures per child [median ($10^{th}$, $90^{th}$ Percentile)] | | |
| Height | 4 (3, 10) | 4 (3, 10) |
| Weight | 5 (3, 13) | 5 (3, 13) |
| BMI | 4 (3, 10) | 4 (3, 10) |

BMI, body mass index; SD, standard deviation; HCN, Health Care Network

[a]OCHIN and HCN patients who, between 1/1/2012 and 12/31/2015, had at least 3 height, weight, or BMI measures when they were 10–18 years of age, regardless of weight status

## Table 2.

Agreement between CDC population and proposed longitudinal outliers: **Test** dataset[a]

| Proposed longitudinal outliers[b] | CDC population outliers[c] [n (column %)] | | | Percent Agreement | Prevalence- Adjusted Bias-Adjusted Kappa |
|---|---|---|---|---|---|
| | Low | Not extreme | High | | |
| **Girls** | | | | | |
| Weight | | | | | |
| Low | 67 (89.3) | 282 (0.1) | 0 (0.0) | | |
| Not extreme | 8 (10.7) | 300,463 (99.8) | 0 (0.0) | 0.9983 | 0.9974 |
| High | 0 (0.0) | 235 (0.1) | 33 (100) | | |
| Height | | | | | |
| Low | 155 (67.1) | 274 (0.1) | 0 (0.0) | | |
| Not extreme | 76 (32.9) | 189,129 (99.8) | 10 (15.4) | 0.9971 | 0.9956 |
| High | 0 (0.0) | 199 (0.1) | 55 (84.6) | | |
| BMI | | | | | |
| Low | 6 (6.8) | 123 (0.1) | 0 (0.0) | | |
| Not extreme | 82 (93.2) | 188,305 (99.9) | 16 (16.3) | 0.9987 | 0.998 |
| High | 0 (0.0) | 27 (0.0) | 82 (83.7) | | |
| **Boys** | | | | | |
| Weight | | | | | |
| Low | 45 (88.2) | 194 (0.1) | 0 (0.0) | | |
| Not extreme | 6 (11.8) | 195,775 (99.8) | 84 (81.6) | 0.998 | 0.9969 |
| High | 0 (0.0) | 117 (0.1) | 19 (18.4) | | |
| Height | | | | | |
| Low | 50 (74.6) | 268 (0.2) | 0 (0.0) | | |
| Not extreme | 17 (25.4) | 140,040 (99.7) | 39 (49.4) | 0.9969 | 0.9954 |
| High | 0 (0.0) | 110 (0.1) | 40 (50.6) | | |
| BMI | | | | | |
| Low | 18 (17.3) | 56 (0.0) | 1 (12.0) | | |
| Not extreme | 86 (82.7) | 139,534 (99.9) | 41 (50.0) | 0.9986 | 0.9979 |
| High | 0 (0.0) | 15 (0.0) | 40 (48.8) | | |

BMI, body mass index; CDC, Centers for Disease Control

[a] Children 10–18 years of age in the ADVANCE Weight Cohort (n=73,776)

[b] Standardized residual >|6| from sex-stratified, linear spline, mixed effects regression

[c] Weight z-score <−5 or >8, height z-score <−5 or >4, BMI z-score <−4 or >8, relative to the CDC 2000 growth curves

**Table 3.**

BMI Category[a] Prevalence (child-level): **Test** Dataset[b]

| | Girls | | Boys | |
|---|---|---|---|---|
| | **CDC Population outlier approach** | **Proposed Longitudinal outlier approach** | **CDC Population outlier approach** | **Proposed Longitudinal outlier approach** |
| Height and weight outliers excluded | n=33,259 | n=33,155 | n=25,860 | n=25,782 |
| Underweight | 2.0 | 1.99 | 2.76 | 2.75 |
| Normal BMI | 51.6 | 51.67 | 52.36 | 52.43 |
| Overweight | 21.32 | 21.38 | 16.38 | 16.39 |
| Obese | 15.3 | 15.29 | 16.76 | 16.73 |
| Severe obesity | 9.78 | 9.67 | 11.73 | 11.7 |
| BMI outliers excluded | n=33,285 | n=33,264 | n=25,868 | n=25,874 |
| Underweight | 2.01 | 2.03 | 2.74 | 2.79 |
| Normal BMI | 51.57 | 51.57 | 52.36 | 52.32 |
| Overweight | 21.33 | 21.34 | 16.38 | 16.37 |
| Obese | 15.31 | 15.3 | 16.77 | 16.76 |
| Severe obesity | 9.79 | 9.77 | 11.75 | 11.76 |

BMI, body mass index index; CDC, Centers for Disease Control

Children classified based on last observed BMI measure, after omission of height and weight or BMI outliers, according to population or longitudinal outlier approach

[a]BMI percentiles were classified according to Centers for Disease Control 2000 growth curves: underweight (<5th percentile), normal weight (5th to <85th), overweight (85th to <95th), obese (95th to <20% higher than the 95th percentile), and severe obese (≥20% higher than the 95th percentile).

[b]Children 10–18 years of age in the ADVANCE Weight Cohort (n=73,776). Children were classified based on last observed BMI measure, after omission of height and weight or BMI outliers, according to the population or longitudinal outlier approach.

**Table 4.**

Annualized change in anthropometry (child level): **Test** dataset[a]

| | Girls | | Boys | |
|---|---|---|---|---|
| | **CDC Population outlier approach** | **Proposed Longitudinal outlier approach** | **CDC Population outlier approach** | **Proposed Longitudinal outlier approach** |
| **Height change**[b] | | | | |
| Full sample | n=33,429 | n=33,391 | n=26,021 | n=25,996 |
| Mean (SD) | 0.78 (3.05) | 0.73 (6.60) | 1.76 (5.00) | 1.74 (7.95) |
| Median (10$^{th}$, 90$^{th}$ percentile) | 0.42 (−0.34,2.58) | 0.40 (−0.42,2.64) | 1.82 (0.00,3.35) | 1.79 (0.00,3.43) |
| >85$^{th}$ percentile at baseline | n=5,802 | n=4,662 | n=5,518 | n=4,717 |
| Mean (SD) | 0.61 (2.93) | 1.24 (7.51) | 1.53 (2.92) | 2.34 (5.45) |
| Median (10$^{th}$, 90$^{th}$ percentile) | 0.52 (−0.44,2.46) | 0.70 (−0.14,3.34) | 1.67 (0.00,3.25) | 2.36 (0.00,3.95) |
| **Weight change**[b] | | | | |
| Full sample | n=42,226 | n=42,164 | n=31,363 | n=31,338 |
| Mean (SD) | 7.98 (28.20) | 8.21 (32.00) | 10.87 (22.46) | 10.43 (42.57) |
| Median (10$^{th}$, 90$^{th}$ percentile) | 6.81 (−4.30,21.56) | 6.78 (−5.57,23.33) | 10.59 (−0.63,23.66) | 10.56 (−2.12,24.72) |
| >85$^{th}$ percentile at baseline | n=17,068 | n=17,434 | n=13,620 | n=13,067 |
| Mean (SD) | 8.22 (37.87) | 12.39 (38.09) | 11.61 (26.18) | 14.08 (39.10) |
| Median (10$^{th}$, 90$^{th}$ percentile) | 7.92 (−7.06,24.76) | 10.73 (−5.14,30.23) | 12.39 (−4.09,27.01) | 15.08 (−2.48,30.09) |
| **BMI change**[b] | | | | |
| Full sample | n=33,230 | n=33,267 | n=25,757 | n=25,871 |
| Mean (SD) | 0.87 (5.64) | 0.91 (8.74) | 0.66 (5.69) | 0.72 (7.94) |
| Median (10$^{th}$, 90$^{th}$ percentile) | 0.73 (−1.12,3.02) | 0.74 (−1.43,3.37) | 0.67 (−1.02,2.53) | 0.67 (−1.28,2.88) |
| >85$^{th}$ percentile at baseline | n=15,153 | n=15,475 | n=12,115 | n=11,661 |
| Mean (SD) | 0.75 (7.37) | 1.53 (8.39) | 0.48 (7.89) | 1.07 (10.33) |
| Median (10$^{th}$, 90$^{th}$ percentile) | 0.80 (−1.71,3.41) | 1.27 (−1.32,4.56) | 0.69 (−1.78,2.83) | 1.11 (−1.46,3.71) |

BMI, body mass index index; CDC, Centers for Disease Control; SD, standard deviation

[a]Children 10–18 years of age in the ADVANCE Weight Cohort (n=73,776).

[b]Annualized change calculated as (last measure – first measurement)/number of years, after omission of height and weight or BMI outliers, according to the population or longitudinal outlier approach.