Shifts in Percentiles of Growth During Early Childhood: Analysis of Longitudinal Data From the California Child Health and Development Study

Zuguo Mei, MD, MPH; Laurence M. Grummer-Strawn, PhD; Diane Thompson, MPH; and William H. Dietz, MD, PhD

ABSTRACT. Objective. To document growth-velocity changes across major percentiles during the preschool years.

Design. Analyses of longitudinal data using height-for-age, weight-for-age, weight-for-height, and body mass index (BMI)-for-age percentiles were performed to examine crossing of major percentiles of the Centers for Disease Control and Prevention 2000 growth charts. The 5th, 10th, 25th, 50th, 75th, 90th, and 95th percentiles were defined as the major percentiles.

Setting. Data from the California Child Health and Development Study were used.

Subjects. A total of 10,844 children up to 60 months of age, with 44,296 height and weight measurements, were included in our final analysis.

Results. For height-for-age, 32% of children between birth and 6 months of age, 13% to 15% of children between 6 and 24 months of age, and 2% to 10% of children between 24 and 60 months of age crossed 2 major percentiles. For weight-for-age, 39% of children between birth and 6 months of age, 6% to 15% of children between 6 and 24 months of age, and 1% to 5% of children between 24 and 60 months of age crossed 2 major percentiles. In contrast, for weight-for-height, 62% of children between birth and 6 months of age, 20% to 27% of children between 6 and 24 months of age, and 6% to 15% of children between 24 and 60 months of age crossed 2 major percentiles. Similar to the pattern observed for weight-for-height, 8% to 15% of children between 24 and 60 months of age crossed 2 major BMI-for-age percentiles. During the preschool years, weight-for-height had the highest percentages of children who crossed 2 major percentiles, and weight-for-age had the lowest percentages of children who crossed 2 major percentiles among these 3 indices.

Conclusions. Shifts in growth rates were very common for children from birth to 6 months of age, somewhat less common for children 6 to 24 months of age, and least common for children 24 to 60 months of age. Shifts in weight-for-height occurred more frequently than did other growth changes. Pediatricians must consider the prevalence of growth rate shifts during infancy and early childhood before they counsel parents regarding growth or refer children for additional evaluations of growth. Pediatrics 2004;113:e617–e627. URL: http://www.pediatrics.org/cgi/content/full/113/6/e617; catch-up growth, catch-down growth, growth variation, height-for-age, weight-for-age, weight-for-height, BMI-for-age, percentile.

ABBREVIATIONS. CDC, Centers for Disease Control and Prevention; BMI, body mass index; CHDS, Child Health and Development Study; NHANES, National Health and Nutrition Examination Survey; FTT, failure to thrive.

Good nutrition is important for achieving normal growth and development. The Centers for Disease Control and Prevention (CDC) 2000 growth charts are routinely used to screen children who may have growth abnormalities. A deceleration of weight across 2 major percentiles (with major percentiles being defined as the 5th, 10th, 25th, 50th, 75th, 90th, and 95th percentiles) is often used by health care providers to identify children at risk of undernutrition. Because the CDC growth charts are derived from a cross-sectional representative sample of children, the growth curves for individuals may differ from the CDC growth charts during the key periods of rapid growth, late infancy, and early adolescence.

Growth-velocity charts are available for height and weight velocities, but these are rarely used in clinical practice. The 6-month-increment growth charts for weight and height reported by Roche and Himes cover children from birth to 18 years of age, but those charts were based solely on data for white children from a longitudinal growth study (1929–1978) by the Fels Research Institute. The height-velocity curves for older children described by Tanner and Davies allow for differences among early-maturing, normal, and late-maturing children. The curves were developed with whole-year growth-velocity data. Therefore, measurement data should be measured and plotted over the course of 1 year.

Regardless of the growth charts used, serial measurements of height and weight plotted on growth charts are essential for determining children’s patterns of growth. When a child’s growth deviates from a given percentile line on the growth charts, the health care provider may suspect an abnormality in growth. Some shifts in growth are normal. Unfortunately, few studies of shifts in growth during early childhood for normal term infants have been pub-
lished. Smith et al.5 found that the linear growth of one-third of normal infants crossed 2 major percentile lines during the first 12 to 18 months of life and that the numbers shifting upward or downward were similar. That study, however, considered infantile linear growth among only 90 normal, term, middle-class, white infants from birth to 24 months of age. The purpose of our study was to describe the normal phenomena of catch-up or catch-down growth in height-for-age, weight-for-age, and weight-for-height during preschool years (from birth to 60 months of age) and body mass index (BMI)-for-age for children 24 to 60 months of age, with the use of the CDC growth charts and a longitudinal growth data sample that represents a broad range of economic, social, and educational characteristics.

METHODS

The Child Health and Development Study (CHDS) was a longitudinal multidisciplinary investigation of the medical and social aspects of women’s pregnancies and deliveries and of the health and development of the children born from those pregnancies.6–8 The objective of the study was to investigate the relationship of parental biologic, genetic, medical, and environmental factors to the development of the offspring. The School of Public Health at the University of California, Berkeley, conducted that study among families who were members of the Kaiser Foundation Health Plan and resided in the Oakland area of California. Approximately 15,000 pregnant women were included between 1959 and 1967, and their children were monitored through adolescence. Details of the study design and methods have been published.6–8

In the CHDS, all height and weight measurements were made by specially trained clinic nursing personnel. Height or length was measured to the nearest [1/4] inch. According to the protocols, a measuring yardstick was used to measure the child’s recumbent length if she or could not stand. For children who could stand, the standing height was measured with a Harpenden stadiometer (Holtain Ltd, Crymych, United Kingdom).6,9 Weight was measured to the nearest [1/4] pound with a pediatric scale or other beam balance scale. All records were abstracted onto standard pediatric cards.6–8

We linked the family background and pregnancy outcome file (N = 20,754) with the child pediatric measurement file (N = 273,647), child visit file (N = 19,944), child status file (N = 19,944), and congenital anomaly file (N = 4231) on the basis of unique child identification numbers, to obtain a full data set that included the children’s anthropometric data, their medical care and health histories, and the socioeconomic backgrounds of their parents. Because we were interested in the general growth of children, data were extracted only from measurements made during routine visits and not from those made because of illness or during hospitalization. A total of 18,085 children with 217,124 visits made until 60 months of age were included in the linked data set. We excluded children with intrauterine growth retardation (N = 335) (in accordance with Alexander et al9), serious congenital anomalies (N = 697),7,11 multiple births (N = 370), missing height or weight measurements (N = 325), or missing birth weight data (N = 2). We also excluded children who underwent only 1 height or weight measurement in their first 5 years of life (N = 814) and children whose age at the time of measurement did not meet our age-pair intervals, as described below (N = 4698). Therefore, our final analyses included 10,844 children with 44,296 height and weight measurements.

We defined the 5th, 10th, 25th, 50th, 75th, 90th, and 95th percentiles as the 5th, 10th, 25th, 50th, 75th, 90th, and 95th percentiles, respectively. We examined the percentages of children crossing major percentiles at each 6-month age-pair interval (0–6 to 54–60 months), we used the CDC 2000 growth charts1 to assign height-for-age, weight-for-age, weight-for-height, and BMI-for-age percentiles for each child’s measurements in the CHDS data set. Then we used each child’s age-paired measurements to calculate the number of percentile lines that the child had crossed in that age-pair interval. For example, if a child’s height-for-age percentiles at ages 6 months and 12 months were 14th and 45th, respectively, then he/she crossed (caught up) 1 major percentile (the 25th) in height-for-age in the 6-month age interval. If another child’s height-for-age percentiles at ages 6 and 12 months were 94th and 55th, respectively, then he/she crossed (caught down) 2 major percentiles (the 90th and 75th) in height-for-age in the 6-month age interval. Finally, we summarized the proportions of children crossing major percentiles (both catch up and catch down) in each age-paired interval to examine the growth patterns during the preschool years for each index. The age-paired interval was defined as 6 months ± 30 days. We could examine the percentages of children crossing major BMI-for-age percentiles only from 24 to 60 months of age, because the CDC 2000 BMI-for-age growth charts start at 24 months of age.1

To increase the sample size, we needed to select visits in each age-paired interval for the same children. For example, if 1 child underwent height and weight measurements at 0, 5, 10, 17, and 24 months of age, then he/she was included in the age-paired intervals of 0 to 6 and 18 to 24 months. If another child underwent height and weight measurements at 5, 11, and 20 months of age, then he/she was included only in the age-paired interval of 6 to 12 months. Details of the age-paired sample sizes in this study are presented in Table 1. On average, each child contributed −2 age-paired measurements (range: 1–6) to this study. To understand better the relationship between growth patterns and the age-pair interval.

### Table 1. Final Age-Paired Sample Sizes From the CHDS Data for Children 0 to 60 Months of Age

<table>
<thead>
<tr>
<th>Age-Paired Interval* (mo)</th>
<th>No. of Measurements† (N = 44,296)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0–6</td>
<td>20,444</td>
</tr>
<tr>
<td>6–12</td>
<td>10,412</td>
</tr>
<tr>
<td>12–18</td>
<td>4548</td>
</tr>
<tr>
<td>18–24</td>
<td>2560</td>
</tr>
<tr>
<td>24–30</td>
<td>1522</td>
</tr>
<tr>
<td>30–36</td>
<td>1192</td>
</tr>
<tr>
<td>36–42</td>
<td>792</td>
</tr>
<tr>
<td>42–48</td>
<td>662</td>
</tr>
<tr>
<td>48–54</td>
<td>648</td>
</tr>
<tr>
<td>54–60</td>
<td>1516</td>
</tr>
</tbody>
</table>

* The age-paired interval was defined as 6 months ± 30 days.
† For each age-paired interval, the number of children is the number of measurements divided by 2.

### Table 2. Comparison of Demographic Characteristics of the NHANES III Data and the CHDS Data for Children 0 to 60 Months of Age

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Birth weight (g)‡</td>
<td>3356 (590)</td>
<td>3399 (496)</td>
</tr>
<tr>
<td>Mean ± SD*</td>
<td>10.0 ± 2500 (g) (%)</td>
<td>4.1</td>
</tr>
</tbody>
</table>

* NHANES III data cover children 2 to 59 months of age, and the original sample weight was applied to the analysis.
† Mean ± SD and SD were based on one random visit per child among the total of 44,292 measurements.
‡ SD in parentheses.
§ Only for children 24 to 60 months of age.
initial measurement (percentile point) at each age-paired interval, we also stratified the aforementioned analyses according to the first age position (<25th, ≥25th but ≤75th, or >75th percentile).

RESULTS

The CHDS study families represented a large sample with a broad range of economic, social, and educational characteristics. Approximately 30% of the husbands had professional occupations; many were union members. Nearly 10% were employed at the University of California, Berkeley, in academic or administrative posts, and 20% were in government service. A total of 96% of the children's parents in our final analysis were married and living together. Fifty-nine percent of their fathers were high school or college graduates, and 54% of their mothers received high school or college education. Twenty-one percent of their families had yearly incomes of >$10,000 during the study years 1959–1967. Table 2 summarizes the basic demographic characteristics of the CHDS data and compares them with National Health and Nutrition Examination Survey (NHANES) III data. Notably, there were no Hispanic children in the CHDS study. The percentage of children with low birth weight in the CHDS sample was lower than that found nationally. The mean birth weight and mean z score of height-for-age, weight-for-age, and weight-for-height in the CHDS sample were similar to those in the nationally representative survey NHANES III.

Stratification according to gender did not reveal any significant differences in the chances of crossing major percentiles for male versus female subjects.

Fig. 1. Percentages of children who crossed major percentiles in height-for-age, from the California CHDS. A, Proportions of children who did not cross a major percentile (0), caught up 1 major percentile (+1), caught up ≥2 major percentiles (+2), caught down 1 major percentile (−1), or caught down ≥2 major percentiles (−2). B, Summary of data in A, indicating proportions of children who did not cross a major percentile (0), caught up or down 1 major percentile (±1), or caught up or down ≥2 major percentiles (±2)
The patterns of catch-up and catch-down growth in weight-for-age and weight-for-height with stratification according to the initial measurements were different from those in height-for-age. First, we observed more rapid catch-up growth (55% caught up 2 major percentiles in weight-for-age and 80% caught up 2 major percentiles in weight-for-height) during the first 6 months of infancy if the children’s percentiles were <25th at birth. After 6 months of age, both catch-up and catch-down growth were slower in weight-for-age but faster in weight-for-height, compared with height-for-age (Figs 5 and 6). Second, if the first age-paired percentile was >75th, then the catch-down growth in each interval was slower in both weight-for-age and weight-for-height, compared with height-for-age, during the first 6 months of life. Finally, if the first age-paired percentile was between the 25th and 75th, then we observed more catch-up than catch-down growth in weight-for-age and weight-for-height between birth and 6 months. Patterns of catch-up and catch-down growth were then similar after 6 months of age (Figs 5 and 6).

**DISCUSSION**

This study shows the degree to which preschoolers (0–60 months of age) shift percentiles of growth in height-for-age, weight-for-age, and weight-for-height. For all 3 indices, it was very common for children 0 to 6 months of age to cross 2 major percentiles (approximately one third for height-for-age and weight-for-age and approximately two thirds for weight-for-height). It was somewhat less common for children 6 to 24 months of age and was least common for children 24 to 60 months of age. In addition, shifts in growth were more common for weight-for-height than for height-for-age or weight-for-age. For children 24 to 60 months of age, the

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**TABLE 3. Summary of Percentages of Children Who Crossed 2 Major Percentiles in Height-for-Age, Weight-for-Age, Weight-for-Height, and BMI-for-Age from the California CHDS Data for Children 0 to 60 Months of Age**

<table>
<thead>
<tr>
<th>Age Interval (mo)</th>
<th>Height-for-Age</th>
<th>Weight-for-Age</th>
<th>Weight-for-Height</th>
<th>BMI-for-Age</th>
</tr>
</thead>
<tbody>
<tr>
<td>0–6</td>
<td>31.9</td>
<td>38.8</td>
<td>61.8</td>
<td></td>
</tr>
<tr>
<td>6–12</td>
<td>15.3</td>
<td>14.8</td>
<td>26.7</td>
<td></td>
</tr>
<tr>
<td>12–18</td>
<td>15.9</td>
<td>6.6</td>
<td>21.1</td>
<td></td>
</tr>
<tr>
<td>18–24</td>
<td>13.5</td>
<td>6.4</td>
<td>20.8</td>
<td></td>
</tr>
<tr>
<td>24–30</td>
<td>10.0</td>
<td>5.1</td>
<td>15.2</td>
<td>14.5</td>
</tr>
<tr>
<td>30–36</td>
<td>5.9</td>
<td>3.3</td>
<td>10.9</td>
<td>14.7</td>
</tr>
<tr>
<td>36–42</td>
<td>4.8</td>
<td>3.5</td>
<td>10.4</td>
<td>11.6</td>
</tr>
<tr>
<td>42–48</td>
<td>4.5</td>
<td>0.6</td>
<td>6.0</td>
<td>10.6</td>
</tr>
<tr>
<td>48–54</td>
<td>2.2</td>
<td>1.2</td>
<td>6.8</td>
<td>9.3</td>
</tr>
<tr>
<td>54–60</td>
<td>4.4</td>
<td>2.1</td>
<td>7.7</td>
<td>8.4</td>
</tr>
</tbody>
</table>

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Therefore, all the following results are for male and female subjects combined. Thirty-two percent of children from birth to 6 months of age crossed 2 major height-for-age percentiles 6 months later, 13% to 15% of children 6 to 24 months of age did so, and 2% to 10% of children 24 to 60 months of age did so (Fig 1; Table 3). Thirty-nine percent of children from birth to 6 months of age crossed 2 major weight-for-age percentiles, 6% to 15% of children 6 and 24 months of age did so, and 1% to 5% of children 24 to 60 months of age did so (Fig 1; Table 3). In contrast, 62% of children from birth to 6 months of age crossed 2 major weight-for-height percentiles, as did 20% to 27% of children 6 to 24 months of age and 6% to 15% of children 24 to 60 months of age (Fig 3; Table 3). Similar to the observed weight-for-height pattern, 8% to 15% of children 24 to 60 months of age crossed 2 major BMI-for-age percentiles (Table 3). During the preschool years, more children crossed 2 major weight-for-height percentiles than crossed 2 major height-for-age or weight-for-age percentiles. A lower percentage of children crossed 2 major weight-for-age percentiles than crossed 2 major height-for-age or weight-for-height percentiles. As shown in Figs 1 to 3, the proportions of catch-up changes (crossing major percentile lines from a lower to a higher percentile) and catch-down changes (crossing major percentile lines from a higher to a lower percentile) at each age-paired interval were similar for all 3 indices.

Figures 4 to 6 show the analyses stratified according to the initial measurements (<25th, ≥25th but ≤75th, or >75th percentile) of height-for-age, weight-for-age, and weight-for-height. Approximately 40% of the children who were in the <25th percentile caught up 2 major height-for-age percentiles in the first growth interval, but only 3% of children caught down 2 major percentiles 6 months after birth; ~14% to 16% of children caught up but only 3% to 4% of children caught down 2 major percentiles between 6 and 24 months of age, and ~7% to 11% of children caught up but only 2% to 3% of children caught down 2 major percentiles between 24 and 60 months of age (Fig 4 A). In contrast, if the first age-paired percentile in height-for-age was >75th, then the patterns of catch-down growth were the opposite of the patterns observed when the first age-paired percentile was <25th. Approximately 4% of children caught up 2 major percentiles but 39% of children caught down 2 major percentiles 6 months after birth, ~3% to 4% of children caught up but 13% to 18% of children caught down 2 major percentiles between 6 and 24 months of age, and ~2% to 3% of children caught up but 1% to 13% of children caught down 2 major percentiles between 24 and 60 months of age (Fig 4 C). However, if the first age-paired percentile in height-for-age was between the 25th and 75th, then the patterns of catch-up and catch-down growth were similar (Fig 4 B).
pattern of crossing 2 major percentiles in BMI-for-age was similar to that for weight-for-height.

Our study confirms the results found by Smith et al5 with a much larger sample and extends their observations to 60 months of age. We found that catch-up or catch-down growth was less common for children >24 months of age, compared with children <24 months of age. The strength of this study is that the CHDS study families represented a broad range of economic, social, and educational characteristics.

Our study has the potential limitations commonly found in routine clinical data. First, because the data came from multiple clinics and the techniques of measurement were not tightly controlled, the quality of the anthropometric measurements cannot be as-
NHANES 1999–2000.1,13 This is why the CDC Growth Charts Committee decided to combine a series of NHANES data from the 1960s to the 1990s to develop the 2000 CDC growth charts for the United States.1 Finally, there may be a potential bias, because some children contributed only 1 age-paired measurement, whereas others had >1 such measurement in our analysis. However, all children’s measurements were made during routine visits and not during visits made because of illness or during hospitalizations.

The catch-up and catch-down growth we observed in this study may be attributable to regression to the mean. Children who are taller or heavier tend to become shorter or lighter on average, and vice versa. These growth patterns could also be simply attributable to measurement errors. However, our purpose was to document shifts in growth percentiles during preschool years as observed in actual clinical settings. Clinicians need to know what to expect, whether caused by catch-up growth, catch-down growth, random variation, regression to the mean, or measurement errors.

In clinical settings, the major concerns for pedia-
Fig. 4. Percentages of children who crossed major percentiles in height-for-age, stratified according to starting point percentiles, from the California CHDS, indicating proportions of children who did not cross a major percentile (0), caught up 1 major percentile (+1), caught up ≥2 major percentiles (+2), caught down 1 major percentile (−1), or caught down ≥2 (−2) major percentiles. A, Starting point of <25th percentile. B, Starting point of ≥25th but <75th percentile. C, Starting point of ≥75th percentile.
Fig. 5. Percentages of children who crossed major percentiles in weight-for-age, stratified according to starting point percentiles, from the California CHDS, indicating proportions of children who did not cross a major percentile (0), caught up 1 major percentile (+1), caught up ≥2 major percentiles (+2), caught down 1 major percentile (−1), or caught down ≥2 major percentiles (−2). A, Starting point of <25th percentile. B, Starting point of ≥25th but ≤75th percentile. C, Starting point of >75th percentile.
Fig. 6. Percentages of children who crossed major percentiles in weight-for-height, stratified according to starting point percentiles, from the California CHDS, indicating proportions of children who did not cross a major percentile (0), caught up 1 major percentile (+1), caught up ≥2 major percentiles (+2), caught down 1 major percentile (-1), or caught down ≥2 major percentiles (-2). A, Starting point of <25th percentile. B, Starting point of ≥25th but ≤75th percentile. C, Starting point of >75th percentile.
tricians or clinicians regarding growth among preschool children are failure to thrive (FTT). Although FTT has been recognized for more than a century, it lacks a precise definition, in part because it describes a condition rather than a specific disease.14–17 Although definitions vary, most pediatricians use this term only when growth is noted to be low or decreases with time. For example, one definition of FTT is that height-for-age or weight-for-age is less than the 3rd or 5th percentile on >1 occasion. Another definition of FTT that is used commonly by pediatricians in clinical settings is that height or weight measurements decrease 2 major percentile lines during a short period.17 Using the standard CDC growth charts,1 With this definition, ~20% of young infants according to the height-for-age charts and ~6% of young infants according to the weight-for-age charts in our study would be diagnosed as demonstrating FTT. Others argue that true malnutrition (<80% of the ideal body weight for age) should be present for the diagnosis of FTT. Most researchers and pediatricians agree, however, that FTT can be suspected or described accurately only by comparing height and weight on growth charts with time.14–17

The increase in the prevalence of overweight status among preschool children in the United States has caused great concern because of its long-term health consequences.18,19 A recent study showed that the anthropometric data collected for patients referred because of FTT or obesity suggest that children are referred because of lesser degrees of underweight than overweight; the study concluded that these referral patterns reflect a more aggressive approach to FTT than obesity.20,21

The high rate of shifting down by at least 2 major percentile lines in weight-for-height among children starting with a high weight-for-height, particularly during infancy, indicates that concern about overweight in infancy is unnecessary. Conversely, a high proportion of thin infants can be expected to increase by at least 2 major percentile lines, indicating that low weight-for-height measurements for infants at a single time point are not of major concern.

In clinical settings, children who are in the >95th or >97th percentile of weight-for-height or BMI-for-age and children who fall below the 3rd or 5th percentile for their age on height/weight charts or who decrease >2 percentile lines on height or weight charts in a short time are likely to be evaluated further to determine whether there is a problem. However, pediatricians need to be aware that catch-up growth and catch-down growth during early childhood are normal phenomena that affect large numbers of children, particularly during infancy. Catch-up or catch-down growth may reflect an adjustment to the genetic potential for growth after intrauterine growth, which becomes increasingly, although not completely, canalized after infancy. The frequency of growth shifts upward and downward suggests that a period of “watchful waiting,” before concerns are raised about over- or undernutrition, is prudent. A careful clinical history can exclude the possibility of an organic basis for FTT. Furthermore, a detailed family history addressing the early growth of the parents or parental size is essential. For example, catch-down growth in weight may be expected for children who are heavy but whose parents are lean. Such children may shift downward in weight-for-age and weight-for-height with little change in height-for-age. In early childhood, shifts in growth percentiles alone should not prompt extensive biochemical tests or invasive procedures.

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We thank all the researchers involved in the CHDS, who made this rich database available to the public. Z.M. designed the study, analyzed the data, and wrote the manuscript. L.M.G.-S. assisted in the study design, data interpretation, supervision of the analyses, and revision of the manuscript. W.H.D. assisted in the study design, data interpretation, supervision of the analyses, and revision of the manuscript. None of the authors have a financial or personal interest in any company or organization connected in any way with the research presented in the article.

REFERENCES

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