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MMWR

Morbidity and Mortality Weekly Report
www.cdc.gov/mmwr

Recommendations and Reports September 10, 2010 / Vol. 59 / No. RR-9

Use of World Health Organization and CDC Growth Charts for Children Aged 0–59 Months in the United States

DEPARTMENT OF HEALTH AND HUMAN SERVICES
CENTERS FOR DISEASE CONTROL AND PREVENTION

The *MMWR* series of publications is published by the Office of Surveillance, Epidemiology, and Laboratory Services, Centers for Disease Control and Prevention (CDC), U.S. Department of Health and Human Services, Atlanta, GA 30333.

Suggested Citation: Centers for Disease Control and Prevention. [Title]. MMWR 2010;59(No. RR-9):[inclusive page numbers].

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Use of World Health Organization and CDC Growth Charts for Children Aged 0–59 Months in the United States

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Summary

In April 2006, the World Health Organization (WHO) released new international growth charts for children aged 0–59 months. Similar to the 2000 CDC growth charts, these charts describe weight for age, length (or stature) for age, weight for length (or stature), and body mass index for age. Whereas the WHO charts are growth standards, describing the growth of healthy children in optimal conditions, the CDC charts are a growth reference, describing how certain children grew in a particular place and time. However, in practice, clinicians use growth charts as standards rather than references.

In 2006, CDC, the National Institutes of Health, and the American Academy of Pediatrics convened an expert panel to review scientific evidence and discuss the potential use of the new WHO growth charts in clinical settings in the United States. On the basis of input from this expert panel, CDC recommends that clinicians in the United States use the 2006 WHO international growth charts, rather than the CDC growth charts, for children aged <24 months (available at https://www.cdc.gov/growthcharts). The CDC growth charts should continue to be used for the assessment of growth in persons aged 2–19 years.

The recommendation to use the 2006 WHO international growth charts for children aged <24 months is based on several considerations, including the recognition that breastfeeding is the recommended standard for infant feeding. In the WHO charts, the healthy breastfed infant is intended to be the standard against which all other infants are compared; 100% of the reference population of infants were breastfed for 12 months and were predominantly breastfed for at least 4 months. When using the WHO growth charts to screen for possible abnormal or unhealthy growth, use of the 2.3rd and 97.7th percentiles (or ±2 standard deviations) are recommended, rather than the 5th and 95th percentiles. Clinicians should be aware that fewer U.S. children will be identified as underweight using the WHO charts, slower growth among breastfed infants during ages 3–18 months is normal, and gaining weight more rapidly than is indicated on the WHO charts might signal early signs of overweight.

Introduction

The physical growth of infants and children has long been recognized as an important indicator of health and wellness (*1,2*). Growth charts have been used for at least a century to assess whether a child is receiving adequate nutrition and to screen for potentially inadequate growth that might be indicative of adverse health conditions. Traditionally, attention has focused on undernutrition. However, in the past few decades, concerns about excessive weight gain have increased, and growth charts have been used to screen for overweight, including obesity.

In April 2006, the World Health Organization (WHO) released a new international growth standard for children aged 0–59 months (*3*). Similar to the 2000 CDC growth reference (*4,5*), these growth charts describe weight for age, length (or stature) for age, weight for length (or stature), and body mass index (BMI) for age. WHO growth curves include BMI for age starting at birth, and CDC growth curves include BMI for age beginning at age 2 years. CDC and WHO growth charts also include a curve for head circumference for age; CDC provides values for children aged <36 months, and WHO charts include a head circumference curve for those aged <60 months.

Because two sets of growth curves exist for assessing child growth, clinicians in the United States need guidelines indicating which curves should be used and for which children. This report provides guidance on the use of the WHO and CDC growth charts and is intended for health-care providers and others who measure and assess child growth.

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Methods

During June 29–30, 2006, CDC, the National Institutes of Health (NIH), and the American Academy of Pediatrics (AAP) convened a meeting in Hyattsville, Maryland, to review scientific evidence and obtain opinions regarding the use of the new WHO growth charts in clinical settings in the United States. The participants at the meeting were selected on the basis of their expertise in child growth, statistical methodology, clinical application, and maternal and child health policy. CDC, NIH, and AAP each had numerous representatives; additional experts from academia, clinical professional groups, and other government agencies were invited.

Participants were provided background documents describing the development of both sets of curves. At the meeting, CDC made presentations on the methods used to create the CDC growth charts, and a principal investigator for the WHO Multicentre Growth Reference Study (MGRS), which generated the data used for the WHO growth curves, made a presentation on the methods used to create the WHO charts. CDC conducted a statistical comparison of the charts and presented the results to participants. Meeting discussions focused on the numerous factors involved in the selection of a chart, including the assessment of child growth using references (i.e., how certain groups of children have grown in the past) compared with standards (i.e., how healthy children should grow in ideal conditions), differences between the growth of breastfed and formula-fed infants, the methods used to create the CDC and WHO charts, and implications of using the charts in clinical practice. At the time of the meeting, WHO was developing but had not released growth charts for head circumference for age; therefore, these charts were not discussed. The charts have since been released and are available at http://www.who.int/childgrowth/standards/hc_for_age/en/index.html.

The panel was not asked to arrive at a consensus. At the end of the meeting, CDC asked all participants to provide written opinions on which curves should be recommended, at which ages, and for which children. After the meeting ended, CDC worked with NIH and AAP to develop these CDC recommendations based on the meeting proceedings.

Creation of the WHO and CDC Growth Curves

History

Until the late 1970s, clinicians used various growth charts to assess child growth (*6–9*). In 1977, the National Center for Health Statistics (NCHS), which became a part of CDC in 1987, published a new set of growth charts for children aged <18 years based on data from the Fels Longitudinal Growth Study and nationally representative surveys (*10*). In 1978, CDC extrapolated the published percentiles to compute z scores, allowing for the generation of more extreme cutoffs, including 2 and 3 standard deviations below the median (*11*). WHO then recommended that these z scores be used as a global reference for the definition of malnutrition. The curves began to be used worldwide.

In spite of their widespread use, there were numerous concerns about these charts, including a lack of racial diversity in the infant sample, an infant sample composed of infants who were almost all formula fed, and the disjunction in length and stature measurements when transitioning from the charts for younger children to those for older children. Therefore, while planning the third National Health and Nutrition Examination Survey (NHANES III), NCHS decided to oversample children aged <6 years so that the 1970s growth charts could be revised. After data collection was completed in 1994, CDC began revising the curves, and the new charts were released in 2000. In 1997, WHO launched the MGRS to collect data on the growth of children worldwide based on strict inclusion criteria. Data collection was completed in 2003, and the growth charts were released in 2006.

Growth Reference Versus Growth Standard

The CDC and WHO growth charts differ in their overall conceptual approach to describing growth. The WHO charts are growth standards that describe how healthy children should grow under optimal environmental and health conditions. The curves were created based on data from selected communities worldwide, which were chosen according to specific inclusion and exclusion criteria. Deviation from the WHO growth standard should prompt clinicians to determine whether suboptimal environmental conditions exist, and if so, whether they can be corrected.

Whereas the WHO charts describe growth of healthy children in optimal conditions, the 2000 CDC growth charts are a growth reference, not a standard, and describe how certain children grew in a particular place and time. The CDC charts describe the growth of children in the United States during a span of approximately 30 years (1963–1994).

Sample Populations

The reference populations used to create the 2006 WHO and 2000 CDC growth curves vary with respect to inclusion and exclusion criteria, geographic location, frequency of measurements, and sample size (Tables 1 and 2).

WHO

The 2006 WHO growth curves for children are based on data from the WHO MGRS, a study conducted during 1997–2003 in six sites: Pelotas, Brazil; Accra, Ghana; Delhi, India; Oslo, Norway; Muscat, Oman; and Davis, California

TABLE 1. Comparison of sample populations used to create the CDC and WHO growth curves for children aged <24 mos

Characteristic	CDC growth reference (2000)*	WHO growth standard (2006)†
Data sources	National vital statistics (birth weights) Missouri and Wisconsin vital statistics (birth lengths) Pediatric Nutrition Surveillance System (lengths, 0.1 to <5 mos) NHANES I (1971–1974) (12–23 mos) NHANES II (1976–1980) (6–23 mos) NHANES III (1988–1994) (2–23 mos)	MGRS longitudinal component, with sites in the following locations: Pelotas, Brazil Accra, Ghana Delhi, India Oslo, Norway Muscat, Oman Davis, California
Type and frequency of data collection	Cross-sectional data on weight and length starting at age 2 mos, with mathematical models used to connect birth weights and lengths to survey data	Longitudinal data with measurements of weight and length at birth; 1, 2, 4, 6, and 8 wks; and 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 14, 16, 18, 20, 22, and 24 mos
Sample size	4,697 observations for 4,697 distinct children	18,973 observations for 882 distinct children
Exclusion criteria	Very low birth weight (<1,500 g [<3 lbs, 4 oz])	Low socioeconomic status Birth at altitude >1,500 m Birth at <37 wks or ≥42 wks Multiple birth Perinatal morbidities Child health conditions known to affect growth Maternal smoking during pregnancy or lactation Breastfeeding for <12 mos Introduction of complementary foods before age 4 mos or after age 6 mos Weight-for-length measurements >3 standard deviations above or below study median for sex
Breastfeeding among infants in sample	Approximately 50% ever breastfed Approximately 33% breastfeeding at 3 mos	100% ever breastfed 100% predominantly breastfeeding at 4 mos 100% still breastfeeding at 12 mos Complementary foods introduced at mean age of 5.4 mos

Abbreviations: MGRS = Multicentre Growth Reference Study; NHANES = National Health and Nutrition Examination Survey; WHO = World Health Organization.

* **Source:** Kuczmarski RJ, Ogden CL, Guo SS, et al. 2000 CDC growth charts for the United States: methods and development. Vital Health Stat 2002;246.

† **Sources:** World Health Organization. WHO child growth standards: length/height-for-age, weight-for-age, weight-for-height and body mass index-for-age: Methods and development. Geneva, Switzerland: World Health Organization; 2006. Available at http://www.who.int/childgrowth/publications/technical_report_pub/en/index.html. Accessed June 1, 2010; and WHO Multicentre Growth Reference Study Group. Enrolment and baseline characteristics in the WHO Multicentre Growth Reference Study. Acta Paediatr Suppl 2006;450:7–15.

(*12*). The criteria for selection of the communities included 1) socioeconomic status that does not constrain growth of the child (based on infant mortality rate; prevalence of underweight, stunting, and wasting; subpopulation size; and access to safe water), 2) low altitude (<1,500 m [4,921 ft]), 3) low enough population mobility to allow for a 2-year follow-up, 4) at least 20% of mothers in the community willing to follow international feeding recommendations, 5) existence of a breastfeeding support system (typically in the form of lactation consultants), and 6) existence of a research institution capable of conducting the study (*12*). The international infant feeding recommendations in effect at the time of the study included exclusive breastfeeding for at least 4 months (although predominantly breastfed infants were also included in the study), introduction of complementary foods by at least 6 months but not before 4 months, and continued breastfeeding for at least 12 months. Study participants were provided breastfeeding support as needed and were counseled on complementary feeding, with an emphasis on timing, energy density, feeding frequency, and micronutrient content.

Exclusion criteria for mothers and infants included maternal smoking during pregnancy or lactation, birth at <37 weeks or ≥42 weeks, multiple birth, substantial morbidity, low socioeconomic status, and unwillingness of the mother to follow feeding criteria (*12*). Weight-for-length measurements of >3 standard deviations from the overall study median were considered to be outliers and excluded from the final sample.

The WHO growth curves for children aged <24 months were based on the longitudinal component of MGRS, in which cohorts of newborns were measured from birth through age 23 months (Table 1). Longitudinal data were collected at birth, 1 week, and every 2 weeks for the first 2 months after birth, monthly through age 12 months, and bimonthly from age 14 to 24 months. Of the initial 1,743 enrolled participants, six were excluded because of substantial morbidities. A total of 882 infants (50.8%) (range: 21.4%–69.2% among sites) met the feeding and maternal nonsmoking criteria and completed the 2-year follow-up; these participants were included in the growth curves (*3*). For the 855 infants who did not meet the feeding and maternal nonsmoking criteria, only the birth mea-

TABLE 2. Comparison of sample populations used to create the CDC and WHO growth curves for children aged 24–59 mos

Characteristic	CDC growth reference (2000)*	WHO growth standard (2006)†
Data sources	NHANES I (1971–1974) NHANES II (1976–1980) NHANES III (1988–1994)	MGRS cross-sectional component, with sites in the following locations: Pelotas, Brazil Accra, Ghana Delhi, India Oslo, Norway Muscat, Oman Davis, California
Type and frequency of data collection	Cross-sectional data	Cross-sectional data
Sample size	9,894	6,669
Exclusion criteria	None	Low socioeconomic status Birth at altitude >1,500 m Birth at <37 wks or ≥42 wks Multiple birth Perinatal morbidities Child health conditions known to affect growth Maternal smoking during pregnancy or lactation Never breastfed or breastfed for <3 mos Multiple birth Preterm birth Weight-for-length measurements >3 standard deviations below or >2 standard deviations above study median for sex
Breastfeeding among infants in sample	Approximately 50% ever breastfed Approximately 33% breastfeeding at 3 mos	100% ever breastfed 100% breastfeeding at 3 mos

Abbreviations: MGRS = Multicentre Growth Reference Study; NHANES = National Health and Nutrition Examination Survey; WHO = World Health Organization.

* **Source:** Kuczmarski RJ, Ogden CL, Guo SS, et al. 2000 CDC growth charts for the United States: methods and development. Vital Health Stat 2002;246.

† **Sources:** World Health Organization. WHO child growth standards: length/height-for-age, weight-for-age, weight-for-height and body mass index-for-age: Methods and development. Geneva, Switzerland: World Health Organization; 2006. Available at http://www.who.int/childgrowth/publications/technical_report_pub/en/index.html. Accessed June 1, 2010; and WHO Multicentre Growth Reference Study Group. Enrolment and baseline characteristics in the WHO Multicentre Growth Reference Study. Acta Paediatr Suppl 2006;450:7–15.

surements were used. A total of 18,973 distinct measurements of weight and length were included in the data set. Data on participants who were not included in the data set were not available to meeting participants.

A primary study hypothesis of MGRS based on previous research (*13,14*) was that all young children have the potential to grow similarly, regardless of their ethnic group or place of birth, if they are in a healthy environment and receive adequate nutrition. This hypothesis was confirmed; the mean length measurements of children aged <24 months in the six country sites were virtually identical (Figure 1).

The WHO growth curves for children aged 24–59 months were based on the cross-sectional component MGRS, in which groups of children at specific ages were measured at a specific point in time; the cross-sectional data represented 6,669 children (Table 2). Data were collected in the same communities as those used to create the curves for children aged <24 months, typically just after completion of the longitudinal study. Other than the infant feeding criteria, the inclusion criteria used for the cross-sectional data collection for ages <24 months and 24–59 months were the same. The infant feeding criteria were much less stringent (breastfeeding for at least 3 months and no requirements for the timing of complementary feeding). Mothers of children aged 24–59 months years did not receive assistance to ensure that the children received optimal nutrition.

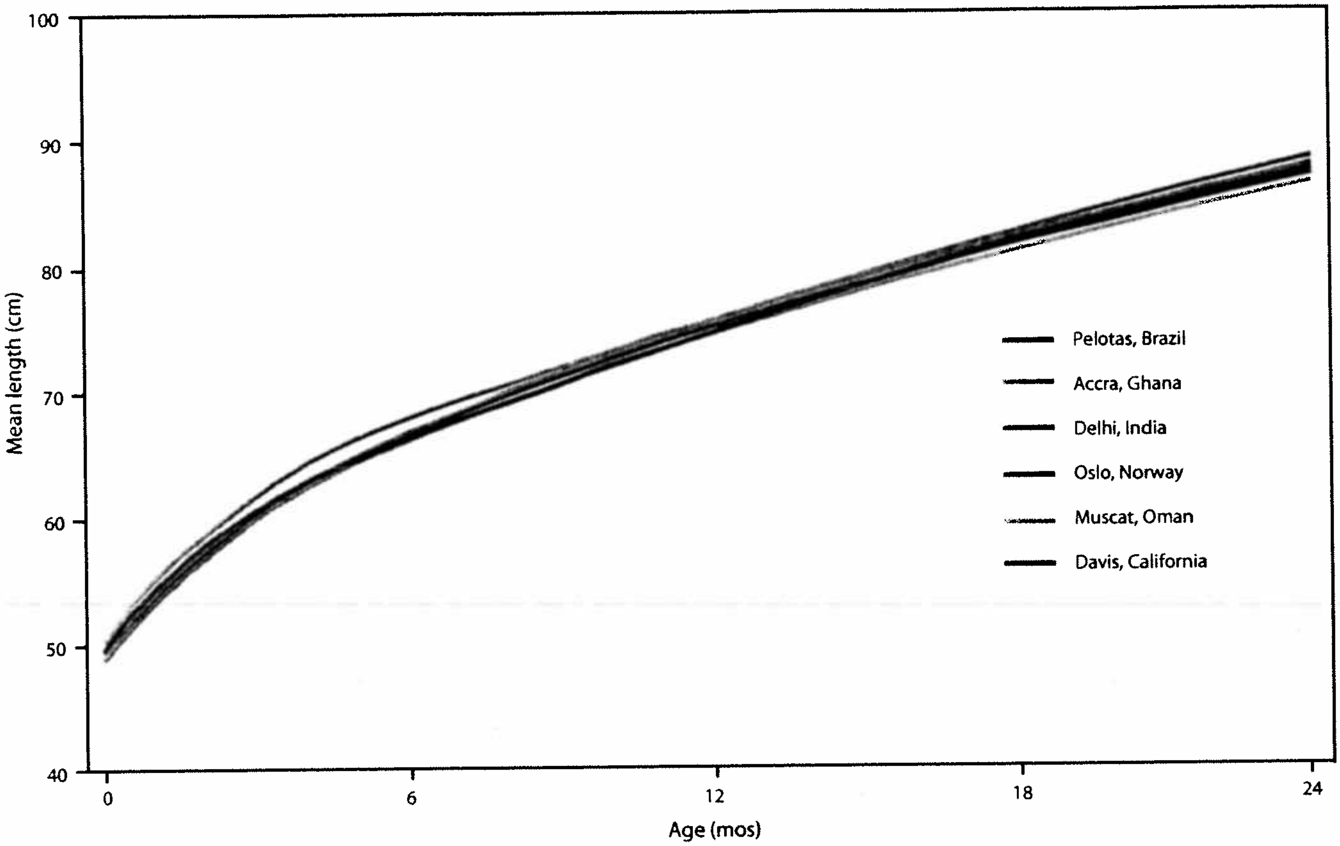
To eliminate the effect of overweight children on the weight distributions in the WHO curves for children aged 24–59 months, weight measurements of >2 standard deviations above the study median were excluded; a total of 226 (2.7%) weight measurements were excluded.

CDC

The CDC growth curves for children aged <36 months were based on cross-sectional data from various sources (Table 1). The curves were anchored at birth using national birth weight data obtained from U.S. birth certificates from 1968–1980 and 1985–1994 and birth length data from Wisconsin and Missouri birth certificates (the only states with these data available on birth certificates) from 1989–1994 (*5*). Birth data were based on 82 million birth weight measurements and 445,000 birth length measurements.

The curves for children aged 2–59 months were primarily based on data from NHANES; no NHANES data were available for infants aged <2 months. NHANES is a continuous cross-sectional survey of the health and nutritional status of the U.S. civilian, noninstitutionalized population. Participants

FIGURE 1. Mean length measurements of children aged <24 months in six sites worldwide — World Health Organization Multicentre Growth Reference Study, 2006



Source: WHO Multicentre Growth Reference Study Group. Assessment of differences in linear growth among populations in the WHO Multicentre Growth Reference Study. Acta Paediatr Suppl 2006;450:56–65.

are selected through a complex, multistage probability design. All NHANES surveys include a household interview and a detailed physical examination that includes anthropometric measurements. Data from NHANES III (1988–1994) were used to create the curves for children aged 2–5 months; NHANES II (1976–1980) and III for ages 6–11 months; and NHANES I (1971–1974), II, and III for ages 12–59 months. In addition, supplementary length data from clinics that participated in the CDC Pediatric Nutrition Surveillance System (PedNSS) (1975–1995) and had data for older infants and children that were similar to the NHANES national surveillance data were used for the length-for-age charts for ages 0.1 to <5 months (*15*).

For the cross-sectional data for children aged 2–23 months, there were 4,697 data points. At age 2 months, 72 weight measurements were available (representing 38 boys and 34 girls), and approximately 200 measurements (each measurement representing one child) per month were available through age 5 years. Data from approximately 35,000 infants aged 0.1 to <5 months from the PedNSS clinics were used. To create curves for children aged 24–59 months, data from 9,894 children, were used. From ages 5–59 months, sample sizes for length were similar to those for weight.

Because the growth of infants with very low birth weight (VLBW) (<1,500 g [<3 lbs, 4 oz]) is distinctly different from that of infants with higher birth weights, data for VLBW infants were excluded from the charts for children aged <36 months (*5*). No other exclusion or inclusion criteria (such as breastfeeding) were used. Approximately 50% of the infants in the data set had ever been breastfed, and 33% were still breastfeeding when they reached age 3 months. No overweight measurements were excluded.

Measurements

Careful procedures for training and measurement standardization were followed, and high-quality instruments were used for weight and length (or stature) measurements. In the WHO study, anthropometrists took two measurements independently and repeated measurements that exceeded preset maximum allowable differences. NHANES anthropometrists took measurements once. In general, both WHO and CDC assessed length (measured lying down) for children aged <24 months and stature (measured standing up) for children aged 24–59 months. A subset of children were measured both recumbent and standing (at ages 18–30 months for WHO, at ages 24–36 months for CDC) to assess the discrepancy between the two measurements and allow for connection of the curves before and after age 24 months. Detailed descriptions of these procedures and instruments have been published (*4,16,17*).

Calculation of Percentiles and z Scores

Optimal data entry and cleaning techniques were used. For both sets of curves, the data analysis treated each data point independently, even if two data points were taken for a single child. Although there were some differences in the statistical smoothing techniques used to create the WHO and CDC charts, both used a variant of the lambda-mu-sigma (LMS) statistical method to describe both percentiles and z scores (standard deviation units) (*5,18–20*). Because no data (other than length for age) were available to connect the birth data to the cross-sectional data after age 2 months in the CDC curves, a 3-parameter linear mathematical model was used to smooth the weight data from 0–35 months (*5*).

Rationale for Recommendations

Use of Growth Reference or Growth Standard in Clinical Settings

Opinions of the participants varied about whether the use of a growth standard or a growth reference would be best for clinical settings in the United States. Several participants explained that identification of growth that is unhealthy (i.e., indicates an underlying adverse health condition) or abnormal first requires a definition of healthy growth, thus a standard is needed. Other participants countered that because many children do not live in ideal environmental conditions, interpreting their growth by comparing them to a growth standard might not be appropriate. Likewise, some children who live in optimal conditions deviate from the normal growth curve but are not unhealthy. Participants acknowledged that adoption of a standard for assessing growth in children would create a substantial need for the education of clinicians but would also create an opportunity for clinicians to identify and address environmental conditions that might be negatively affecting growth. Meeting participants agreed that in practice, clinicians often use growth references, such as the CDC growth charts, as a standard to evaluate healthy growth rather than a reference as intended.

Children Aged <24 Months

Available Data

The meeting participants were concerned about the paucity of data for the first several months of age in the data set used to create the 2000 CDC growth charts, as well as about the effects of combining various disparate data sets (e.g., birth records, NHANES national survey data, and PedNSS clinical surveillance data) to generate the charts. In contrast, the WHO charts for children aged <24 months were created with longitudinal data that were collected more frequently than the data used for the CDC charts, especially during the first few months of life when children grow the most quickly. However, the panel also was concerned that the exclusion of weight-for-length data that were >3 standard deviations from the median from the WHO charts was inappropriate because these data represented children who were part of the actual distribution of observed physiological growth. The data for the WHO growth charts were generally considered to be strong during the first several months of age.

Breastfeeding and Growth Patterns

When the WHO growth curves were created, the difference in growth between primarily formula-fed infants and primarily breastfed infants was an important consideration (*12*). The WHO charts were based on the premise that the healthy breastfed infant is the standard against which all other infants should be compared. This is consistent with U.S. dietary reference intakes, in which norms for infant intakes of most nutrients are determined on the basis of the composition of human milk and the average volume of human milk intake (*21*). In the WHO charts, 100% of the reference population of infants were breastfed for 12 months and were predominantly breastfed for at least 4 months. In contrast, approximately 50% of the infants in the CDC data set had ever been breastfed, and 33% were still breastfeeding when they reached age 3 months, rates that are lower than those for infant cohorts born today. Data from the CDC National Immunization Survey indicate that in 2007 in the United States, 75% of infants had ever been breastfed, and 58% had been breastfed for at least 3 months (*22*). In addition, the composition of infant formula has changed considerably during the preceding 35 years (*23*). Therefore, the current growth of U.S. infants might not be the same as the growth of infants used in the creation of the CDC growth curves.

The expert panel universally agreed that breastfeeding is the optimal form of infant feeding and recognized that the growth of breastfed infants differs from that of formula-fed infants. The panel also recognized that AAP has stated the breastfed infant "is the reference or normative model against which all alternative feeding methods must be measured with regard to growth, health, development, and all other short- and long-term outcomes" (*24*).

Some U.S. clinicians who are currently using the CDC charts might be unaware of or not understand the growth pattern of exclusively breastfed infants, which differs from that of formula-fed infants. These clinicians might inappropriately recommend that mothers supplement breastfeeding with formula or advise them to wean their infants from breastfeeding completely.

The WHO and CDC charts show different growth patterns that might lead clinicians to different conclusions about variations in growth. Healthy breastfed infants typically gain weight faster than formula-fed infants in the first few months of life but then gain weight more slowly for the remainder of infancy (*25,26*). Therefore, in the first few months of life, WHO curves show a faster rate of weight gain than the CDC charts for boys and girls (Figures 2 and 3). Use of the WHO charts in the United States might lead to an increase in the misperception of poor growth at this age.

Beginning at approximately age 3 months, WHO curves show a slower rate of weight gain than the CDC charts, both in weight for age and weight for length. Because WHO curves are derived from infants who breastfeed through 12 months, infants who are still breastfeeding at approximately age 3 months are more likely to maintain their percentages on the WHO growth charts but to decrease in percentages on the CDC charts. In contrast, if WHO charts are used to assess the growth of formula-fed infants, these infants might be identified as growing too slowly during the first few months of life but then be identified as gaining weight too quickly after approximately 3 months.

Children Aged 24–59 Months

CDC curves allow for a transition period from 24–35 months when children can be assessed using either the charts for children aged 0–36 months or for persons aged 2–19 years. Children in this age range can have their measurements plotted on the chart for younger children to show continuity with previous growth and on the chart for older children to show continuity with subsequent growth. For weight for length (or stature) and length (or stature) for age, assessing children using both curves requires measuring the child both recumbent and supine and therefore is not a common practice.

The meeting participants raised concerns that weights >2 standard deviations above the median should not have been deleted in creation of the WHO curves because they were part of the full weight distribution of the study population. They also noted that the methods for selecting the study participants for this age range was not substantively different between the WHO and CDC charts. CDC and WHO growth charts for ages 24–59 months were both based on cross-sectional data, and compared with the methods used to create the growth curves for children aged <24 months, the methodological differences between CDC and WHO in creating growth curves for ages 24–59 months were minor. For these reasons, the expert panel found little reason to recommend a change from the current use of the CDC curves among older children.

Transition from WHO to CDC Charts

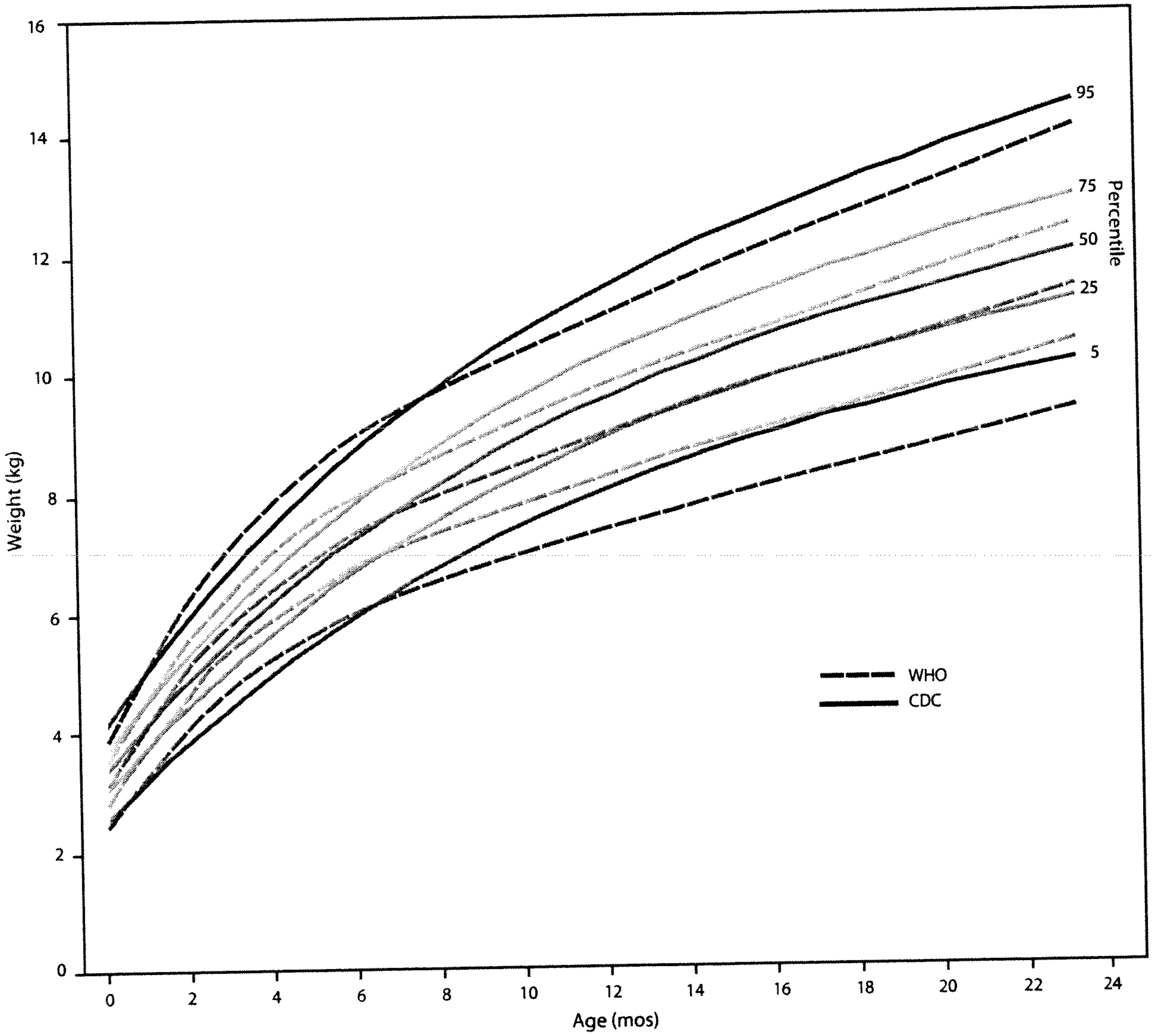
The panel discussed the possibility of using the WHO charts for children aged <24 months but the CDC charts for older children. During these discussions, participants explained that transitioning from one chart to another might create a disjunction by changing how a particular child's growth is classified. For example, a child aged 24 months who is classified as overweight according to the WHO charts might be classified in the normal range on the CDC charts at the same age. Regardless, both the WHO and CDC growth charts already have somewhat of an internal disjunction because length measurements switch from recumbent to stature measurements when children are aged 2 years; measurements of length are greater (0.7–0.8 cm) than measurements of stature. Therefore, a child aged 2 years might seem to be approximately 1 cm shorter when a clinician transitions from using length to stature measurements, potentially leading to a change in the plotted percentile.

Because CDC charts are printed on separate pages, clinicians must switch charts when they switch from length to stature measurements at age 24 months. Likewise, clinicians would switch to a separate page if they were to transition from the WHO to the CDC charts at age 24 months. Thus, if the WHO charts were to be used for infants and the CDC charts for older children, transitioning at age 24 months seemed to be the most feasible age to switch.

Selection of Percentiles

Predetermined percentiles on growth charts are used to identify children who might not be growing normally. Traditionally, the 5th or 95th percentiles have been used with the CDC charts; however, they are arbitrary statistical values and are not based on analysis of health outcomes. Likewise, the WHO percentiles (2.3rd and 97.7th, or ±2 standard deviations) also are arbitrary and not based on health outcomes. Using the WHO-recommended percentiles with the WHO curves in the United States would result in a prevalence of short stature

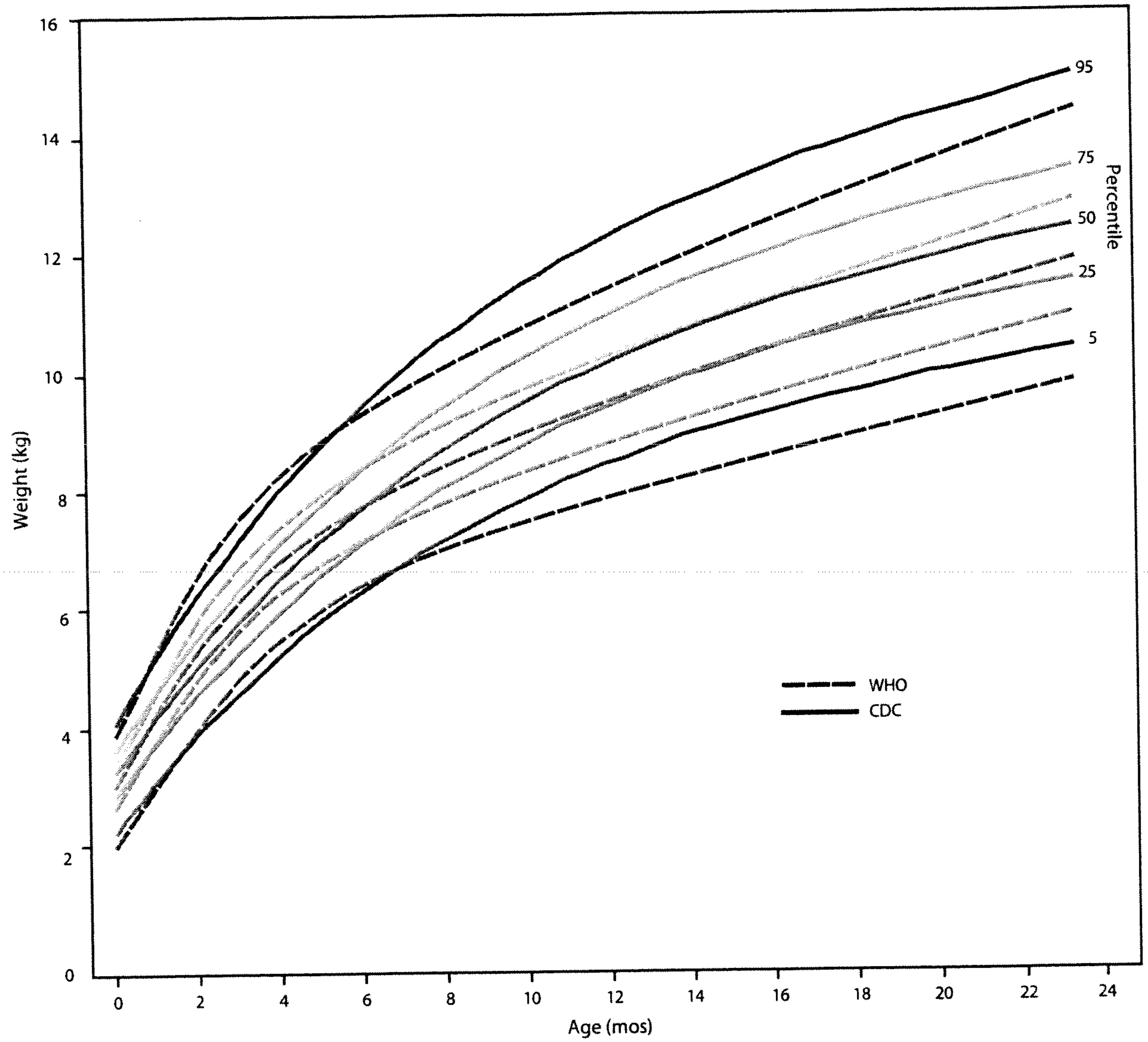
FIGURE 2. Comparison of World Health Organization (WHO) and CDC growth chart weight-for-age measurements for girls aged <24 months



and overweight that is similar to the prevalence from the CDC curves using the 5th and 95th percentiles (*27*). Therefore, in pediatric practice, the number of children identified for additional follow-up because of short stature and overweight would be similar to current numbers. In contrast, use of the 5th and 95th percentiles with the WHO weight charts would result in 10% of the WHO growth curve population being categorized as underweight or overweight, even though the population comprises healthy children who were fed according to international recommendations. The population used to create the CDC charts includes children with various health problems and children who were not fed according to international recommendations. Use of the 5th and 95th percentiles with the WHO curves to assess the U.S. population might overestimate the prevalence of short stature, underweight, and overweight in the United States. For example, the mean stature included in the WHO and CDC charts is similar, but the WHO charts have less variability than the CDC charts among children aged <24 months, leading to an increased prevalence of both shortness and tallness for children aged <2 years when the 5th and 95th percentiles are applied (Figures 4 and 5).

The estimated prevalences of low weight for age and high weight for length among U.S. children differ depending on whether the CDC charts (using the 5th and 95th percentiles)

FIGURE 3. Comparison of World Health Organization (WHO) and CDC growth chart weight-for-age measurements for boys aged <24 months



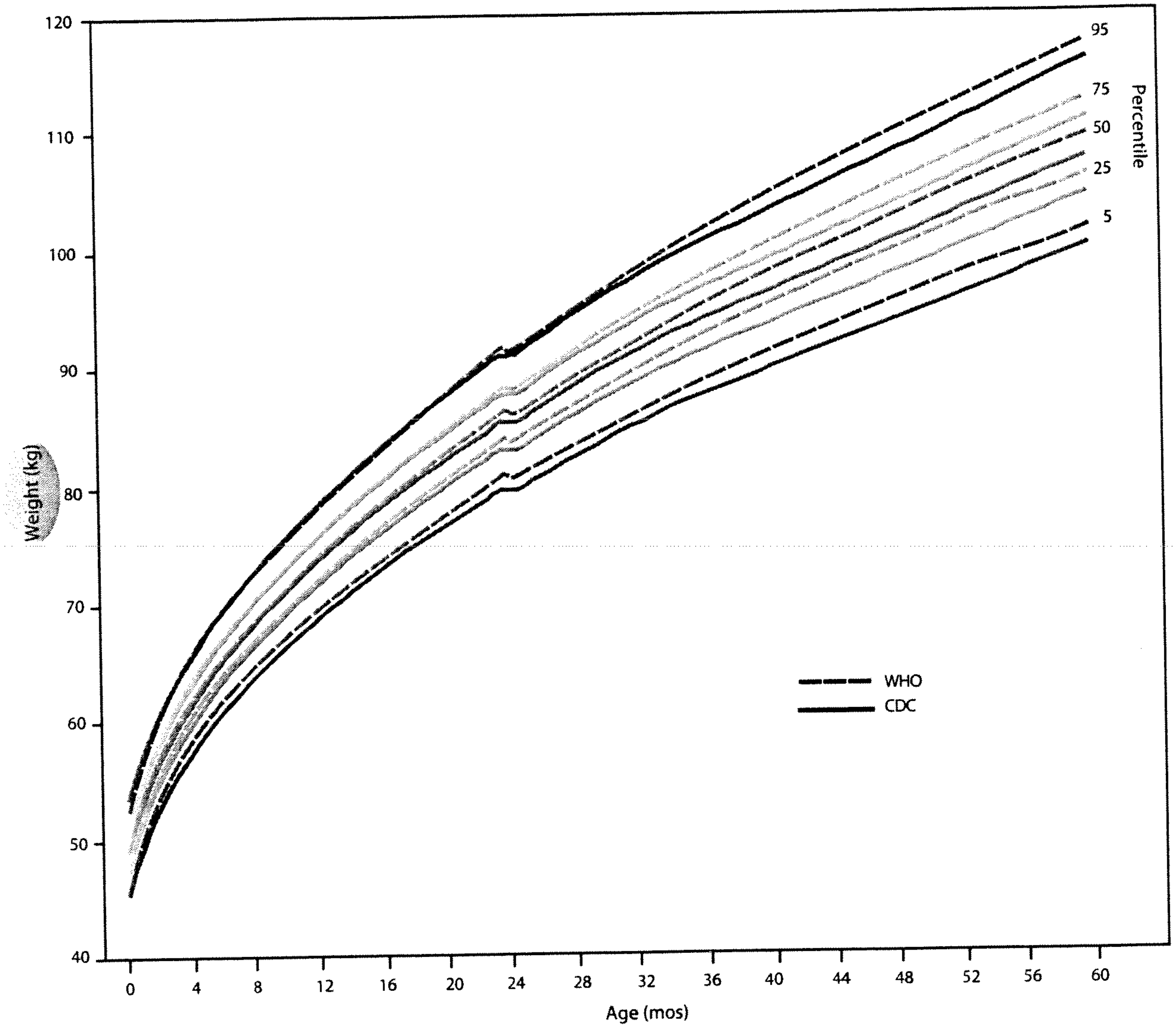
or the WHO charts (using the 2.3rd and 97.7th percentiles) are used (Figure 6). A substantial difference exists in the prevalence of low weight for age, with the WHO standard showing a lower prevalence beginning at age 6 months. The CDC reference identifies 7%–11% of children aged 6–23 months as having low weight for age, whereas the WHO standard identifies <3%. The WHO standard also identifies fewer infants (aged <12 months) as having high weight for length (5%–9%) than the CDC reference (9%–13%). For children aged 18–23 months, the differences in high weight for length essentially disappear. The prevalence of short stature is similar for both sets of curves.

Recommendations

Use of WHO Growth Charts for Children Aged <24 Months

Use of the 2006 WHO international growth standard for the assessment of growth among all children aged <24 months, regardless of type of feeding, is recommended. (The charts are available at https://www.cdc.gov/growthcharts.) When using the WHO growth charts, values of 2 standard deviations above and below the median, or the 2.3rd and 97.7th percentiles (labeled as the 2nd and 98th percentiles on the growth charts),

FIGURE 4. Comparison of World Health Organization (WHO) and CDC growth chart length/stature-for-age measurements for girls aged <5 yrs

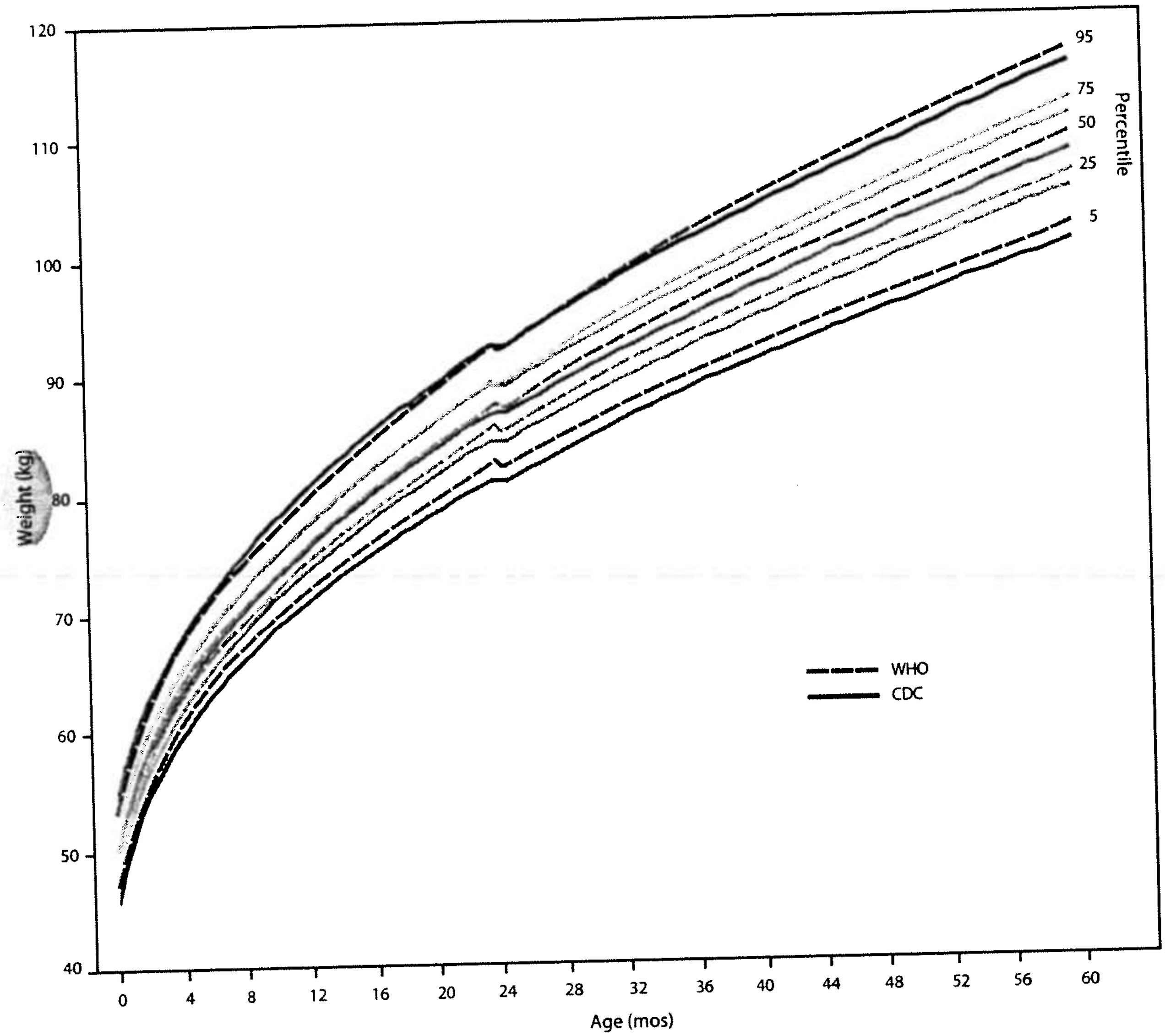


are recommended for identification of children whose growth might be indicative of adverse health conditions. The rationale for use of the WHO growth charts for this age group includes the following: 1) the recognition that breastfeeding is the recommended standard for infant feeding and, unlike the CDC charts, the WHO charts reflect growth patterns among children who were predominantly breastfed for at least 4 months and still breastfeeding at age 12 months; 2) clinicians already use growth charts as a standard for normal growth; and 3) the WHO charts are based on a high-quality study, the MGRS.

Continued Use of CDC Growth Charts for Children Aged 24–59 Months

Use of the CDC growth charts for children aged 24–59 months is recommended. The CDC charts also should be used for older children because the charts extend up to age 20 years, whereas the WHO standards described in this report apply only to children aged 0–59 months. The rationale for continuing to use CDC growth charts includes the following: 1) the methods used to create the WHO and CDC charts are similar after age 24 months, 2) the CDC charts can be used continuously through age 19 years, and 3) transitioning at age

FIGURE 5. Comparison of World Health Organization (WHO) and CDC growth chart length/stature-for-age measurements for boys aged <5 yrs



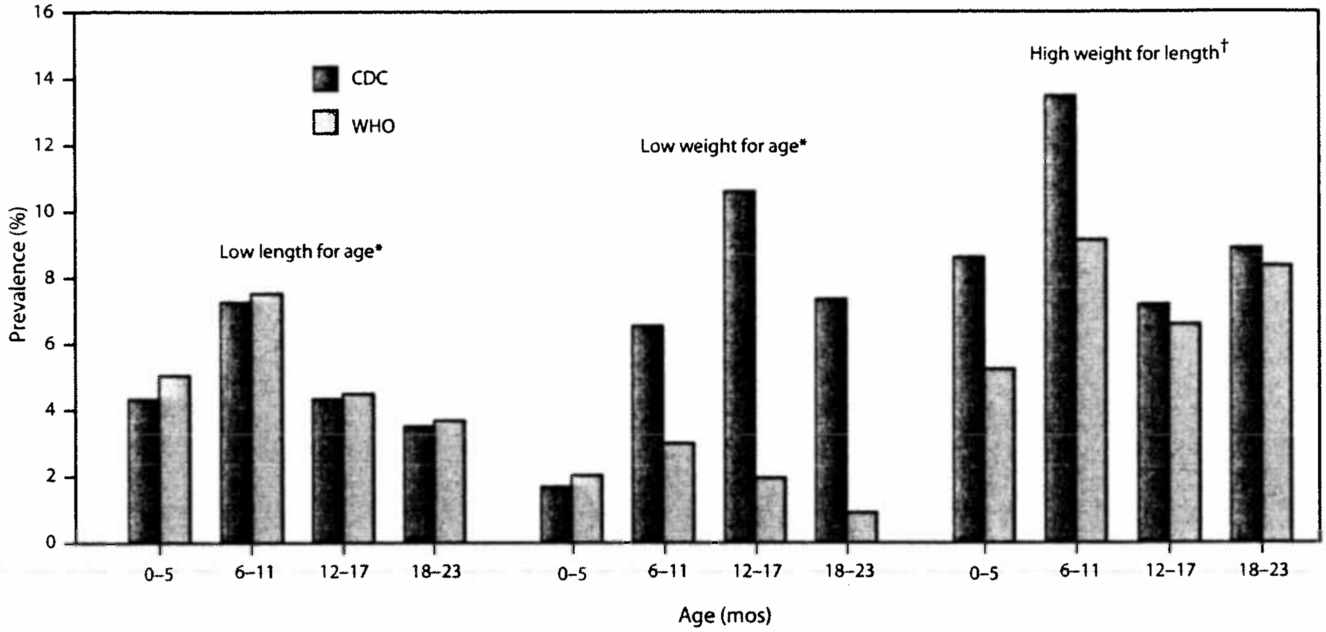
24 months is most feasible because measurements switch from recumbent length to standing height at the this age, necessitating use of new printed charts.

Use of Recommended Growth Charts in Clinical Settings

CDC recommends the use of modified versions of the WHO curves for children aged <24 months that include the 2.3rd and 97.7th percentiles and are appropriate for clinicians. These curves have been developed and are available at http://www.cdc.gov/growthcharts. Training tools for clinicians are being developed and also will be available at this website.

Clinicians should recognize that the WHO charts are intended to reflect optimal growth of infants and children. Although many children in the United States have not experienced the optimal environmental, behavioral, or health conditions specified in the WHO study, the charts are intended for use with all children aged <24 months. Therefore, their growth might not always follow the patterns shown in the WHO curves. For example, formula-fed infants tend to gain weight more rapidly after approximately age 3 months and

FIGURE 6. Comparison of the World Health Organization (WHO) and CDC growth chart prevalences of low length for age, low weight for age, and high weight for length among children aged <24 months — United States, 1999–2004



Source: Data from the National Health and Nutrition Examination Survey, 1999–2004.
* ≤5th percentile on the CDC charts; ≤2.3rd percentile on the WHO charts.
† ≥95th percentile on the CDC charts; ≥97.7th percentile on the WHO charts.

therefore cross upward in percentiles, perhaps becoming classified as overweight. Although no evidence-based guidelines for treating overweight in infancy exist, early recognition of a tendency toward obesity might appropriately trigger interventions to slow the rate of weight gain.

For the first 3 months of age, the WHO charts show a somewhat faster rate of weight gain than the CDC charts, leading to the identification of more infants who appear to be growing slowly. Clinicians should recognize that this slower rate of weight gain is typical for formula fed infants. For breastfed infants identified as growing slowly, clinicians need to carefully assess general health issues and ensure appropriate management of lactation. Only if there is evidence of lactation inadequacy should they consider supplementation with formula.

Differences in the length-for-age WHO and CDC charts are small, and clinical differences based on these charts are expected to be insignificant. In contrast, when the WHO charts are used to assess the growth of U.S. children, fewer children aged 6–23 months will be identified as having inadequate weight for age. Some assert that this might be beneficial because overdiagnosis of underweight might damage the parent-child interaction, subjecting families to unnecessary interventions and possibly unintentionally creating an eating disorder (*28*). However, children who are identified as having low weight for age on the WHO charts will be more likely to have a substantial deficiency. Clinicians need to seek out the causes for poor growth and propose changes accordingly. For example, poor weight gain might result from neglect, substantial morbidities, or other medical problems that require immediate attention (*29*).

Recent WHO Growth Chart Policies and Publications

According to WHO, 111 countries had adopted the WHO growth standards as of July 1, 2010 (A. Onyango, WHO, personal communication, July 26, 2010.). Canada has recommended the use of the WHO growth charts (*30*), including the more recently published charts for children aged 5–17 years (*31*). The United Kingdom Department of Health has recommended use of the WHO growth standards for children aged 2 weeks to 5 years in combination with United Kingdom birth weight charts (32–42 weeks' gestation) (*32,33*).

In 2007, the AAP board of directors voted to support the use of the WHO growth charts for children aged <24 months

(D. Burrowes, American Academy of Pediatrics, personal communication, November 7, 2007), with the recognition that substantial educational measures are needed to assist with interpretation of the charts. AAP has waited for the availability of clinically useable charts to publicize this recommendation.

Various studies have compared the WHO growth standards with other growth references (*34–37*). Researchers also have analyzed ways in which use of the WHO standards might affect prevalences of wasting, stunting, and underweight worldwide (*38*), as well as the distribution of z scores, a commonly used indicator of data quality in international surveys (*39*). WHO has developed an algorithm to convert population prevalences that were computed using the previous NCHS, CDC, and WHO growth curves (*10,11*) to those expected using the new charts (*38*). Several studies have conducted field testing of the WHO charts in clinical settings worldwide, showing differences in prevalence compared with existing charts but also documenting that the WHO standards generally correspond with clinical assessment of malnutrition (*36,40,41*).

Conclusion

Because the CDC charts are currently in use in clinical settings to assess growth of children, use of the WHO charts for children aged <24 months will require training of health-care providers and others who measure and assess child growth. Training should focus on how to interpret growth on the charts, differences between references and standards, the characteristics of the WHO cohort (especially regarding socioeconomic status, infant feeding patterns, and maternal lack of smoking), the disjunction created by switching from the WHO to the CDC curves at age 2 years, growth patterns of children who breastfeed compared with those who formula feed, and the potential contribution of education and support programs for breastfeeding and complementary feeding. Development of appropriate guidance based on clinical and applied experience is needed so that clinicians can interpret the growth of infants and children who do not meet all optimal environmental and health criteria (e.g., breastfeeding) used for participants in the WHO study. Growth patterns over time using multiple data points should be used in conjunction with other medical and family history to assess appropriate growth. Training on accurate measurement techniques, especially for recumbent length, is critical for any assessment to be valid.

The clinical consequences of using the WHO standards compared with the CDC reference should be evaluated over time to identify advantages and unforeseen adverse consequences of the use of the WHO standards. Research is needed on health outcomes related to different growth patterns during infancy, particularly with regard to identifying percentiles that are indicative of health problems. Finally, research should be conducted on the use of BMI measurements based on length in infants and toddlers as predictive of future adverse health effects.

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☆U.S. Government Printing Office: 2010-623-026/41275 Region IV   ISSN: 1057-5987

WHO Growth Standards Are Recommended for Use in the U.S. for Infants and Children 0 to 2 Years of Age

The World Health Organization (WHO) released a new international growth standard statistical distribution in 2006, which describes the growth of children ages 0 to 59 months living in environments believed to support what WHO researchers view as optimal growth of children in six countries throughout the world, including the U.S. The distribution shows how infants and young children grow under these conditions, rather than how they grow in environments that may not support optimal growth.

Recommendation

CDC recommends that health care providers:

- Use the **WHO growth charts** to monitor growth for infants and children 0 to 2 years of age in the U.S.
- Use the **CDC growth charts** to monitor growth for children age 2 years and older in the U.S.

Why use WHO growth standards for infants and children ages 0 to 2 years of age in the U.S?

- **The WHO standards establish growth of the breastfed infant as the norm for growth.**

  Breastfeeding is the recommended standard for infant feeding. The WHO charts reflect growth patterns among children who were predominantly breastfed for at least 4 months and still breastfeeding at 12 months.

- **The WHO standards provide a better description of physiological growth in infancy.**

  Clinicians often use the CDC growth charts as standards on how young children should grow. However the CDC growth charts are references; they identify how typical children in the US did grow during a specific time period. Typical growth patterns may not be ideal growth patterns. The WHO growth charts are standards; they identify how children should grow when provided optimal conditions.

- **The WHO standards are based on a high-quality study designed explicitly for creating growth charts.**

  The WHO standards were constructed using longitudinal length and weight data measured at frequent intervals. For the CDC growth charts, weight data were not available between birth and 3 months of age and the sample sizes were small for sex and age groups during the first 6 months of age.

Why use CDC growth charts for children 2 years and older in the U.S.?

- The CDC growth charts can be used continuously from ages 2-19. In contrast the WHO growth charts only provide information on children up to 5 years of age.
- For children 2-5 years, the methods used to create the CDC growth charts and the WHO growth charts are similar.

Content source: Centers for Disease Control and Prevention, National Center for Health Statistics

Birth to 24 months: Boys
Head circumference-for-age and Weight-for-length percentiles

NAME ______________________

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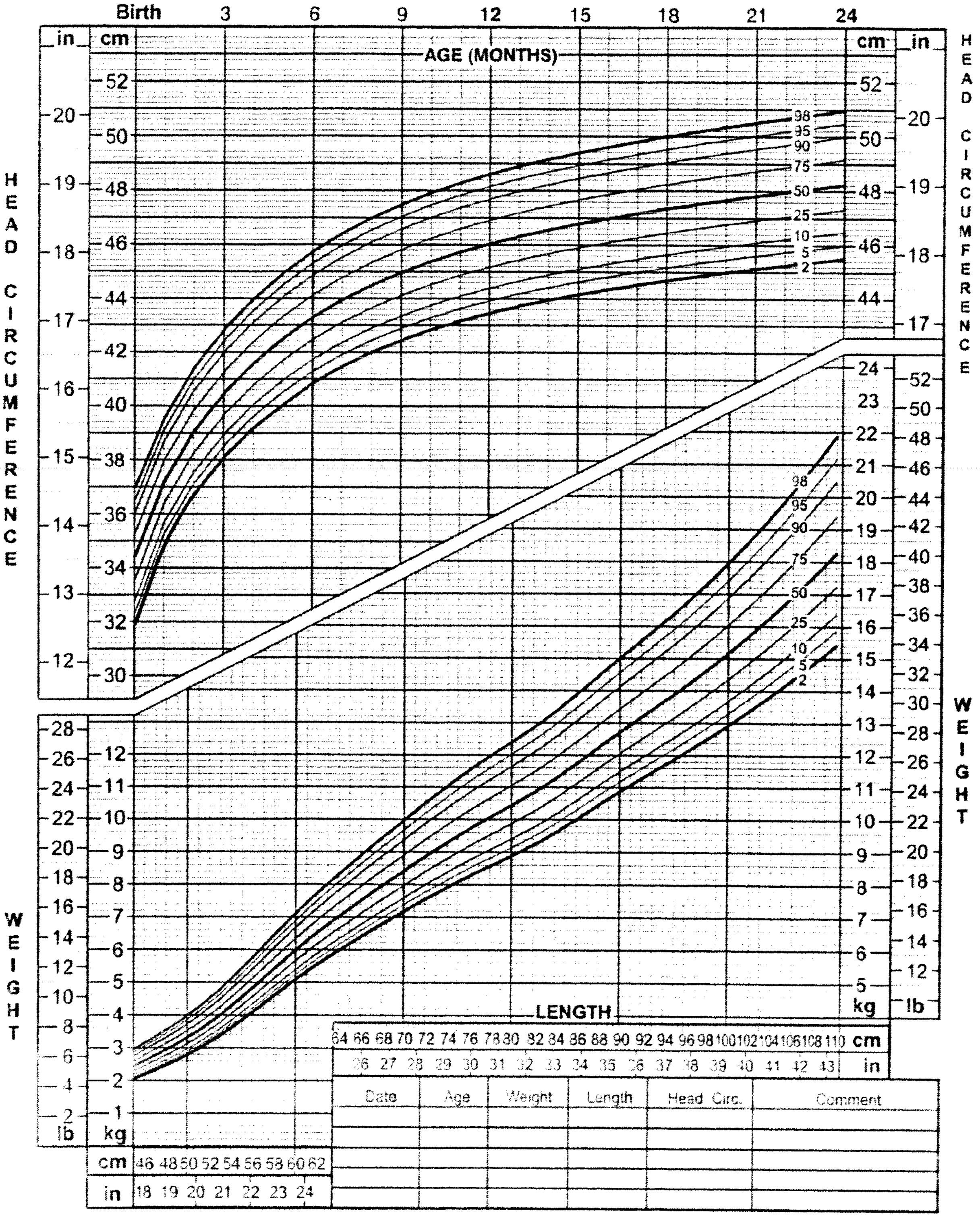

Date	Age	Weight	Length	Head Circ.	Comment

Published by the Centers for Disease Control and Prevention, November 1, 2009
SOURCE: WHO Child Growth Standards (http://www.who.int/childgrowth/en)

Birth to 24 months: Boys
Length-for-age and Weight-for-age percentiles

NAME ______________________

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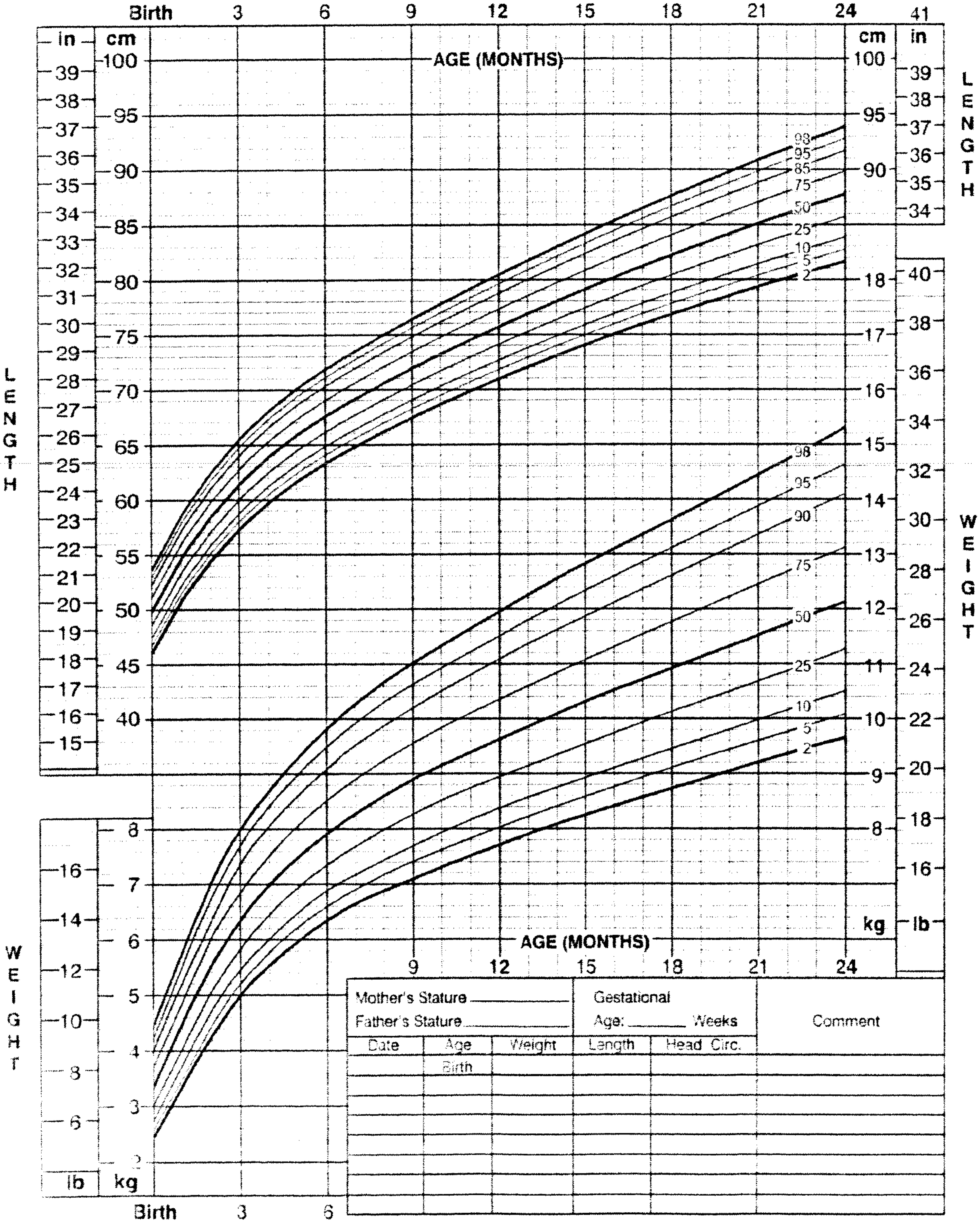

Mother's Stature ______ Father's Stature ______			Gestational Age: ______ Weeks		Comment
Date	Age	Weight	Length	Head Circ.	
	Birth				

Published by the Centers for Disease Control and Prevention, November 1, 2009
SOURCE: WHO Child Growth Standards (http://www.who.int/childgrowth/en)

Birth to 24 months: Girls
Head circumference-for-age and
Weight-for-length percentiles

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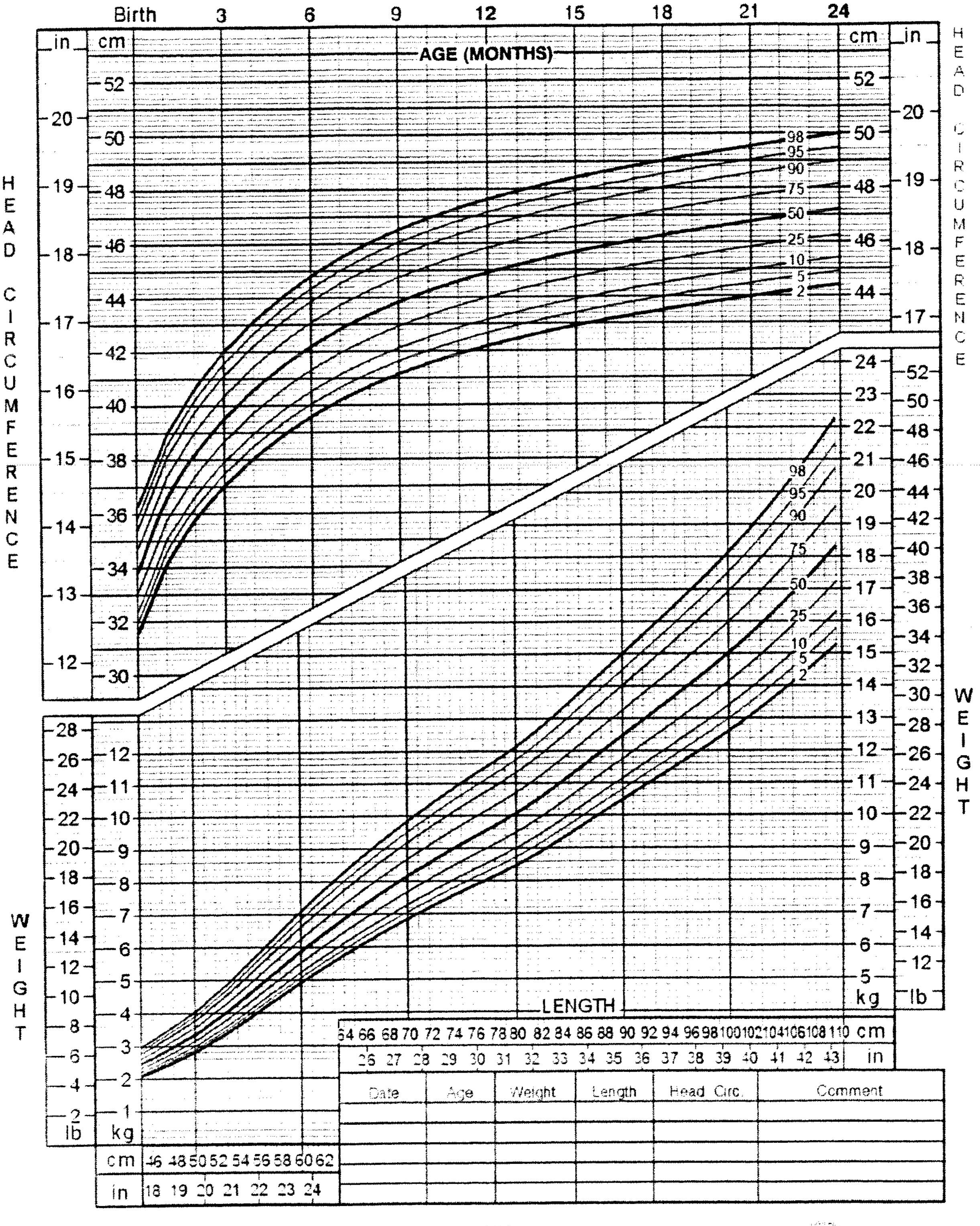

Date	Age	Weight	Length	Head Circ.	Comment

Published by the Centers for Disease Control and Prevention, November 1, 2009
SOURCE: WHO Child Growth Standards (http://www.who.int/childgrowth/en)

Birth to 24 months: Girls
Length-for-age and Weight-for-age percentiles

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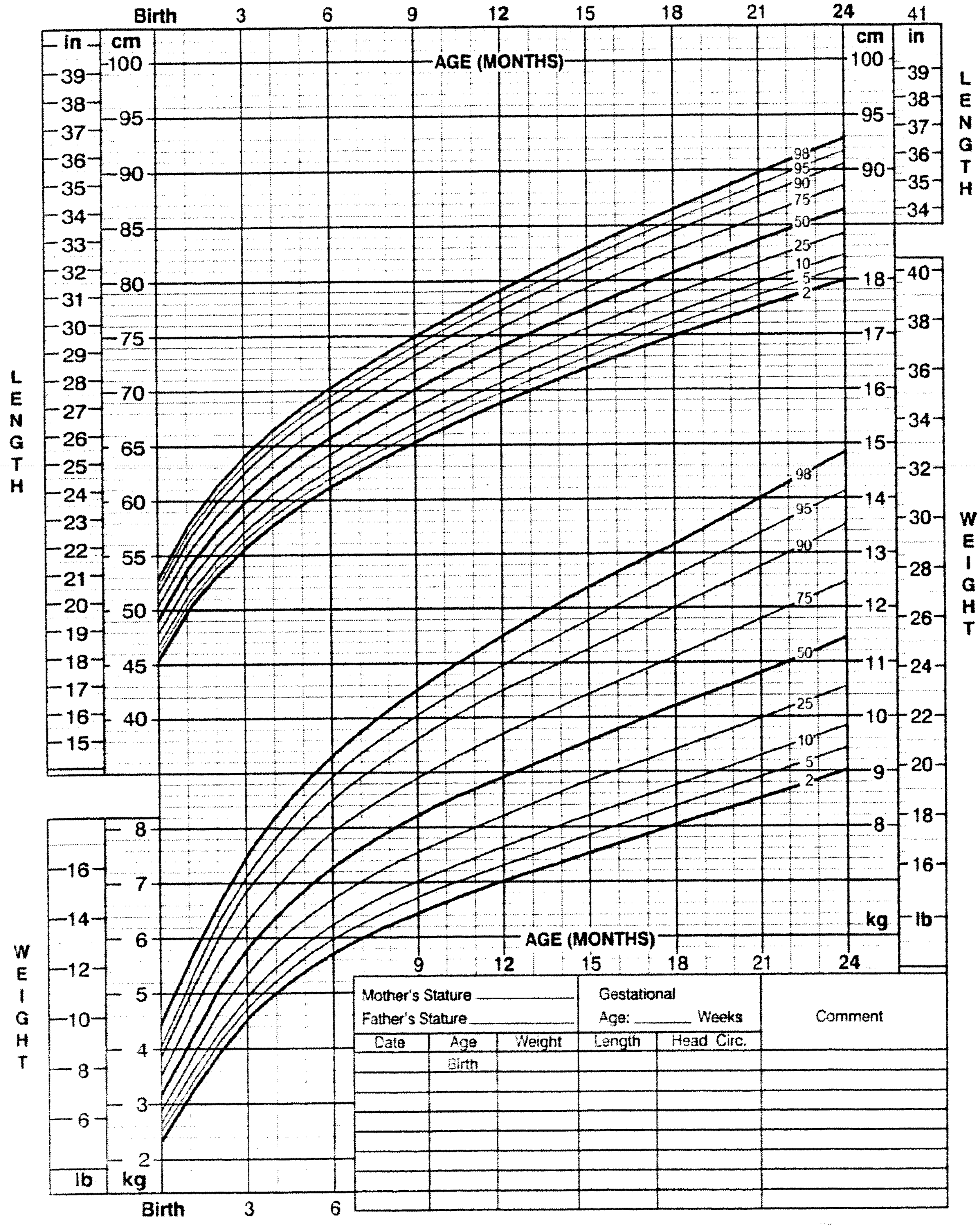


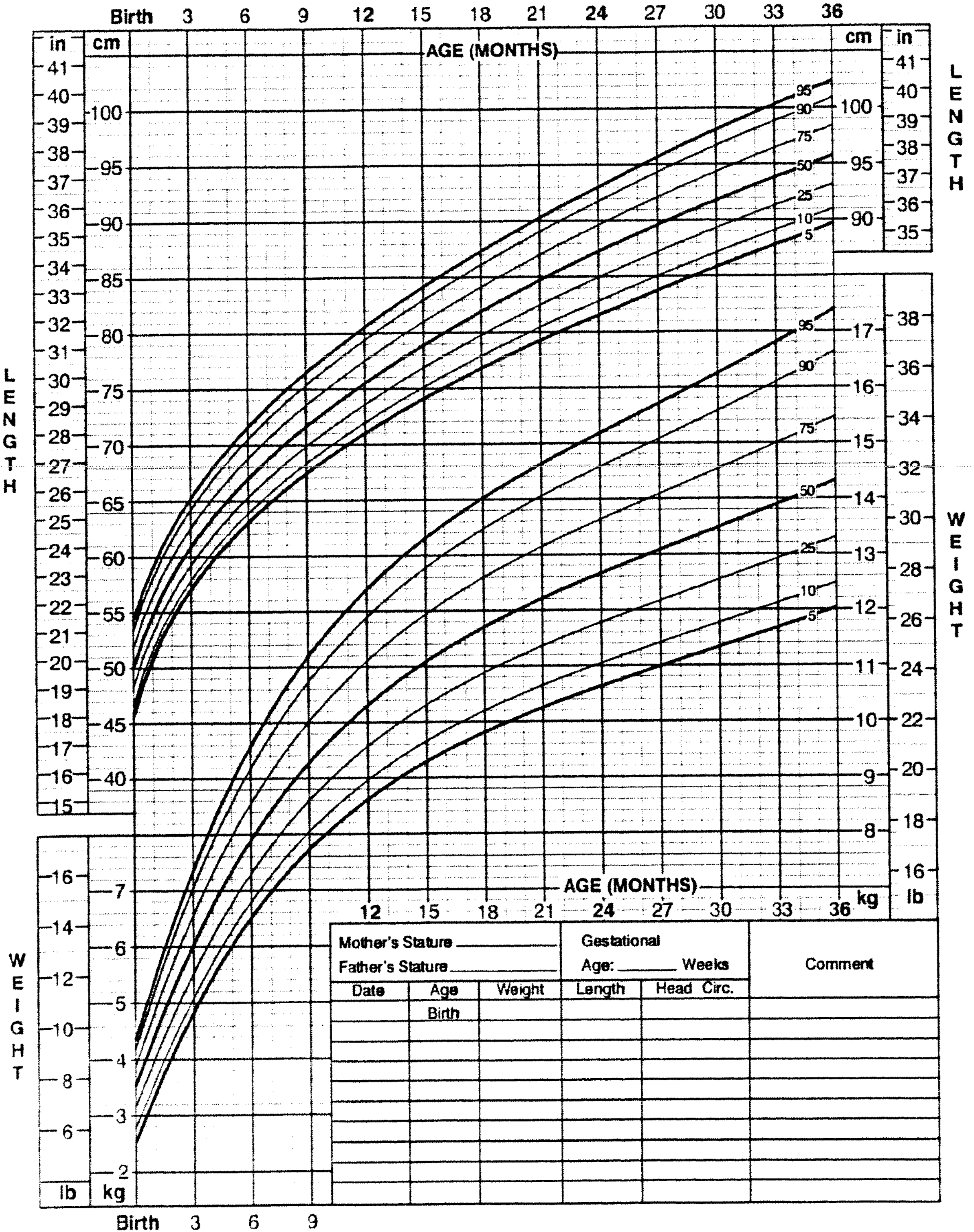
Mother's Stature ________			Gestational		Comment
Father's Stature ________			Age: ______ Weeks		
Date	Age	Weight	Length	Head Circ.	
	Birth				

Published by the Centers for Disease Control and Prevention, November 1, 2009
SOURCE: WHO Child Growth Standards (http://www.who.int/childgrowth/en)

Birth to 36 months: Boys
Length-for-age and Weight-for-age percentiles

NAME ____________________

RECORD # ____________



Mother's Stature ____________
Father's Stature ____________
Gestational Age: ________ Weeks
Comment

Date	Age	Weight	Length	Head Circ.	Comment
	Birth				

Published May 30, 2000 (modified 4/20/01).
SOURCE: Developed by the National Center for Health Statistics in collaboration with
the National Center for Chronic Disease Prevention and Health Promotion (2000).
http://www.cdc.gov/growthcharts

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Birth to 36 months: Boys
Head circumference-for-age and Weight-for-length percentiles

NAME ______________________

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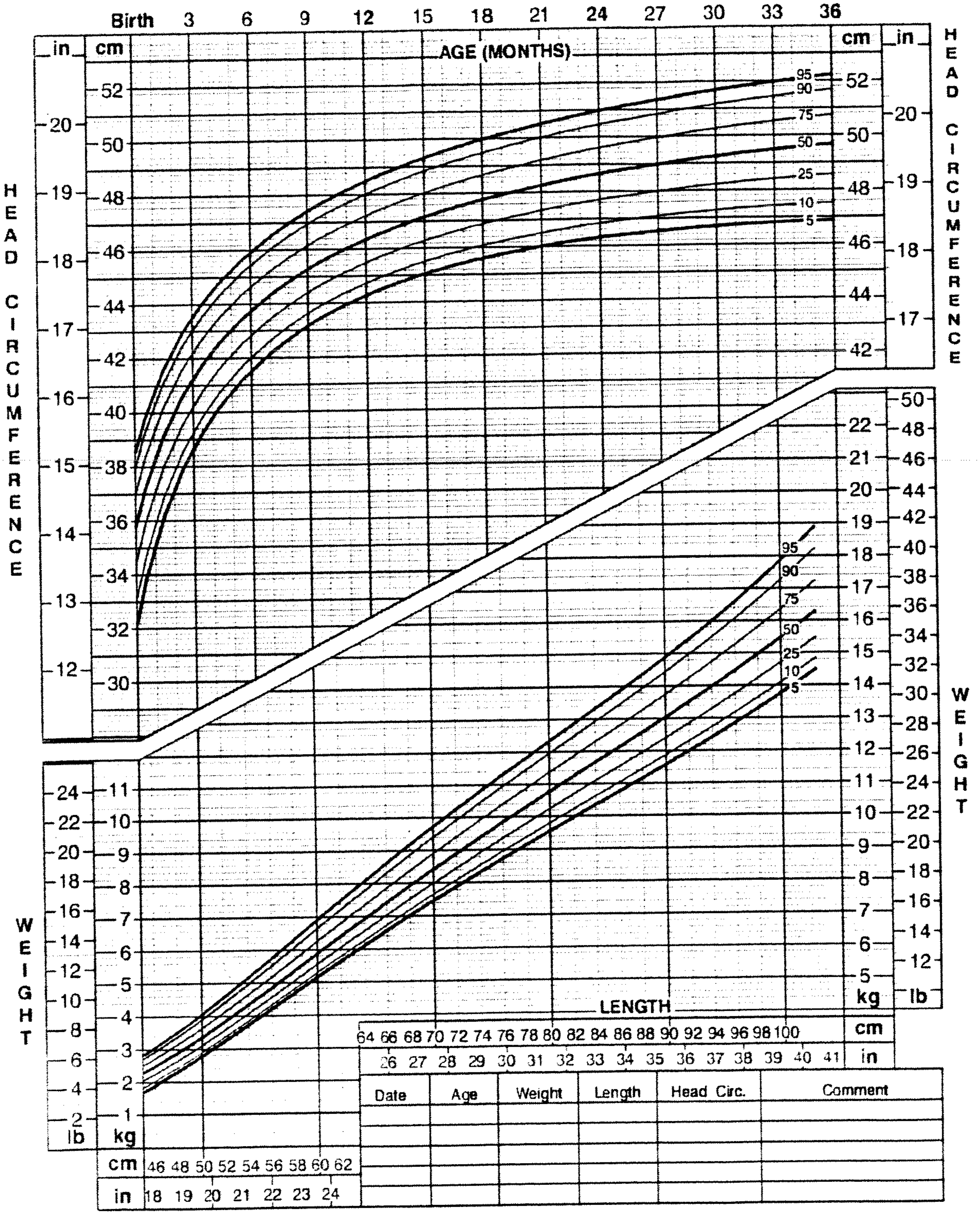

Date	Age	Weight	Length	Head Circ.	Comment

Published May 30, 2000 (modified 10/16/00).
SOURCE: Developed by the National Center for Health Statistics in collaboration with
the National Center for Chronic Disease Prevention and Health Promotion (2000).
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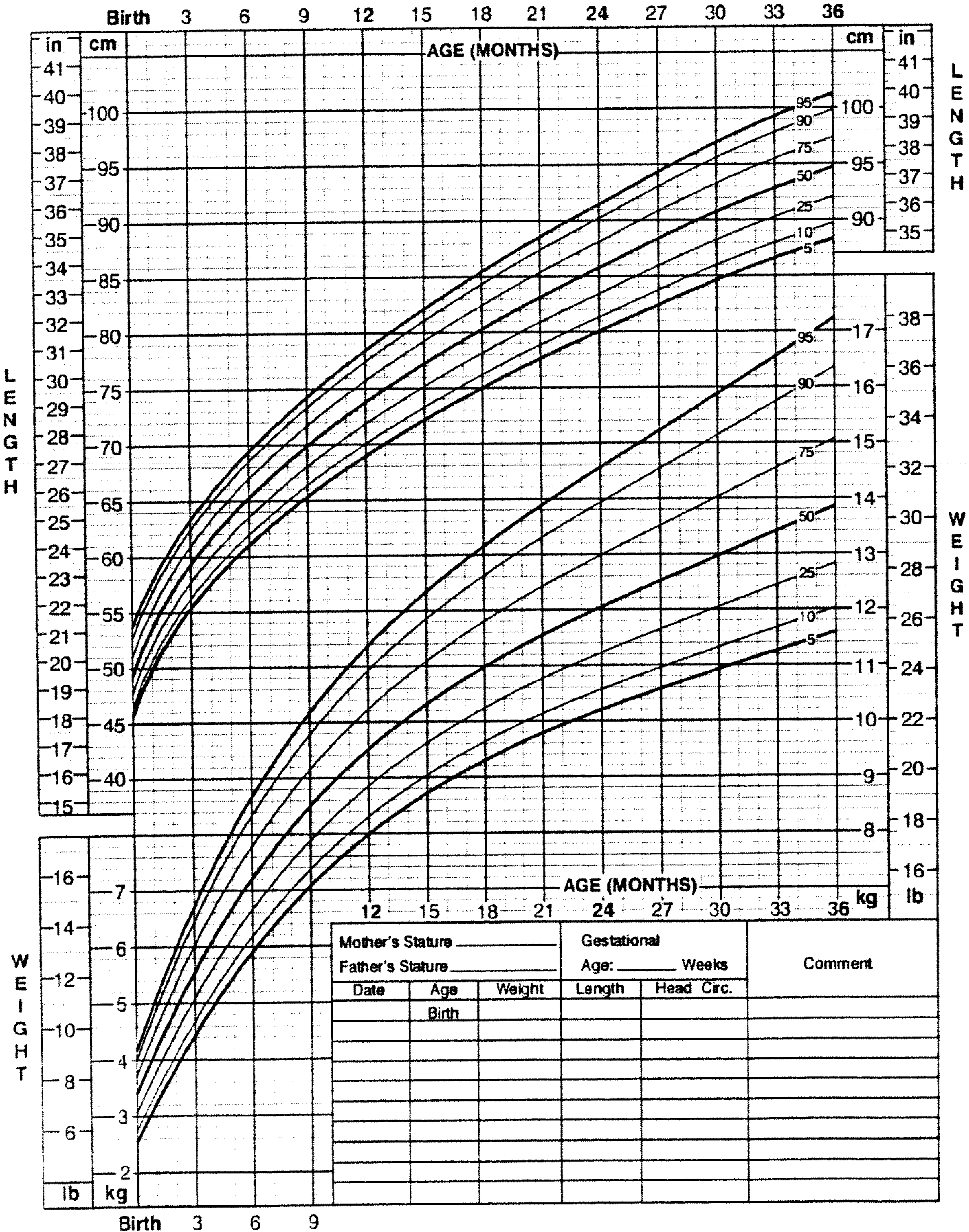
Birth to 36 months: Girls
Length-for-age and Weight-for-age percentiles

NAME ____________________

RECORD # ____________



Mother's Stature ____________

Father's Stature ____________

Gestational Age: ________ Weeks

Date	Age	Weight	Length	Head Circ.	Comment
	Birth				

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SOURCE: Developed by the National Center for Health Statistics in collaboration with
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Birth to 36 months: Girls
Head circumference-for-age and Weight-for-length percentiles

NAME ______________________

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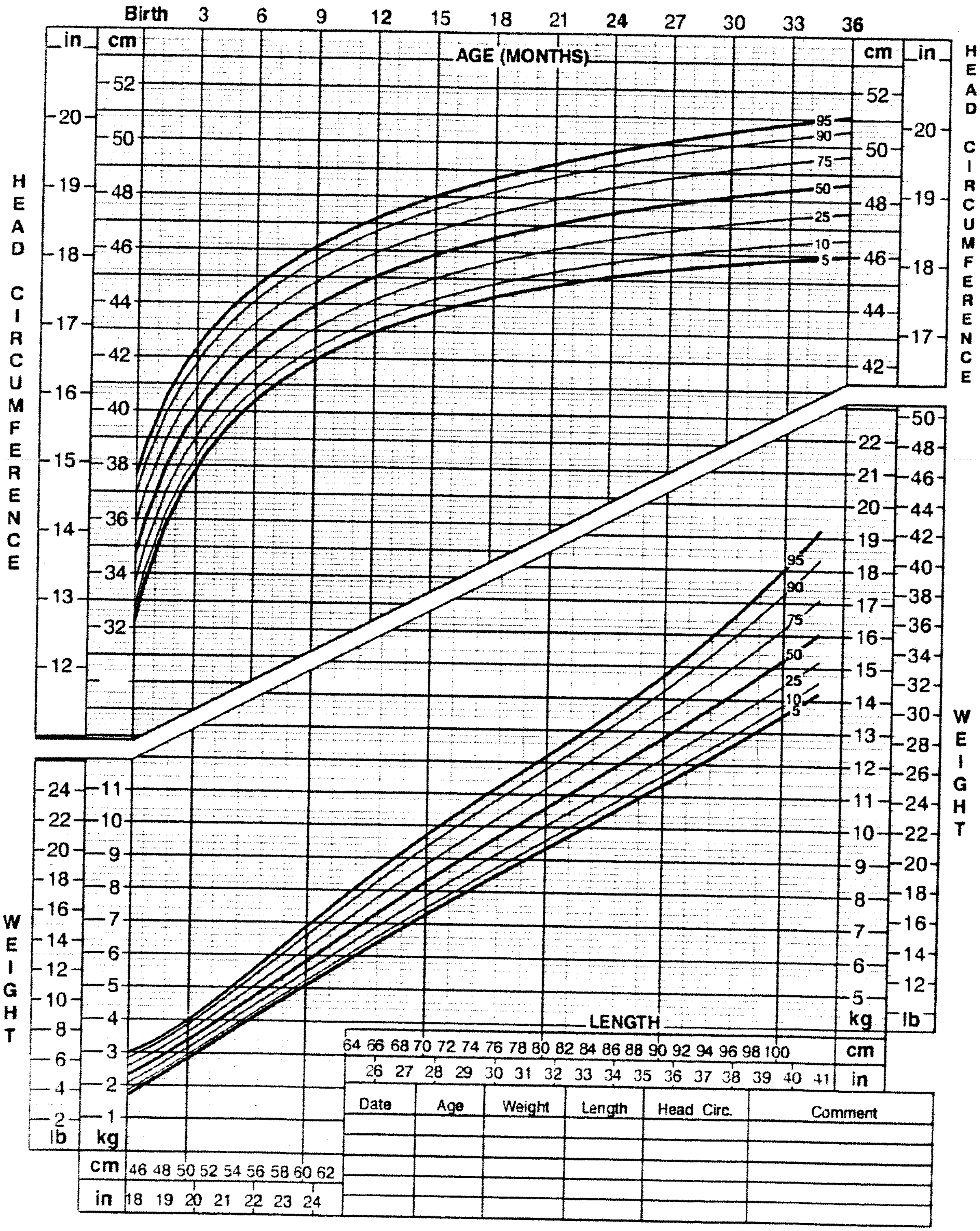

Date	Age	Weight	Length	Head Circ.	Comment

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http://www.cdc.gov/growthcharts

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Neonatal Weight Loss at a US Baby-Friendly Hospital

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ARTICLE INFORMATION

Article history:
Accepted 17 October 2011

Keywords:
Breastfeeding
Infant feeding
Weight loss
Infant nutrition

2212-2672/$36.00
doi: 10.1016/j.jada.2011.10.024

ABSTRACT

Few if any studies have examined weight loss among term newborns by weighing infants daily for the first week of life. Perhaps because so few data exist, there is no standard in the United States for normal newborn weight loss. Our objective was to investigate normal newborn weight loss among infants born in a US Baby-Friendly hospital, by weighing infants daily for the first week of life. Using a prospective cohort design, infants born at an urban Boston, MA, hospital were enrolled within 72 hours of delivery and weighed daily for the first week of life. In hospital, infant weight was obtained from the medical record; post discharge, a research assistant visited the home daily and weighed the baby. All feeds in week 1 of life were recorded. Birth-related factors potentially affecting weight loss were abstracted from the medical record. Complete data were collected on 121 infants. Mean weight loss was 4.9% (range=0.0% to 9.9%); 19.8% (24 of 121) of infants lost >7% of their birth weight; no infant lost >10%. Maximum percent weight loss was significantly associated with feeding type: exclusively and mainly breastfed infants lost 5.5%, mainly formula-fed infants lost 2.7% and exclusively formula-fed infants lost 1.2% ($P<0.001$). Type of delivery and fluids received during labor were not associated with weight loss. Clinical practices at a Baby-Friendly hospital, which support and optimize breastfeeding, appear to be associated with only moderate weight loss in exclusively and mainly breastfed infants.

J Acad Nutr Diet. 2012;112:410-413.

THERE IS NO ONE STANDARD FOR NORMAL NEONATAL weight loss among term infants in the medical literature, and guidelines differ by, and sometimes within, medical organizations. In their policy statement, *Breastfeeding and the Use of Human Milk*, the American Academy of Pediatrics' section on breastfeeding states that "weight loss in the infant of greater than 7% from birth weight indicates possible breastfeeding problems" (1). However, the American Academy of Pediatrics *Clinical Practice Guidelines for Hyperbilirubinemia* state that "adequacy of intake should be evaluated and the infant monitored if weight loss is more than 10%" (2). The American Academy of Breastfeeding Medicine protocol, *Hospital Guidelines for the Use of Supplementary Feedings in the Healthy Term Breastfed Neonate*, acknowledges that although weight loss of 8% to 10% can be normal, "it is an indication for careful assessment and possible breastfeeding assistance" (3). These guidelines do not address timing of weight loss, nor do they take into account other factors that can affect infant weight loss, such as type of delivery or maternal fluids in labor.

Differences between guidelines might reflect a paucity of evidence-based data regarding neonatal weight loss. We were unable to locate any studies reporting mean weight-loss nadir for infants weighed daily for the first week of life. Because weight-loss nadir (ie, maximum point of weight lost) can occur on any day in the first week postpartum, studies that do not weigh infants daily can only estimate weight loss and might have failed overall to capture this measurement. Macdonald and colleagues weighed infants at birth, before discharge, and then on subsequent home visits by a midwife, which generally occurred on days 5, 7, and 10 of life (4). Chantry and colleagues measured weight on days 3 and 7 (5), and Martens and Romphf assumed maximum weight loss to be the difference between birth weight and weight at discharge (6). Accurate knowledge of normal weight loss is important to support exclusive breastfeeding and optimal breastfeeding policies and practices, as well as to identify infants that are having feeding difficulties and create safe discharge plans.

The goals of our study were to determine weight-loss nadir among infants born at a Baby-Friendly hospital and to identify predictors of weight loss in the first week of life using a prospective design. Infant-feeding policies and procedures at a Baby-Friendly hospital comply with *The Ten Steps to Successful Breastfeeding* (7), considered by the World Health Organization as the optimal standard of breastfeeding management in hospitals. It is routine practice at a Baby-Friendly hospital to put the newborn skin-to-skin at birth, practice rooming-in, help a mother initiate breastfeeding within an hour of birth, and give a breastfeeding newborn food or drink other than breast milk only when medically indicated. Thus, neonatal weight loss among exclusively breastfed infants in our cohort likely reflects normal neonatal weight loss, and is unlikely to reflect patterns caused by poorly managed early infant feeding.

METHODS

Between June 2008 and June 2009, mother/infant dyads who consented to participate in a 2-year-long prospective cohort study to investigate the influence of early nutrition on obesity were given the option of participating in a nested cohort study in which infant weights would be measured daily for the first week of life. Following the enrollment criteria for the larger cohort study, infants were enrolled within 72 hours of birth and were healthy, term, singleton, appropriate for gestational age, and born at Boston Medical Center, an urban Baby-Friendly hospital in Boston, MA.

Daily weights were obtained from the medical record while the infant was hospitalized. In-hospital weights were obtained by standard hospital procedure using a Scale-Tronix Model 4800 digital scale (Scale-Tronix, Carol Stream, IL), which is accurate to 5 g. Post discharge, research assistants visited the home daily and weighed the infant using a digital Medela BabyWeigh scale (Medela, McHenry, IL), which is accurate to 2 g. Following standard procedures, the clothing and diaper were removed before weighing and the scale was zeroed with a blanket to maintain the infant's body temperature. Hospital weights were measured during the night; post-discharge weights were completed during the day. All feeds in week 1 of life were obtained from the bedside feeding chart postpartum and from a food diary completed by the mother post discharge, in which she recorded all feeds given at home. At each home visit, the research assistant answered any questions that the mother had about completing the food record; no nutrition counseling was provided. In addition, a verbal questionnaire was administered at the time of enrollment to obtain demographic data; birth-related factors that can affect weight loss were abstracted from the medical record. This study was approved by the Boston University Medical Center Institutional Review Board.

Infant feeding at the time of weight-loss nadir was categorized into one of four feeding categories based on the number of feeds: exclusive breast milk (100% breast milk feeds), mainly breast milk (≥50% breast milk feeds), mainly formula (>50% formula feeds), and exclusive formula (100% formula feeds).

Independent *t* tests, analyses of variance, and Pearson or Spearman correlation coefficients were run to determine bivariate predictors of maximum percent infant weight loss. Variables that were significant at $P<0.20$ in bivariate analysis were entered as predictor variables into an initial regression model, and variables that were not significant at $P<0.05$ were removed using backwards stepwise regression. All statistical analyses were conducted using Statistical Analysis Software (version 9.1, 2002-3, SAS Institute Inc, Cary, NC).

RESULTS AND DISCUSSION

One hundred and thirty-two mother/infant dyads were enrolled between June 2008 and June 2009. Of these, 11 were excluded from analysis for the following reasons: lost to follow-up before infant weight-loss nadir was reached (n=6), mother or infant hospitalized and unable to complete feeding records or obtain infant weights (n=3), and missing data (n=2). Final analyses were conducted on 121 mother/infant dyads with complete information. Descriptive information is presented in the Table.

Mean weight loss was 4.9%±2.4% (range=0.0% to 9.9%); 19.8% (24 of 121) of infants lost >7% of their birth weight, 7.4% (9 of 121) of infants lost >8%, and no infant lost >10%. Mean weight loss differed significantly based on feeding type; exclusively breastfed infants lost 5.5% and mainly breastfed infants lost 5.5% of birth weight; mainly formula-fed infants lost 2.7% and exclusively formula-fed infants lost 1.2% of birth weight ($P<0.001$) (Table). In bivariate analysis, maternal birthplace (US-born vs non-US-born), gestational age, volume of fluids received in labor, and infant feeding category were significantly associated with percent weight-loss nadir.

Mean time to nadir was 2.5 days after birth and ranged from 0 to 7 days after birth (Figure); 58.7% (71 of 121) of infants reached their weight nadir within 2 days after birth. Only one infant reached weight-loss nadir on day 7 of life. This infant was followed for an additional day to ensure that nadir was captured. At time of weight-loss nadir, 26.4% of infants had been exclusively breastfed, 54.6% had been mainly breastfed, 13.2% had been mainly formula-fed, and 5.8% had been exclusively formula-fed. There was no difference in mean time to nadir by feeding group ($P=0.56$). Given the small number of exclusive formula feeders (n=7), mainly and exclusive formula feeders were combined for linear regression analyses.

The following variables ($P<0.20$ in bivariate analysis) were entered into the initial regression as possible predictors of percent weight-loss nadir: infant-feeding category, maternal birthplace, volume of fluids received in labor, medical insurance, gestational age, and birth weight. After backwards selection, only infant-feeding category, gestational age, and medical insurance remained in the final model. Compared with formula-fed infants, exclusively breastfed infants lost, on average, 3.2% more weight (standard error [SE]=0.5; $P<0.001$), and mainly breastfed infants lost 3.4% more weight (SE=0.5; $P<0.001$). For each 1-week increase in gestational age, there was a 0.4% decrease in weight loss (SE=0.2; $P=0.009$). Compared with infants of mothers with private insurance, those with public insurance lost 1.6% less weight (SE=0.6; $P=0.005$). Overall, feeding category, gestational age, and insurance were the most robust predictors of percent weight-loss nadir, contributing to 37.8% of the variability in the model.

In contrast to other reports (4-6,8-11), no infant lost ≥10% of birth weight. This is most similar to that found in a study by Konetzny and colleagues, in which 2.4% (67 of 2,788) of exclusively breastfed infants lost at least 10% of birth weight at a Baby-Friendly hospital in Switzerland (8). In contrast, in Manganaro and colleagues' Italian study of 686 exclusively breastfed infants, 7.7% of infants lost at least 10% of their birth weight (9); in Dewey and colleagues' study, 12% of breastfed infants (those who consumed <2 oz non–breast milk in the first 72 hours of life) lost at least 10% of birth weight (10); and in Chantry and colleagues' recent study, 19% of 134 exclusively breastfed infants and 14% of the entire study sample lost at least 10% of their birth weight (5).

At Boston Medical Center, the newborn service reviews each infant weight loss >7% (normal vaginal delivery) and 8% (cesarean birth), at which point a referral is made to the lactation service, and an International Board Certified Lactation Consultant provides a consultation for the dyad. Although it is theoretically possible that the minimal weight loss found in our study could reflect aggressive remedial formula supplementation in infants who are losing weight, this is not routine practice, considering the hospital's Baby-Friendly status and referral guidelines. The authors propose that the limited weight loss in this cohort was likely a result of optimal infant-feeding support and policies in a Baby-Friendly hospital. Of interest, exclusively breastfed infants lost the same amount of weight as mainly breastfed infants.

Some studies have found cesarean section delivery (9) and maternal fluid balance (5) to be associated with increased neonatal weight loss, others have not (11). Given that lactogenesis stage II can be delayed after a cesarean section (12,13), it was surprising to find that infants delivered by cesarean section did not lose more weight than infants born vaginally. This finding might result because we were weighing all infants every day; in other studies, cesarean-born infants might be weighed more often and for more days because they are more closely followed and remain in the hospital for longer than vaginally delivered infants. In addition, no association was found between maternal fluid intake during labor and maximum weight loss in our final regression model. This supports findings by Lamp and Macke (11), but differs from Chantry and colleagues (5). Weights in this study might be more accurate than those obtained by Chantry and colleagues because of daily weighing, or this outcome might be a result of a limitation in our study; ie, fluid intake in labor was our variable of interest instead of fluid balance, as fluid output in the medical record was not reliably recorded.

This study has clinical relevance by demonstrating that with supportive breastfeeding policies and practices in place, exclusively and mainly breastfed newborns lose relatively little weight. Using the American Academy of Pediatrics section on breastfeeding's weight-loss cut-off of 7% (1), 19.8% of the infants in this sample would have been identified as potentially having a breastfeeding problem. This raises a complex issue. Although it is indeed possible that 5.5% is normal for weight loss among exclusively breastfed infants in the supportive environment, these findings should not be clinically interpreted to define infants who lose >5% of birth weight as high-risk candidates for remedial care requiring formula supplementation. The vast majority of US hospitals do not have Baby-Friendly status, and there is no indication that infants who lose >5% in a non–Baby-Friendly setting are in imminent danger of dehydration. Although more data are needed to confirm these findings, under optimal settings, neonatal weight loss among exclusively or mainly breastfed infants appears moderate.

At the opposite extreme, mainly and exclusively formula-fed infants lost almost no weight. More research is needed to determine whether a lack of weight loss among these infants, when compared with optimally managed exclusive or mainly breastfed

Table. Descriptive characteristics and variables associated with mean weight loss nadir among 121 infants born at a US Baby-Friendly hospital

Variable	n	%	Mean weight loss± standard deviation (%)	*P* value
Ethnicity[a]				0.52
Black non-Hispanic	33	27.3	4.6±2.4	
White non-Hispanic	5	4.1	3.8±3.5	
Hispanic	78	64.5	5.1±2.3	
Asian/other	5	4.1	4.5±2.5	
US-born[b]				0.01
Yes	29	24.0	3.9±2.4	
No	92	76.0	5.2±2.3	
Insurance[a]				0.10
MassHealth/CareNet/self-pay	95	78.5	4.7±2.4	
Private	13	10.7	6.2±2.3	
Healthy start	13	10.7	5.1±1.6	
Received WIC[bc]				0.41
Yes	111	91.7	4.8±2.4	
No	10	8.3	5.5±2.1	
Parity[b]				0.56
1 Child	50	41.3	4.7±2.7	
>1 Child	71	58.7	5.0±2.1	
Type of delivery[b]				0.71
Vaginal	88	72.7	4.8±2.3	
Cesarean section	33	27.3	5.0±2.5	
Infant sex[b]				0.48
Male	63	52.1	4.7±2.5	
Female	58	47.9	5.0±2.3	
Infant feeding category at nadir[a]				<0.001
Exclusive breast milk (100% breast milk feeds)	32	26.4	5.5±2.0	
Mainly breast milk (≥50% breast milk feeds)	66	54.6	5.5±2.1	
Mainly formula (>50% formula feeds)	16	13.2	2.7±1.7	
Exclusive formula (100% formula feeds)	7	5.8	1.2±1.0	

	n	Mean (SD[d])	Correlation	*P* value
Birth weight (g)[e]	121	3,261 (359)	−0.120	0.19
Gestational age (weeks)[e]	121	39 4/7 (1 1/7)	−0.181	0.05

	n	Median (lower to upper quartile)	Correlation	*P* value
Fluids received in labor (cc)[f]	119	1,506 (310-2,747)	−0.338	0.0002

[a] Analysis of variance.

[b] *t* test.

[c] WIC=Special Supplemental Nutrition Program for Women, Infants, and Children.

[d] SD=standard deviation.

[e] Pearson correlation.

[f] Spearman correlation.

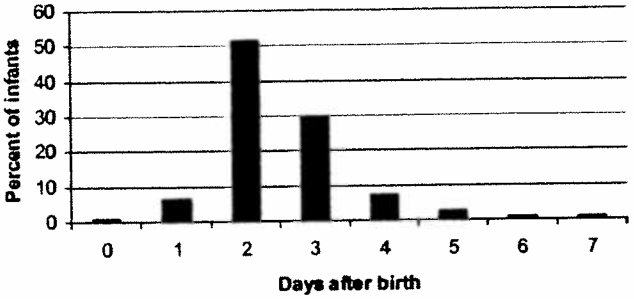

Figure. Days after birth when weight loss nadir reached at a US Baby-Friendly hospital.

infants, has future adverse health outcomes, such as a predisposition toward obesity later in life.

CONCLUSIONS

By weighing infants daily for the first week of life and until weight started to rebound, the authors are confident that maximum weight-loss nadir was captured. Studies that used convenience measurements, such as those limited to in-hospital or based around clinical visits, will not always capture maximum weight loss.

Infant feeding pattern was a strong predictor of newborn weight loss. Infants fed exclusively or mainly formula lost less weight than those fed exclusively or mainly breast milk, and none of the newborns in the sample lost >10% of birth weight. Clinical practices at a Baby-Friendly hospital, which support and optimize breastfeeding, appear to be associated with only moderate weight loss in exclusively and mainly breastfed infants.

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STATEMENT OF POTENTIAL CONFLICT OF INTEREST:

No potential conflict of interest was reported by the authors.

FUNDING/SUPPORT:

This project was supported by National Research Initiative Grant no. 2008-35215-18838 from the US Department of Agriculture, National Institute of Food and Agriculture, and The Joel and Barbara Alpert Endowment for Children of the City. The Medela BabyWeigh scales used in this study were donated by Medela (McHenry, IL).

ARTICLE

Risk of Bottle-feeding for Rapid Weight Gain During the First Year of Life

Scan for Author
Audio Interview

Ruowei Li, MD, PhD; Joselito Magadia, PhD; Sara B. Fein, PhD; Laurence M. Grummer-Strawn, PhD

Objective: To better understand the mechanisms behind breastfeeding and childhood obesity, we assessed the association of weight gain with the mode of milk delivery aside from the type of milk given to infants.

Design: A longitudinal study of infants followed up from birth to age 1 year. Multilevel analyses were conducted to estimate infant weight gain by type of milk and feeding mode.

Setting: Pregnant women were recruited from a consumer mail panel throughout the United States between May 2005 and June 2007.

Participants: One thousand eight hundred ninety nine infants with at least 3 weight measurements reported during the first year.

Main Exposures: Six mutually exclusive feeding categories and proportions of milk feedings given as breastmilk or by bottle.

Main Outcome Measures: Weight measurements reported on 3-, 5-, 7-, and 12-month surveys.

Results: Compared with infants fed at the breast, infants fed only by bottle gained 71 or 89 g more per month when fed nonhuman milk only ($P < .001$) or human milk only ($P = .02$), respectively. Weight gain was negatively associated with proportion of breastmilk feedings, but it was positively associated with proportion of bottle-feedings among those who received mostly breastmilk. Among infants fed only breastmilk, monthly weight gain increased from 729 g when few feedings were by bottle to 780 g when most feedings were by bottle.

Conclusions: Infant weight gain might be associated not only with type of milk consumed but also with mode of milk delivery. Regardless of milk type in the bottle, bottle-feeding might be distinct from feeding at the breast in its effect on infants' weight gain.

Arch Pediatr Adolesc Med. 2012;166(5):431-436

THE ESTIMATED PERCENTage of US children aged 2 to 5 years and 6 to 11 years classified as overweight increased from 5.0% and 6.5% in 1980 to 10.4% and 19.6%, respectively, in 2007-2008.[1-3] The increase in childhood obesity was also observed among those aged 6 to 23 months, from 7.2% in 1980 to 11.6% in 2000.[1] Given the numerous health risks related to childhood obesity,[1-7] its prevention is becoming a public health priority.[8] It has been reported that feeding practices affect growth and body composition in the first year of life, with breastfed infants gaining less rapidly than formula-fed infants.[9-14] There is also evidence that breastfed infants continue to have a low risk for later childhood obesity.[15-18]

For editorial comment see page 483

There are multiple hypotheses for the mechanisms behind breastfeeding and childhood obesity and one of them pertains to the poor self-regulation of energy intake among formula-fed infants.[19] In contrast to infants fed at the breast who may need to actively suckle, formula-fed infants are more likely to be passive in the feeding process, and caregivers' control might undermine infants' capability for self-regulation to balance energy intake against internal cues of hunger and satiety. Theoretically, feeding babies with expressed breastmilk could increase infant weight gain because it is fed by bottle. So far, only one pilot study has examined early growth patterns of babies fed breastmilk by breast vs by bottle.[20] The purpose of this study was to compare infant weight gain by both milk type (human vs nonhuman milk) and feeding mode (breast vs bottle) and examine whether bottle-fed infants gain weight more rapidly than those fed at the breast during the first year. The study had 2 specific hypothesis: (1) Infant weight

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gain is not only affected by type of milk but also by mode of milk delivery and (2) Regardless of the type of milk in the bottle, bottle-feeding might put infants on a faster track of weight gain.

METHODS

SAMPLE

The Infant Feeding Practices Study II is a longitudinal study of new mothers and their infants conducted by the Food and Drug Administration and the Centers for Disease Control and Prevention from May 2005 to June 2007. Women were recruited in their third trimester of pregnancy from a consumer opinion panel of approximately 500 000 households throughout the United States. Eligibility criteria included mothers aged 18 years or older and infants born after 35 weeks' gestation with a birth weight of at least 2.25 kg. About 3000 infants were followed up from birth for 1 year, with 10 postnatal questionnaires mailed at approximately monthly intervals. The response rates for each postpartum survey varied from 63% to 83%. All data collection procedures were approved by the Food and Drug Administration institutional review board. The details of overall Infant Feeding Practices Study II design and response rates were presented elsewhere.[21]

OUTCOME MEASURES

The outcome measures were 4 weight measurements reported on the 3-, 5-, 7-, and 12-month surveys. Mothers were asked at each of these surveys what was their infant's weight measured at the most recent doctor's visit and visit date. Because weights reported on each survey were measured at different times across infants, age at weight measurement varied from infant to infant. To limit reporting errors, we calculated the z score of weight for age using the Centers for Disease Control and Prevention's reference and considered z scores of 5 or greater or −5 or less as biologically implausible.[22]

MAIN EXPOSURES

Because infant weight is a cumulative function of previous feedings over time, we first identified the time interval between 2 consecutive weight measurements and then aggregated all the feeding data available within each interval to tie each weight outcome to its corresponding feeding exposures. The 3 main exposure variables from each interval were milk feeding category, percentage of milk feedings given as breastmilk, and percentage of milk feedings given by bottle.

At each postpartum survey (about 1, 2, 3, 4, 5, 6, 7, 9, 10, and 12 months of age), mothers were asked how often they breastfed or fed pumped breastmilk as well as how often they fed formula and other types of milk in the past 7 days, which was used to categorize infants by whether they were fed at the breast, by expressed milk, or by formula and other types of milk. Aggregating all the feeding data within the same weight measurement interval, each infant was classified into 1 of the 6 mutually exclusive overall milk feeding categories: (1) Breastfed only; (2) Breastfed and human milk by bottle; (3) Breastfed and nonhuman milk by bottle; (4) Human milk by bottle only; (5) Human and nonhuman milk by bottle; and (6) Nonhuman milk by bottle only.

For the percentage of milk feedings given as breastmilk or by bottle, we first calculated the percentage of total milk feedings that were of the breast (BF%); expressed breastmilk (EBM%); or nonhuman milk (NHM%) including formula, cow's, or other milk at each survey (BF% + EBM% + NHM% = 100%). We then calculated the mean proportion of milk feedings as breastmilk (BF% + EBM%) or by bottle (EBM% + NHM%) during each interval. Both breastmilk and bottle-feeding proportions were further classified as less than 33%, 33% to 66%, and greater than 66% to represent low, medium, or high frequency of milk feedings as breastmilk or given by bottle.

OTHER MEASURES

To control for potentially confounding effects, we adjusted for the following factors in our multilevel analysis: maternal age; race/ethnicity; maternal education; percentage of poverty; marital status; parity; postpartum participation in the Special Supplemental Nutrition Program for Women, Infants, and Children program; prepregnancy body mass index (calculated as weight in kilograms divided by height in meters squared); infant sex; gestational age; age at solid food introduction; average number of sweet drinks consumed per day during the first half year (including juice drinks, soft drinks, soda, sweet tea, Kool-Aid, etc); and birth weight. Percentage of poverty was defined as a ratio of household income to the poverty threshold by household size. Prepregnancy body mass index was based on maternal recall during the prenatal survey. Age at solid food introduction was defined as the infant's age when any solid food was first reported on any of the monthly surveys. Birth weight was obtained from a short telephone interview with prenatal respondents within a week after birth. Except for gestational age, age at solid food introduction, sweet drinks consumption, and birth weight, all other confounding factors were adjusted using categorical variables as shown in **Table 1**.

STATISTICAL ANALYSIS

Neonatal questionnaires were available from 3033 mothers. Of these, 13% (n=392) did not complete the 3-, 5-, 7-, and 12-month surveys; 6% (n=184) reported fewer than 3 out of 5 possible weight measurements; 1% (n=41) reported biologically implausible weight; 2% (n=75) had an invalid visit date for the weight measurement; 4% (n=126) reported smaller weight in the subsequent survey; 1% (n=38) had missing data on feeding exposures; and 9% (n=278) had missing data on covariates. This yielded a final sample of 1899 mother-infant pairs with a total of 5719 observations from 4 weight measurement intervals.

Individual growth curve models were developed for multilevel analysis and specifically designed for exploring longitudinal data on individual changes over time.[23] Using this approach, we applied the MIXED procedure in SAS (SAS Institute) to account for the random effects of repeated measurements.[24] To specify the correct model for our individual growth curves, we compared a series of MIXED models by evaluating the difference in deviance between nested models.[23] Both fixed quadratic and cubic MIXED models fit our data well, but we selected the fixed quadratic MIXED model because the addition of a cubic time term was not statistically significant based on a log-likelihood ratio test. We first modeled infant weight as a function of corresponding milk feeding categories. This model estimated linear slopes of weight gain for each feeding category with final estimates adjusted for the potential confounding factors listed previously. Infant age at weight measurement was the time variable, and age squared was the quadratic term included in the model. Because milk feeding categories varied from time to time, we entered them into the model as a time-varying covariate to allow the linear effect of milk feedings to vary with age. As such, the model accommodates infants who were fed in one category for one period but another category for a different period.

We then modeled infant weight as a function of proportions of milk feedings given as breastmilk or by bottle with both terms entered simultaneously into the model as continuous variables. Because the association of weight gain with proportion of bottle-feedings might vary by proportion of breastmilk feedings, we added a product term between these 2 continuous variables in the model to test the significance of its interaction. We also categorized these 2 proportions into 3 groups (<33%, 33%-66%, and >66%) and conducted a log-likelihood ratio test for the nested models with and without all 2-way interactions between them. Because both interaction tests suggested a significant interaction between type of milk and feeding mode ($P < .001$), we conducted stratified analysis to examine the association of weight gain with proportion of milk feedings either as breastmilk or by bottle separately. Specifically, for each level of bottle-feedings proportion, we examined monthly weight gain by 10% increments in breastmilk-feedings proportion; for each level of breastmilk feedings proportion, we examined monthly weight gain by 10% increments in bottle-feedings proportion. To further separate the effects of bottle use from type of milk, we also estimated the monthly weight gain by proportion of bottle-feedings among infants fed only breastmilk as well as monthly weight gain by proportion of breastmilk feedings among infants fed only by bottle. All the data analyses for this study were conducted using SAS software version 9.2 (SAS Institute Inc).

RESULTS

Most of the study sample was aged 25 to 34 years, white, married, and had education beyond high school (Table 1). Approximately half were overweight or obese prior to pregnancy and one-third was participating in the Special Supplemental Nutrition Program for Women, Infants, and Children program. Although infant weight was reported at 3, 5, 7, and 12 months, it was measured at an average of 10, 18, 28, and 52 weeks, respectively.

Table 2 shows weight gain by corresponding feeding categories from the same interval. Not counting groups 4 and 5, which had very small sample sizes, infants fed with nonhuman milk by bottle only (group 6) had the largest weight gains at 3 to 5 months, >5 to 7 months, and >7 to 12 months. Infants who were breastfed and fed nonhuman milk (group 3) had rates of weight gain intermediate between those who were breastfed only (group 1) and those who were only fed nonhuman milk (group 6) in each of these age ranges.

To summarize the estimates for fixed-effect parameters from the MIXED modeling in an easy way to interpret, we present linear monthly weight gain for each feeding category compared with infants fed at the breast only (**Table 3**). Compared with infants fed at the breast only, infants fed only by bottle gained 71 or 89 g more per month when fed nonhuman milk only ($P < .001$) or expressed human milk only ($P = .02$), but they gained only 37 g more per month when fed both expressed human milk and nonhuman milk ($P = .08$). Infants fed both at the breast and by bottles of expressed human milk gained similar to infants fed at the breast only, whereas infants fed both at the breast and by bottles of nonhuman milk gained 45 g more per month ($P < .001$).

Table 1. Characteristics of Analytical Sample of 1899 Mother-Infant Pairs

Characteristic	%
Maternal age, y	
18-24	16.01
25-29	33.65
30-34	31.60
≥ 35	18.75
Race/ethnicity	
White	86.99
Black	3.32
Hispanic	5.21
Other	4.48
Education level	
≤High school	18.11
Some college	36.23
College graduate	45.66
Household income as percentage of poverty level	
<185%	36.55
185%-350%	37.02
>350%	26.43
Married	
No	15.90
Yes	84.10
Parity	
Primaparous	28.33
Multiparous	71.67
Postpartum WIC participation	
Yes	33.18
No	66.82
Prepregnancy body mass index, kg/m^2	
Underweight (<18.5)	3.95
Normal (18.5-24.9)	45.97
Overweight (>25.0-29.9)	25.07
Obese (≥30.0)	25.01
Infant's sex	
Male	48.18
Female	51.82
Gestational age, mean (SD), wk	39.31 (1.25)
Infant age at first introduction of solid food; mean (SD), wk	22.95 (8.91)
Sweet drinks consumed per day during the first half year, No.	0.02 (0.11)
Infant weight reported from each survey, mean (SD), kg	
At birth	3.48 (0.46)
3 mo (actual measurement age=10.01±2.28 wk)	5.55 (0.81)
5 mo (actual measurement age=18.29±2.40 wk)	6.81 (0.93)
9 mo (actual measurement age=27.65±2.70 wk)	7.88 (1.05)
12 mo (actual measurement age=52.01±3.62 wk)	9.59 (1.22)

Abbreviation: WIC, Special Supplemental Nutrition Program for Women, Infants, and Children.

The results from a main-effects model with both breastmilk-feedings proportion and bottle-feedings proportion considered as primary exposure variables indicated that a 10% increase in the proportion of breastmilk feedings was associated with a 3.6-g decrease in weight gain per month ($P = .07$), whereas a 10% increase in proportion of bottle-feedings was associated with a 4.1-g increase in weight gain per month ($P = .05$). Because of the significant interactions between feeding mode and type of milk, we stratified the analysis by examining their effects separately (**Table 4**). Among those with more than 66% of feedings by bottle, a 10% increment in the proportion that were of breastmilk was associated with a 5.9-g decrease in monthly weight gain. In contrast, infants gained 8 g more per month for each 10% increment in the proportion of

Table 2. Crude Gain in Weight (g/mo) by Corresponding Feeding Categories at Each Weight Measurement Interval for 1899 Infants

Group No./Feeding Category	Birth to 3 mo		>3 to 5 mo		>5 to 7 mo		>7 to 12 mo	
	No.	Mean (SD)	No.	Mean (SD)	No.	Mean (SD)	No.	Mean (SD)
1/Breastfed only	333	937 (299)	211	640 (282)	191	433 (177)	128	275 (167)
2/Breastfed and human milk by bottle	369	916 (286)	326	614 (366)	214	452 (172)	102	280 (114)
3/Breastfed and nonhuman milk by bottle	442	896 (287)	311	686 (348)	244	496 (258)	288	319 (124)
4/Human milk by bottle only	13	1024 (263)	9	634 (147)	6	561 (156)	3	438 (92)
5/Human and nonhuman milk by bottle	39	953 (273)	26	678 (588)	19	590 (245)	9	304 (71)
6/Nonhuman milk by bottle only	377	913 (270)	459	742 (348)	467	576 (298)	468	346 (170)

Table 3. Multilevel Analyses of Linear Monthly Weight Gain for Each Feeding Category Compared With Infants Fed at Breast Only for 1899 Infants[a]

Group No./Feeding Category	No.	Weight Gain, g/mo	95% CI
1/Breastfed only (reference)	936	0	
2/Breastfed and human milk by bottle	1108	10.11	−8.72 to 26.88
3/Breastfed and nonhuman milk by bottle	1518	45.15	30.00 to 60.30
4/Human milk by bottle only	34	88.83	13.19 to 164.47
5/Human and nonhuman milk by bottle	107	37.18	−5.06 to 79.42
6/Nonhuman milk by bottle only	2016	71.25	56.03 to 86.47

[a] The estimates were obtained after adjusting for maternal age; race/ethnicity; education; household income; marital status; parity; postpartum Special Supplemental Nutrition Program for Women, Infants, and Children program participation; prepregnancy body mass index; infant sex; gestational age; birth weight; age at solid food introduction; and sweet drinks consumption.

Table 4. Multilevel Analyses of Associations of Weight Gain With Increment in Proportion of Milk Feedings Either as Breastmilk or by Bottle for 1899 Infants[a]

	No.	Mean	95% CI
Proportion of Bottle Feedings	**Weight Gain by Every 10% Change in Proportion of Breastmilk Feedings, g/mo**		
Low (<33%)	2730	−15.38	−26.95 to −3.77
Medium (33%-66%)	495	0.75	−9.59 to 11.09
High (>66%)	2494	−5.89	−10.42 to −1.36
Proportion of Breastmilk Feedings	**Weight Gain by Every 10% Change in Proportion of Bottle-feedings, g/mo**		
Low (<33%)	2287	−0.19	−17.78 to 17.38
Medium (33%-66%)	398	−8.13	−22.69 to 6.43
High (>66%)	3034	8.08	4.45 to 11.71

[a] The estimates were obtained after adjusting for maternal age; race/ethnicity; education; household income; marital status; parity; postpartum Special Supplemental Nutrition Program for Women, Infants, and Children program participation; prepregnancy body mass index; infant sex; gestational age; birth weight; age at solid food introduction; and sweet drinks consumption.

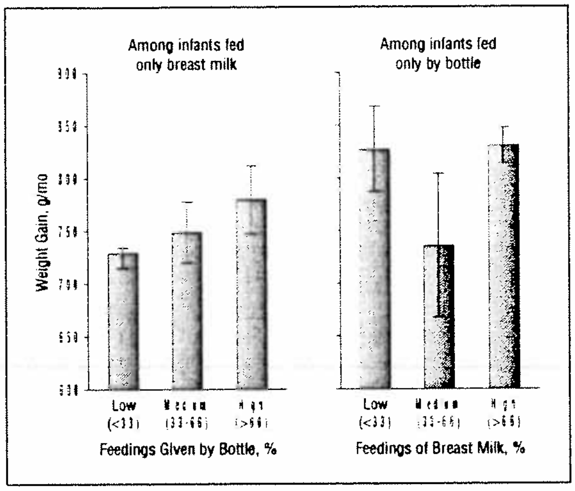

Figure. Mean and standard errors of monthly weight gain after adjusting for maternal age; race/ethnicity; education; household income; marital status; parity; postpartum Special Supplemental Nutrition Program for Women, Infants, and Children program participation; prepregnancy body mass index (calculated as weight in kilograms divided by height in meters squared); infant sex; gestational age; birth weight; age at solid food introduction; and sweet drinks consumption.

bottle-feedings among those who received at least two-thirds of their feedings with breastmilk.

Because type of milk and feeding mode were confounded by each other, examining bottle effects among infants fed by breastmilk only and examining breastmilk effects among infants fed by bottle only would be useful to tease out this confounding effect (**Figure**). Among infants fed by breastmilk only, weight gain increased from 729 g per month at low bottle-feedings to 780 g per month at high bottle-feedings. However, the relationship between weight gain and percentage of breastmilk feedings among infants fed by bottle only was U-shaped.

COMMENT

Our study suggests that bottle-feeding, aside from the type of milk used, might be an independent factor associated with infant weight gain. Regardless of milk type in the bottle, bottle-feeding might be distinct from feeding at the breast in its effect on infants' weight gain.

The mechanisms behind breastfeeding and childhood obesity are unclear. In addition to the biological mechanism of unique properties of breastmilk, such as leptin and adiponectin found in human milk,[25-27] the ability of breastfed infants to self-regulate their energy intake might be another possibility. Infants might play a more active role in determining their intake when feeding at the breast. Mothers who breastfeed might also develop a feeding style that is less controlling.[28] On the contrary, the duration and amount of bottle-feeding more likely depend on the caregivers' decisions, which are often based on visual observations of the remaining milk in the bottle with encouragement to finish the bottle.[29,30] In addition, the variations in the taste and nutrient content within each breastfeeding episode (much higher fat content toward the end) might also serve as a physiological signal for babies to stop suckling. This variation does not occur with bottle-feeding. Thus, infants frequently fed by bottles may gradually lose their ability to self-regulate and ultimately gain weight more rapidly than those fed at the breast.

Giving expressed breastmilk provides benefits when direct breastfeeding is impossible, but breastfeeding and breastmilk feeding might be fundamentally different. In addition to caregivers' control of feeding expressed breastmilk, some of the immune components, vitamins, and fat might be lost during the storage and handling.[31] Nevertheless, feeding expressed breastmilk is certainly as close to breastfeeding as one can get when breastfeeding is infeasible. We found that infants categorized as "breastfed and human milk by bottle" grew similarly to those fed only at the breast, but infants categorized as "breastfed and nonhuman milk by bottle" grew more rapidly (Table 3). This suggests that supplementing breastfeeding with expressed breastmilk would be preferable to supplementing breastfeeding with nonhuman milk. Thus, breastfeeding mothers who need to feed their infant by bottle should be supported for expressing breastmilk.

Infants categorized as consuming "human milk by bottle only" and "nonhuman milk by bottle only" gained more weight than infants fed at the breast only, but there was no such bottle effect observed among infants categorized as consuming "human and nonhuman milk by bottle." This might be owing to the fact that infants in this mixed feeding category were more likely fed at the breast previously than the other 2 groups (data not shown). Our previous study suggests that infants fed at the breast develop a better self-regulation of milk intake, which may be carried over even after feeding is transitioned from breast to bottle.[32] Similarly, mothers who previously breastfed might better recognize infants' cues of hunger and satiety, which may last even after they stop breastfeeding.[28]

Stratified analysis allowed us to examine the effects of bottle use and breastmilk feeding separately. While weight gain was negatively associated with breastmilk feeding, it was positively associated with bottle-feeding when the proportion of breastmilk feedings was high (Table 4). The dose-response relations between weight gain and bottle use among infants fed only breastmilk further implies a potential risk of bottle-feeding for rapid weight gain during infancy (Figure).

There are several limitations of this study. First, because black and Hispanic mothers were underrepresented in the study population, our results may not be applicable to the entire US population. Second, because both weight measurement and feeding practice were reported by mothers, reporting errors may have occurred. However, the recall period was relatively short and it is unlikely that the misclassification of feeding exposures depended on weight outcomes given the longitudinal design of this study. For nondifferential misclassification, the reporting errors would bias the results toward the null value.[33] Third, the final analytical sample excluded 278 cases owing to missing data on covariates. However, our sensitivity analysis based on the full sample without controlling for these covariates in the models indicated similar results. Fourth, despite our statistical efforts to minimize the confounding effects, we may not have completely separated out the effects of bottle use from the type of milk because of the complexity of infant feeding and observational nature of this study. Lastly, a large number of infants were fed completely at the breast or completely with nonhuman milk, so the continuous results presented in Table 4 could be driven by patterns in these extreme groups. However, we eliminated these infants to limit the contribution of extreme values to the estimates but observed similar findings.

The strengths of this study include that the Infant Feeding Practices Study II was the largest longitudinal study on infant feeding practices in the United States, the reporting bias for the feeding variables was minimized by a short 7-day retrospective recall at a monthly interval, and the residual effects of other variables were limited by controlling a wide range of potentially confounding variables in the multilevel analysis. Of the many advantages of multilevel analyses, individual growth modeling accounts for correlated data from repeated weight measurements as well as the changes in feeding categories from time to time on an individual basis.[34,35]

In conclusion, regardless of milk type in the bottle, bottle-feeding might be distinct from breastfeeding in its effect on infant weight gain. Feeding at the breast needs to be the first feeding choice for babies. When feeding at the breast is not always feasible, supplementing breastfeeding with expressed breastmilk is a good alternative, but special attention is needed for infants' internal feeding cues while bottle-feeding.

Accepted for Publication: November 19, 2011.

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Author Contributions: Dr Li had full access to all the data in the study and takes full responsibility for the integrity of the data and the accuracy of the analysis. *Study concept and design:* Li, Fein, and Grummer-Strawn. *Acquisition of data:* Li, Fein, and Grummer-Strawn. *Analysis and interpretation of data:* Li, Magadia, Fein, and Grummer-Strawn. *Drafting of the manuscript:* Li and Magadia. *Critical revision of the manuscript for important intellectual content:* Li, Fein, and Grummer-Strawn. *Statistical analysis:* Li, Magadia, and Grummer-Strawn. *Obtained funding:* Grummer-Strawn. *Administrative, technical, and material support:* Li, Fein, and Grummer-Strawn. *Study supervision:* Grummer-Strawn.

Financial Disclosure: None reported.

Funding/Support: The Infant Feeding Practices Study II was funded by the Food and Drug Administration, Centers for Disease Control and Prevention, Office of Women's Health, National Institutes of Health, and Maternal and Child Health Bureau in the US Department of Health and Human Services.

Disclaimer: The findings and conclusions in this article are those of the authors and do not necessarily represent the official position of the Centers for Disease Control and Prevention or the Food and Drug Administration.

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