

**The Use of NCHS and CDC Growth Charts in
Nutritional Assessment of Young Infants**

A White Paper

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by

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In May 2000, the Centers for Disease Control and Prevention (CDC) released a revision of the NCHS 1977 childhood growth charts. These revised growth charts have become the standard of care for assessing the appropriateness of growth for the approximately 82 million children under the age of 20 in the United States. Because growth during infancy is directly determined by good nutrition, it is not surprising that growth charts are used to evaluate the adequacy and appropriateness of breastmilk substitutes. In this paper, we focus on similarities and differences between the NCHS 1977 growth charts and the revised CDC 2000 charts, with particular emphasis on the portion of the curves from birth to 6 months of age. We also will discuss various statistical issues in their use and interpretation.

The basic characteristics of the growth curves were not altered in the revised growth curves. Both sets of curves cover the same indicators (weight-for-age, length-for-age, weight-for-length, and head circumference-for age). Both sets of curves are sex-specific. Both sets of curves are expected to be used for all U.S. populations regardless of race/ethnicity, parental anthropometry, or infant feeding modality. Both sets of curves represent "references" rather than "standards," in that they should be interpreted as the actual growth of other infants in the U.S., not how infants optimally should grow. Both sets of curves represent attained size, and do not describe rates of growth as might be represented in incremental or longitudinal growth charts. Finally, both sets of curves utilize percentile rankings to describe the relative size of a given child.

The most important change in the infant growth charts (aged 0-35 months), was that the population that the charts were based on was changed from a local, relatively homogeneous study to a nationally representative study. In the nationally representative data, the infants included come from a broader spectrum of racial/ethnic groups, socioeconomic backgrounds, and modes of infant feeding.

Data Sources

The data used to construct the NCHS 1977 growth charts [Hamill et al. 1977, 1979] and their revision as CDC 2000 charts [Kuczmarski et al. 2000, 2002] emanated from quite different studies. The infant charts in 1977 were developed using longitudinal data from the Fels Research Institute, collected in Yellow Springs, Ohio between 1929 and 1975 [Roche 1992].

While the Fels data had many technical strengths as a study of child growth, its sample was acknowledged to be quite limited in geographic, cultural, socioeconomic and genetic variability.

Basic characteristics of the Fels Study are summarized in Table 1.

Data for the infant portions of the CDC 2000 charts were derived from a number of different sources, including the National Health and Nutrition Examination Surveys (NHANES), National Natality Files, Natality Files in Wisconsin and Missouri, the CDC Pediatric Nutrition Surveillance System, and the Fels Research Institute child growth study.

Third National Health and Nutrition Examination Survey. The primary source of data for the infant charts up to age 6 months was NHANES III. Table 1 shows the basic characteristics of the NHANES III alongside those of the Fels Study. In designing the NHANES III, the

National Center for Health Statistics intentionally oversampled children under the age of six years in order to generate data for a revised set of growth charts, based on a representative U.S. sample [NCHS 1994]. However, because the NHANES III did not include measurements of infants younger than 2 months of age, additional data were needed to create growth curves beginning at birth. For each growth indicator, different datasets were used to supplement the NHANES III data in extending the curves downward to birth (Figure 1).

National Natality Files. In constructing weight-for-age curves, the distribution of birthweights from the national file of birth certificates was used. Only birth years corresponding to the years in which NHANES children 0-3 years old would have been born were included (1968-80 and 1985-94). In total, 82,375,312 births with birthweight ≥ 1500 grams were included. To ensure that inclusion of this data point would not introduce a disjunction in the curves, comparison was made to the birthweights of children included in NHANES III, for whom the survey data were linked to birth certificate data on an individual basis. No substantive differences in the birthweight distribution were noted. There is no standardization of procedures for measuring birthweight in hospitals and a wide variety of equipment are employed. However, because weight is a relatively straightforward measure, this was not considered to be a critical data quality problem.

Natality Files in Wisconsin and Missouri. In constructing length-for-age and weight-for-length curves, birth length data from the birth certificate files from these two states were used. National Natality Files do not include birth length. In total, 869,128 births with a birthweight ≥ 1500 grams were included. The distribution of birthweights in these two states were compared

to birthweights in the national data and found to be quite similar, indicating the appropriateness of including them in the curves. There is no standardization of procedures for measuring birth length in hospitals in either Wisconsin or Missouri and a wide variety of equipment are employed. The data quality of this measure is therefore problematic, but no alternative datasets were identified.

Pediatric Nutrition Surveillance System. After initial construction of the growth curves, the curves were tested against a number of external datasets, including the Chicago growth study [Binns et al 1996], the WHO breastfed dataset [WHO 1994, 1995], and the Pediatric Nutrition Surveillance System data [CDC 1998]. While growth patterns in the external datasets generally matched those of the new curves, a noticeable difference was observed in the length-for-age curves between birth and 6 months—the rate of increase in length between birth and 3 months was consistently slower than observed in all three external datasets. Upon review, it was believed that the lack of length data between birth and 3 months (NHANES III only had data for ~35 two-month-old infants) was responsible for this aberration. As a result, length data from the CDC Pediatric Nutrition Surveillance System (PedNSS) were also included between birth and 5 months of age.

Data in the PedNSS are collected in federally funded public health clinics across the U.S., primarily from the WIC program. Because the PedNSS is not representative of the U.S. population and comes from low-income children only, a limited subset of the PedNSS was included. This subset was selected by including only clinics in which the mean, standard deviation, and skewness of both length and weight closely matched that found in the NHANES

datasets for infants 3 to 11 months. A total of 213 PedNSS clinics were selected, having a total of 14,846 observations between birth and 5 months. There is no national program of standardization of the weights and heights in PedNSS, although WIC staff are regularly trained in anthropometric techniques, which often include standardization exercises. Because only clinics matching the national distribution were included, the resulting data quality in the PedNSS data used for the growth charts is not considered to be problematic.

Fels Research Institute. In constructing the head circumference-for-age curves, no large datasets containing head circumference at birth were identified other than in the Fels data, described above and in Table 1. Therefore, the head circumference data at birth from Fels were utilized in constructing these curves.

First and Second National Health and Nutrition Examination Survey. While NHANES I and NHANES II did not contribute any data in the age range of birth to 6 months, they did contribute data for construction of the infant curves at older ages. Because the curves were smoothed across age, the data points at older ages have some influence on the final placement of the growth curves for the younger infants. NHANES II (conducted 1976-80) began at age 6 months, with approximately 30 observations per single month of age [McDowell et al 1981]. NHANES I (conducted 1971-74) began at 12 months of age, with approximately 25 observations per single month of age [NCHS 1973]. Due to the use of sample weights, the relative contribution of NHANES II and III is approximately equal at 6-11 months of age and the relative contribution of NHANES I, II, and III is approximately equal at 12-35 months of age. All three

surveys were nationally representative at the time they were conducted. As a result, the earlier surveys include a smaller percent who were breastfed than did the NHANES III.

Curve fitting

Both the NCHS 1977 and the CDC 2000 curves were developed by fitting parametric or semi-parametric curves to the chosen indicators as a function of age (or length in the case of weight-for-length). However, the chosen procedures were somewhat different for the two sets of curves, as will be described in this section.

Percentile curves and z-scores

The original publication of the NCHS 1977 charts included only percentile representations of the growth parameters, presenting only 7 “main percentiles” at the 5th, 10th, 25th, 50th, 75th, 90th, and 95th percentiles. These percentile curves are considered the official NCHS growth curves and were used for all the graphic representations of the growth charts used clinically up until 2000.

Subsequent to the publication of the growth charts, Dibley and colleagues [1987a] published a “normalized” version of the NCHS reference for the weight and length-based indices. Briefly, these authors calculated the distance between the published 5th and 50th percentiles and divided by 1.65 to estimate the standard deviation of a normal distribution that would exactly match the smoothed 5th and 50th percentiles. Similarly, the distance between the 10th and 50th percentiles was divided by 1.28 and the distance between the 25th and 50th percentiles was divided by 0.67. These three estimates of the standard deviation below the median were averaged to generate the standard deviation of the lower half of a normal

distribution. In a similar way, the standard deviation of the upper half of a normal distribution was estimated using the published 95th, 90th and 75th percentiles. Because length-for-age is essentially symmetrically distributed, the upper and lower standard deviations were averaged to create a truly normal distribution. Standard deviation scores, or z-scores could then be computed for any given measurement, using the lower standard deviation below the median and the upper standard deviation above the median. Also, any percentile, not just the 7 main percentiles could be calculated, although the percentiles would not exactly match the originally published ones, except at the 50th percentile. This "normalized" reference, was incorporated into many software packages, including CASP, ANTHRO, and Epi-Info and is generally used in any computer application of the growth charts. Furthermore, the WHO adopted this normalized reference as the international growth reference [WHO 1978].

Only one version of the CDC 2000 growth charts exists, and the percentile and z-score representations of them are identical. The statistical smoothing procedures first generated smoothed percentile curves, but then computed normalization parameters to estimate these smoothed curves. The published centile curves were then based on the normalized parameters, not on the first stage smoothing, in order to ensure an exact match between the two representations. While the publication of the growth charts and the graphics made available only include "major percentiles" (3rd, 5th, 10th, 25th, 50th, 75th, 90th, 95th and 97th), the parameter estimates are also published such that any desired centile can be calculated and graphed.

Whereas the normalized NCHS curves used distinct values of the standard deviation above and below the median to account for a slightly right skewed weight distribution, the CDC 2000 curves accounted for skewness in a smoother fashion. The selected measures were first transformed into a symmetric distribution using a Box-Cox transformation [Box and Cox 1964].

The power was denoted by a parameter "L". Then the mean "M" and the coefficient of variation "S" were estimated for this transformed distribution. The L, M and S parameters were estimated as the best solution (minimum sum of squared errors) to a system of equation, based on the nine previously smoothed empirical centile curves as described in the next section. This "LMS" methodology was applied to all of the curves to generate both z-scores and percentiles [Cole 1988, 1990; Cole and Green 1992].

Statistical smoothing.

For both sets of curves, the first step of smoothing consisted of empirically calculating the major percentile values among all the observations at each distinct age (5th, 10th, 25th, 50th, 75th, 90th, and 95th). In the NCHS 1977 curves, the ages were simply those used in the original study (Birth, 1, 3, 6, 9, 12 months, etc.) For weight-for-length curves, the data were grouped into 2-centimeter-wide intervals for computation of the observed main percentiles. A curve was then fit through each of the points of a given centile. The curve was a cubic spline, defined as a series of cubic polynomials in which the polynomials must meet at the "knots" and in which the first and second derivatives of the polynomials to the left and right of the knot must match. For example, in the case of weight-for-age, knots were placed at birth, 6 months, 18 months and 36 months, so a cubic polynomial was fit for the data between birth and 6 months, another cubic polynomial was fit for the data between 6 and 18 months, and a third was fit for the data between 18 and 36 months. These polynomials were fit with the constraint that the weights had to match at 6 and 18 months and the first and second derivatives had to be equal at 6 and 18 months. The placement of knots was somewhat arbitrary, but followed a few key principles: 1) the authors strove to use as few knots as possible, given that growth is generally quite smooth, 2) knots

should be placed where the curve showed the most change, particularly where second and third derivatives changed sign, and 3) knots were placed at endpoints. The same knots were used for all 7 centile curves for a given chart to improve parallelism between the curves. Knots for head circumference were the same as for weight-for-age. Knots for length-for-age were at birth, 9, 24 and 36 months. Knots for weight-for-length were at 49, 72 and 90 cm.

In the CDC 2000 curves, infants were grouped together in one-month age increments up to 12 months of age and in 2-centimeter length increments for the weight-for-length curves. Again, observed main percentiles were calculated for each age or length group, although 3rd and 97th centiles were also included (3rd, 5th, 10th, 25th, 50th, 75th, 90th, 95th and 97th). For all three curves indexed by age, the empirical centiles were smoothed using a family of 3-parameter linear models that have been used previously to describe infant growth [Guo et al 1988, 1990, 1991]:

$$\text{Weight } (t) = a + b * \ln(t+0.5) + c (t+0.5)^{0.75}$$

$$\text{Length } (t) = a + b * \ln(t+1) + c (t+1)^{0.5}$$

$$\text{Head circum } (t) = a + b * \ln(t+2) + c (t+2)^{0.5}$$

Where a , b , and c are independent parameters that determine the placement of each curve and t represents age in months. The weight-for-length centiles were smoothed jointly with the weight-for-stature centiles of older children using a 5th-degree polynomial. For the weight-for-age and length-or-age curves, additional smoothing steps were taken to merge them with the corresponding weight-for-age and stature-for-age curves for children two years of age and older, but because these steps have minimal impact on the curves under 12 months of age, we will not describe these steps here.

Advantages and disadvantages

The revised CDC 2000 growth charts are considered to be a significant improvement over the NCHS 1977 charts for several reasons. Most importantly, the 2000 charts are representative of all (non-VLBW) infants in the U.S., not a select group of middle-class white infants in a small U.S. community. Second, although the extent of breastfeeding in the NHANES III sample is not high (in terms of either duration or exclusivity), it is certainly greater than was the case for the Fels sample and thus comes closer to the growth of breastfed infants than did the previous curves. The CDC 2000 curves were created by pooling the data from breastfed and non-breastfed infants alike. In comparing the old and new curves against a dataset of breastfed infants compiled by the WHO, the new curves match the pattern of growth for breastfed infants better on length-for-age and weight-for-length, but not for weight-for-age. Third, the percentile curves used clinically and the z-score curves more often used in research are identical in the CDC 2000 curves, but were not in the NCHS 1977 curves.

One disadvantage of the revised CDC 2000 curves is the pooling of multiple datasets to construct the curves. Although the growth charts working group took great care to ensure the comparability of the datasets being pooled, we cannot rule out the possibility that the shape of the curves was affected by using different datasets at different ages.

Both the NCHS 1977 and the CDC 2000 curves are considered references, not standards. Other than the exclusion of VLBW infants (<1500 g), no exclusions were made to limit the sample to healthy infants growing optimally. The curves potentially include infants who were inappropriately fed, had infectious or chronic diseases, or were growing up in substandard living conditions. If used simply as a point of reference for comparing different populations, this may

not be considered a disadvantage. But in evaluating the growth of infants, the use of reference curves could lead to inappropriate conclusions that a child is growing normally when he/she is not or is not growing normally when he/she is. Curves developed specifically to define healthy growth, as are being developed by the WHO, may be more appropriate to this purpose [WHO 1998; Victora et al. 1998].

Use of growth charts in the evaluation of infant formula

Group means and individual data.

As a reference that describes the growth of infants across the U.S., the growth charts can be used to compare aggregate data for groups of infants, or to assess the growth of individual children. In dealing with groups, population means or the percent falling beyond outer percentiles can be used. If the age of all the infants is the same, then the mean of the growth parameter itself can be computed, and this value compared to the growth charts. However, if ages vary, the growth parameters should first be converted to z-scores, before computing means (percentile values cannot be averaged) [Dibley 1987b]. Group means will have greater statistical power than will percentages that fall in the tails of the growth distribution, but fail to recognize aberrant growth that occurs in both directions. For example, if an infant formula leads to increased weight in some children (because of a higher fat content) but decreased weight in others (because of intolerance to the formula), the mean weight for the population may appear perfectly normal.

Meaningful increments in daily growth

Neither the NCHS 1977 nor the CDC 2000 growth references included incremental growth charts, so differences in individual growth that is 3 g/dy faster for one child than for another cannot be said to be meaningful or not meaningful. For this purpose, incremental growth charts are needed [Roche and Himes 1980; Baumgartner et al. 1986]. However, such comparisons can be made for group means. While the definition of a "substantively important" difference between two groups is a subjective decision, a common rule of thumb is that two distributions are substantively different if they differ by more than one-fifth of a standard deviation from each other. To illustrate the impact of this magnitude of difference, consider two populations normally distributed, the second shifted 0.2 SD to the left of the first. In this case 4.6% of the second population would fall below the 3rd percentile of the first, 7.5% would fall below the 5th percentile of the first, and 14.0% would fall below the 10th percentile of the first. Thus, a one-fifth standard deviation shift in the distribution corresponds roughly to a 50% increase in the percent of the population falling in the tails (i.e. what we normally consider aberrant growth).

For boys in the CDC 2000 growth curves, the standard deviation of weight at 5.5 months of age is approximately 0.850 kg below the median and 0.966 kg above the median (using Dibley's method for calculation of the standard deviation). This difference in standard deviations implies that somewhat larger differences in growth above the 50th percentile might be tolerated, because of the right skewness in weight. However, the discrepancy is not large. Also, because group means will tend to be closer to the 50th percentile, the distinction between the upper and standard deviation is in most cases unimportant. For our purposes, it is reasonable to average the standard deviations (0.908). Thus, for two groups starting at birth with a mean

roughly at the 50th percentile, an average daily gain of 1.1 g/dy lower in one group than the other (.908/167 days * 0.2) would yield a one-fifth standard deviation lower mean at 5.5 months, which is arguably substantively important. For girls, the corresponding value would be 1.0 g/dy. In summary, gender-specific criteria do not appear to be warranted, but the 1988 recommendation by CON/AAP to only consider differences greater than 3 g/dy appears to be too generous.

The above calculations were made assuming that the infant groups were followed from birth to 5.5 months. If the age at follow-up were younger than this, the standard deviation would be smaller, as would the number of days that the total weight gain was averaged over. In general, the difference in average daily gain that is substantively important would be higher than that calculated above, but the calculations should be redone to compute the actual rate of gain pertinent to the study design. If, on the other hand, the age at study enrollment were later but follow-up were still to occur at 5.5 months, the substantive differential rate of daily weight gain would clearly rise, simply because the number of days of follow-up over which the total weight gain is to be averaged would be smaller. Again, the actual differential in rate of gain would need to be recalculated for the specific study design. Put differently, it is the difference in attained weight at the end of the study that is more relevant in determining substantive differences between two groups than is the average daily rate of gain.

Use of indices other than weight

The Institute of Medicine has concluded that there is significant evidence that short stature is caused by inadequate nutrition and would respond to appropriate nutritional intervention [Food and Nutrition Board, 1996]. They also conclude that, although evidence is

not as clear, head circumference is also affected directly by nutritional factors, especially in the first 6 months of life. It is not known whether these tracking of length and head circumference indices would behave differently from tracking of weight for purposes of detected differences in infant formulas, but these indices do appear to be alternatives and may provide additional information. The standard deviation of length at 5.5 months is 2.56 cm and 2.53 cm for boys and girls, respectively. The standard deviation of head circumference at 5.5 months is 1.35 cm and 1.30 cm for boys and girls, respectively. Again, separate criteria for boys and girls are probably not needed.

Use of z-scores in longitudinal studies

The z-score system directly accounts for gender and age differences in growth. Therefore, if z-scores are used, it is not necessary to analyze boys and girls separately [Dibley et al. 1987b]. Also, measurements taken at different ages can be converted to z-scores and then combined together for summary indices. Thus, the z-score system can greatly simplify the handling of growth data in longitudinal studies.

Summary

The revised CDC 2000 growth reference provides several important advantages over the previous NCHS 1977 reference. The new reference is considered the standard of care in pediatric practice in the U.S. However, the way in which the reference can be used is not dramatically altered from the older curves, and thus the transition from old to new should be relatively straightforward. When a new reference is available from the WHO based on the

growth of infants living in unconstrained environments and being fed according to international feeding recommendations, there may be reason to judge growth against this new reference.

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Figure 1. Reference Datasets: Birth to 36 Months

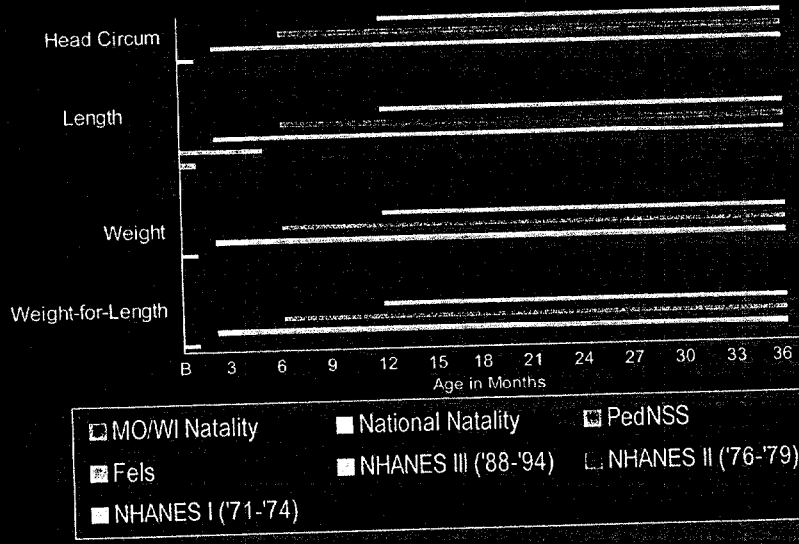


Table 1. Characteristics of the Fels Research Institute data used for construction of the NCHS 1977 growth charts and the third National Health and Nutrition Examination Survey use for construction of the CDC 2000 growth charts

Characteristic	NCHS 1977 (Fels Research Institute)	CDC 2000 (Third National Health and Nutrition Examination Survey)																																																										
Location	Within a convenient distance of Yellow Springs, OH	U.S. nationwide, non-institutionalized population																																																										
Study design	Longitudinal followup	Cross sectional survey																																																										
Years of data collection	1929-1975	1988-1994																																																										
Exclusion criteria	Triples excluded	VLBW (<1500 g) excluded																																																										
Socio-economic background	Middle class	Representative of U.S.																																																										
Racial/ethnic background	Caucasian	Representative of U.S. – matches census distribution for non-Hispanic white, non-Hispanic black, and Mexican American. Other racial groups subject to random variation.																																																										
Ages	Measurements made at Birth, 1, 3 and 6 months	Cross-section of population spanning 2 to 6 months of age.																																																										
Sample size	<p>867 infants total, number measured varies by indicator and age</p> <table border="1"> <thead> <tr> <th rowspan="2"></th> <th colspan="2">Length</th> <th colspan="2">Weight</th> </tr> <tr> <th>M</th> <th>F</th> <th>M</th> <th>F</th> </tr> </thead> <tbody> <tr> <td>Birth</td> <td>156</td> <td>142</td> <td>300</td> <td>296</td> </tr> <tr> <td>1 mo</td> <td>274</td> <td>251</td> <td>296</td> <td>281</td> </tr> <tr> <td>3 mo</td> <td>438</td> <td>426</td> <td>496</td> <td>482</td> </tr> <tr> <td>6 mo</td> <td>425</td> <td>409</td> <td>458</td> <td>438</td> </tr> </tbody> </table> <p>Sample sizes for head circumference similar to those for length</p>		Length		Weight		M	F	M	F	Birth	156	142	300	296	1 mo	274	251	296	281	3 mo	438	426	496	482	6 mo	425	409	458	438	<table border="1"> <thead> <tr> <th rowspan="2"></th> <th colspan="2">Length</th> <th colspan="2">Weight</th> </tr> <tr> <th>M</th> <th>F</th> <th>M</th> <th>F</th> </tr> </thead> <tbody> <tr> <td>2-2.99 mo</td> <td>--</td> <td>--</td> <td>38</td> <td>34</td> </tr> <tr> <td>3-3.99 mo</td> <td>89</td> <td>118</td> <td>89</td> <td>118</td> </tr> <tr> <td>4-4.99 mo</td> <td>104</td> <td>92</td> <td>104</td> <td>93</td> </tr> <tr> <td>5-5.99 mo</td> <td>96</td> <td>99</td> <td>95</td> <td>98</td> </tr> </tbody> </table> <p>Sample sizes for head circumference similar to those for weight</p>		Length		Weight		M	F	M	F	2-2.99 mo	--	--	38	34	3-3.99 mo	89	118	89	118	4-4.99 mo	104	92	104	93	5-5.99 mo	96	99	95	98
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Infant feeding pattern	Nearly all formula-fed	<table border="1"> <thead> <tr> <th></th> <th>Currently Breastfed (%)</th> <th>Exclusively Breastfed (%)*</th> </tr> </thead> <tbody> <tr> <td>2 mos</td> <td>56.3</td> <td>32.2</td> </tr> <tr> <td>4 mos</td> <td>37.3</td> <td>19.4</td> </tr> <tr> <td>6 mos</td> <td>27.9</td> <td>9.5</td> </tr> </tbody> </table> <p>* Exclusive breastfeeding rates based on retrospective reports in phase II only</p>		Currently Breastfed (%)	Exclusively Breastfed (%)*	2 mos	56.3	32.2	4 mos	37.3	19.4	6 mos	27.9	9.5
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