Use of a Body Proportionality Index for Growth Assessment of Preterm Infants

IRENE E. OLSEN, PhD, RD, LDN, M. LOUISE LAWSON, PhD, JAREEN MEINZEN-DERR, PhD, AMY L. SAPSFORD, RD, KURT R. SCHIBLER, MD, EDWARD F. DONOVAN, MD, AND ARDYTHE L. MORROW, PhD

Objective To evaluate the utility of weight-for-length (defined as gm/cm³, known as the “ponderal index”) as a complementary measure of growth in infants in neonatal intensive care units (NICUs).

Study design This was a secondary analysis of infants (n = 1214) of gestational age 26 to 29 weeks at birth, included in a registry database (1991-2003), who had growth data at birth and discharge. Weight-for-age and weight-for-length were categorized as small (<10th percentile), appropriate, or large (>90th percentile).

Results Statistical agreement between the weight-for-age and weight-for-length measures was poor (κ = 0.02 at birth, 0.10 at discharge; Bowker test for symmetry, P < .0001). From birth to discharge, the percentage of small-for-age infants increased from 12% to 21%, the percentage of small-for-length infants decreased from 10% to 4%, the percentage of large-for-age infants remained similar (<1%), and the percentage of large-for-length infants increased from 5% to 17%. At discharge, 92% of the small-for-age infants were appropriate or large-for-length, and 19% of the appropriate-for-age infants were large-for-length.

Conclusions Weight-for-age and weight-for-length are complementary measures. Weight-for-length or other measures of body proportionality should be considered for inclusion in routine growth monitoring of infants in the NICU. (J Pediatr 2009;154:486-91)
of body proportionality in addition to weight-for-age may be justified. We hypothesized that the categorization of weight growth status as small, appropriate, or large by these 2 methods would have modest to poor agreement, and that at discharge a significant proportion of infants classified as small-for-age would be considered appropriate or large weight-for-length.

METHODS

This study was a secondary analysis of infants cared for in Cincinnati’s 3 NICUs using an existing database, the National Institute of Child Health and Human Development (NICHD) Neonatal Research Network registry. This database (the “Cincinnati very low birth weight cohort”) includes all infants admitted to the NICUs within 14 days of birth who weighed 401 to 1500 g at birth between 1991 and 2003 (n = 3975). GA was based on obstetrical best estimate (using last menstrual period dates and prenatal ultrasound). Obstetrical GA was missing for 5 infants; in these infants, the Ballard score (from a neonatologist’s examination) was used. GA was presented in terms of completed weeks. The study design was approved by the Cincinnati Children’s Hospital Medical Center and Drexel University Institutional Review Boards.

Infants were excluded for factors expected to negatively affect growth status (total, n = 380), including mortality within the first 12 hours (n = 249), one or more major congenital anomalies (including central nervous system, congenital heart, gastrointestinal, or genitourinary defects and chromosomal abnormalities; n = 97), and intrauterine infection exposure (any TORCH infections, untreated maternal syphilis, or HIV; n = 37). Healthy multiples were not excluded, because these infants represent normal size variations in infants in the NICU. Infants were not excluded for postnatal factors, because our goal was to capture the postnatal change in size in NICU infants in our sample. After the foregoing exclusions, a total of 3595 infants were eligible for the analysis.

The sample was further restricted to 26 to 29 weeks GA at birth (n = 1750). This was because very low birth weight cohorts like this one overrepresent small-for-age infants over 29 weeks GA at birth, as reported previously. In addition, the sample was restricted to infants ≥26 weeks GA at birth because the Lubchenco growth curves start at 26 weeks.

Extreme outliers for weight and length measurements were excluded to avoid distortion of our growth outcome, as was done in previous growth studies. Extreme outliers were defined as values > 2 times the interquartile range (25th to 75th percentiles around the median) for each GA. A total of 27 extreme values were excluded (11 for weight or length at birth and 16 at discharge); however, 3 infants had 2 outliers each, and 9 infants also had missing data (eliminated in the next step). Outliers represented <1% of the data available for analyses at each time point and appeared to be due to measurement or recording errors, because either weight or length was affected for all but 2 cases, in which both weight and length were outliers based on GA.

The final sample included 1 214 infants who had weight and length measurements at birth and discharge from the NICU to home (n = 1075) or to another hospital (n = 80), or who died (n = 59). This end time point is referred to as “discharge” based on the majority of infants.

Assessment of Growth Status

Lubchenco growth curves were the only growth curves available for assessing weight-for-age and weight-for-length accommodating infants between 26 to 42 weeks GA, based on intrauterine growth data (vs postnatal growth data) from the same data set and presented in percentiles. We used these curves to categorize weight growth status at birth and at discharge.

WEIGHT-FOR-AGE (WEIGHT-FOR-GA). Using the Lubchenco weight-for-age growth curve, each infant’s weight at birth and discharge was plotted against GA and then categorized based on the percentile of weight-for-GA as small-for-age (if < the 10th percentile), appropriate-for-age (if between the 10th and 90th percentiles), or large-for-age (if > the 90th percentile).

WEIGHT/FOR-LONGTH³ RATIO-FOR-AGE (WEIGHT-FOR-LENGTH). The Lubchenco growth curves use weight/length³ ratio-for-age as the measure of body proportionality. The weight/length³ ratio was calculated as (weight divided by length cubed) * 100 (in gm/cm³) and then plotted against GA. At birth and discharge, each infant’s weight-for-length was categorized based on the percentile of weight/length³ ratio-for-age as small-for-length (if < the 10th percentile), appropriate-for-length (if between the 10th and 90th percentiles), or large-for-length (if > the 90th percentile).

Data Analysis

All data analyses were conducted using SAS 9.1 (SAS Institute Inc, Cary, North Carolina). Concordance coefficients (ie, κ statistics) and the Bowker test for symmetry were used to evaluate agreement and discordance (or lack of agreement), respectively, between the weight-for-age and weight-for-length methods. High agreement was defined as a κ ≥ 0.8. High agreement between the weight-for-age and weight-for-length methods would mean that these 2 methods categorize infant weight growth status similarly (eg, small infants are typically categorized as small by both methods). In turn, lack of agreement would mean that the 2 methods categorize infant weight growth status differently, and thus each provides different information about weight growth status. In Table 1, the center diagonal line, comprising the small/small, appropriate/appropriate, and large/large cells shows the infants in which there was agreement between methods.

RESULTS

Infant characteristics are presented as mean ± standard deviation, because variables were approximately normal except...
for GA at birth and the means and medians were equivalent. At birth, mean GA was 27.7 \pm 1.1 weeks, mean weight was 1054 \pm 218 g, and mean length was 36.3 \pm 2.7 cm. At discharge, mean GA was 35.5 \pm 3.1 weeks, mean weight was 2213 \pm 589 g, and mean length was 43.3 \pm 3.5 cm. The sample was 49.3% female and 68.3% Caucasian. Based on the Lubchenco weight cutoffs for the 90th percentile weight-for-age, our sample composed less than the expected 10% of large weight-for-age infants at birth (Table I); however, the Lubchenco weight cutoffs are higher than those of the newer Riddle growth curves, which are based on a more racially diverse sample of infants.5 Using the newer Riddle curves, our sample contained 11.8% large-for-age infants. (We could not use the Riddle curves for this study, because they do not include a weight-for-length curve.)

Comparison of Weight Growth Status Assessment Methods

**At Birth.** We found poor agreement at birth between the weight-for-age and weight-for-length methods of weight growth status assessment in assigning the small, appropriate, and large categories to the infants in our sample (κ = 0.1; Bowker test, P < .0001; Table I). Among the infants who were small-for-age at birth, some were small, most were appropriate, and a few were large according to weight-for-length. Of the infants who were appropriate-for-age at birth, most also were appropriate-for-length, but some were small or large. Results for the infants who were large-for-age at birth are limited by small sample size.

**At Discharge.** We found significant discordance at discharge between the weight-for-age and weight-for-length methods of weight growth status assessment (κ = 0.02; Bowker test, P < .0001; Table I), due primarily to the small-for-age infants being mostly appropriate-for-length. Of the 944 infants considered appropriate-for-age, 22.1% were found to be inappropriate-for-length (Table I), and of the 949 considered appropriate-for-length, 22.5% were found to be inappropriate-for-age (data not shown); again illustrating that the 2 measurement methods categorize infants differently.

Change in Weight Growth Status over Time

Table II shows the distribution by weight growth status category (small, appropriate, and large) of the overall rise in large-for-length infants and decline in small-for-length infants from birth to discharge. Of the 210 large-for-length infants by discharge, only 11 were large-for-age, and most started as appropriate-for-age (86.7%) and appropriate-for-length (88.1%) at birth (data not shown).

The overall percentage of small-for-age infants almost doubled from birth to discharge (Table I). Although the weight-for-age categorization indicates that the majority of small-for-age infants at birth remained small-for-age at discharge, including length in the categorization shows that

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<th>Table I. Weight growth status categorization: weight-for-age versus weight-for-length (n = 1214)</th>
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<td>At birth</td>
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<tr>
<td>Weight-for-length*</td>
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<td>Small</td>
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Weight-for-GA (weight-for-age) and weight/length3 ratio-for-age (weight-for-length) based on Lubchenco fetal growth charts.12 Unshaded cells present column percentages.

| Small, appropriate, and large are defined as < 10th, 10th to 90th, and > 90th percentile, respectively, weight-for-age or -length, as appropriate. |

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<th>Table II. Weight-for-length growth status categorization at birth versus at discharge (n = 1214)</th>
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<td>Birth weight-for-length*</td>
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<td>Discharge weight-for-length*</td>
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Weight/length3 ratio-for-age (weight-for-length) based on Lubchenco fetal growth charts.12 Unshaded cells present column percentages.

| Small, appropriate, and large defined as < 10th, 10th to 90th, and > 90th percentile weight-for-length. |
most of the infants were at appropriate weight-for-length (Figure 1). Of the infants who were born appropriate-for-age, most remained appropriately sized based on weight-for-age and weight-for-length at discharge (Figure 2). Figures 1 and 2 also illustrate that a substantial proportion of small-for-age and appropriate-for-age infants at birth became large-for-length by discharge.

**DISCUSSION**

Using weight-for-age to assess weight growth status indicates that the preterm infants in our study fell behind in growth between birth and discharge, with the percentage of small-for-age infants increasing from 12% to 21%. Weight-for-length gives a very different impression; the percentage of large-for-length are unknown. Extrauterine growth rates that exceed intrauterine growth rates may result in higher rates of body fat accretion. Some nutrition practices and environments that achieve rapid postnatal weight gain have been shown to contribute to excess body fat. Formula-fed very low birth weight infants have higher accretion of body fat and less linear growth postnatally compared with fetuses of the same GA. A high-calorie diet has been shown to promote rapid postnatal fat accretion. Thus, the shift of small- and appropriate-for-length infants to large-for-length may be a result of accelerated weight gain, poor linear growth, or, most likely, a combination of both. More research is needed on body composition in preterm infants and its long-term risks and the effect of diet. Detailed dietary data were not available for our analysis.

The relationship between small size and poor neurodevelopment has been well explored. Even though poor neurodevelopment has been repeatedly associated with low
weight\textsuperscript{29,30} and small head size at birth,\textsuperscript{31,32} such an association with low weight-for-length has not been as well documented. The NICHD Neonatal Research Network’s 18-month follow-up data included a personal communication indicating a positive association between low weight/length ratio and poor neurodevelopment.\textsuperscript{32} This relationship warrants closer examination.

The American Academy of Pediatrics recommends that growth of preterm infants replicate that of fetuses of the same GA,\textsuperscript{17} and data are available that describe in utero changes in body composition.\textsuperscript{23} However, preterm infants in the ex utero environment are known to grow\textsuperscript{8,9,24,25} and accrete nutrients\textsuperscript{26-28} differently than fetuses in utero. More research on postnatal growth, including its composition and related outcomes, is needed to better understand and define the “ideal” for preterm infants.

In the meantime, the evaluation of preterm infant postnatal growth status continues to use available tools. Intrauterine growth curves illustrate the “ideal” or fetal growth for preterm infants but not growth over time, because there is a different group of newborn infants for each GA.\textsuperscript{7,12} In contrast, postnatal growth curves illustrate the actual growth of preterm infants over time, but as a result do not evaluate whether or not growth is ideal. Although intrauterine growth curves are intended for the evaluation of growth status at birth, they are used to assess the growth of preterm infants throughout their NICU stay because of the lack of a better assessment tool.

Our study has several limitations. The “end” time point in our study included infants who were discharged to home (the majority) or transferred to another hospital or who died. Although the variation in this time point could have affected our results, the primary analyses (Table I) performed only on infants discharged to home produced the same results.

We used an early, historically accepted measure of body proportionality, Rohrer’s ponderal index, which we defined as weight-for-length, because body proportionality in preterm infants has not been well characterized, and no anthropometric measure has been fully or functionally validated. Much remains unknown about body proportionality indexes in preterm infants, including their efficacy and utility in the care of preterm infants in the NICU.

Although the ideal body proportionality index for preterm infants remains unclear, the Lubchenco weight-for-length growth curve was used in this study because it met the needs of our study. The use of Lubchenco curves has been criticized, because these data are not generalizable to the current US NICU population; however, no reference curves for any weight-for-length ratio based on a large, contemporary US data set were available at the time of our study. We found that the Lubchenco weight cutoffs for 10th and 90th percentiles were higher than those of a more contemporary weight-for-age curve,\textsuperscript{5} which may have underrepresented the larger infants and overrepresented the smaller infants in our sample. Nonetheless, the lack of agreement between growth status assessment methods found in the present study should be valid, because the same reference data were used for both growth status assessment methods.

Finally, the accuracy of the clinically measured growth measurements in this study may represent a limitation. Although NICU weight measurements are considered reliable, length is more difficult to measure precisely in the clinical setting.\textsuperscript{33} Length measurements can be highly reproducible in the research setting, however.\textsuperscript{34} Furthermore, we demonstrated in a Cincinnati NICU that clinical length measurements (conducted by NICU nurses as usual practice) did not differ significantly from repeated research measurements (using a standardized technique and equipment) on average (Olsen, unpublished data). Thus, the use of weight-for-length offers a potentially reliable assessment tool in the NICU setting.

The assessment of weight growth status of preterm infants should include both weight-for-age and a body proportionality index, such as weight-for-length, because these methods often provide different information. In combination, these measures may provide clinicians with more information on which to base decisions about care. Research is needed to determine the “ideal” body proportionality index for preterm infants and its ability to predict later outcomes.

\textbf{REFERENCES}


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