# Weight Growth Velocity and Postnatal Growth Failure in Infants 501 to 1500 Grams: 2000–2013

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abstract

**BACKGROUND:** Very low birth weight infants often gain weight poorly and demonstrate growth failure during the initial hospitalization. Although many of the major morbidities experienced by these infants during their initial NICU stays have decreased in recent years, it is unclear whether growth has improved.

**METHODS:** We studied 362 833 infants weighing 501 to 1500 g without major birth defects born from 2000 to 2013 and who were hospitalized for 15 to 175 days at 736 North American hospitals in the Vermont Oxford Network. Average growth velocity (GV; g/kg per day) was computed by using a 2-point exponential model on the basis of birth weight and discharge weight. Postnatal growth failure and severe postnatal growth failure were defined as a discharge weight less than the 10th and third percentiles for postmenstrual age, respectively.

**RESULTS:** From 2000 to 2013, average GV increased from 11.8 to 12.9 g/kg per day. Postnatal growth failure decreased from 64.5% to 50.3% and severe postnatal growth failure from 39.8% to 27.5%. The interquartile ranges for the hospitals participating in 2013 were as follows: GV, 12.3 to 13.4 g/kg per day; postnatal growth failure, 41.1% to 61.7%; and severe postnatal growth failure, 19.4% to 36.0%. Adjusted and unadjusted estimates were nearly identical.

**CONCLUSIONS:** For infants weighing 501 to 1500 g at birth, average GV increased and the percentage with postnatal growth failure decreased. However, in 2013, half of these infants still demonstrated postnatal growth failure and one-quarter demonstrated severe postnatal growth failure.

**WHAT'S KNOWN ON THIS SUBJECT:** Postnatal growth failure is common for very low birth weight infants. Although many of the major morbidities experienced by these infants during their initial NICU stays have decreased in recent years, it is unclear whether growth has improved.

**WHAT THIS STUDY ADDS:** For infants weighing 501 to 1500 g, average growth velocity increased and postnatal growth failure decreased from 2000 to 2013. Still, in 2013, half were discharged with a weight below the 10th percentile for postmenstrual age.

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Dr Horbar conceptualized and designed the study and drafted the initial manuscript; Mr Badger, Dr Edwards, and Ms Morrow carried out the initial analyses and critically reviewed and revised the manuscript; Drs Ehrenkranz, Soll, Bertino, Gagliardi, and Bellú made substantial contributions to the conception and design of the study and critically reviewed and revised the manuscript; Dr Buzas contributed to the methods outlined in the Supplemental Information and reviewed the manuscript; and all authors approved the final manuscript as submitted.

www.pediatrics.org/cgi/doi/10.1542/peds.2015-0129

**DOI:** 10.1542/peds.2015-0129

Accepted for publication Apr 15, 2015

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PEDIATRICS (ISSN Numbers: Print, 0031-4005; Online, 1098-4275).

The goals for the nutritional management of preterm infants, first proposed in 1977 by the American Academy of Pediatrics Committee on Nutrition,[1] are to achieve a growth rate and a composition of weight gain similar to those of a normal fetus.[2–6] Despite these goals, poor postnatal growth is a nearly universal problem among very low birth weight (VLBW) infants.[7,8] Furthermore, growth failure is associated with both adverse neurodevelopmental and growth outcomes in early childhood and adulthood.[9–12]

In an attempt to promote improved growth and prevent the associated adverse outcomes, efforts have increased in recent years to optimize nutritional support in the NICU.[13–15] Such efforts have included the early initiation of parenteral nutrition, increased protein administration, the early initiation of enteral feedings, and a focus on human milk and breastfeeding.[16,17] The effects of these interventions on growth are uncertain.

Compared with preterm infants who do not experience major morbidities, preterm infants with necrotizing enterocolitis, bronchopulmonary dysplasia, and late-onset infection experience slower growth.[9,18] In recent years, the rates of these morbidities have decreased.[19] How these decreases have affected growth is also uncertain.

In light of the recent changes in nutritional practices and the reductions in major morbidities, we hypothesized that growth during the initial hospitalization would be improved for VLBW infants. To test this hypothesis we analyzed average growth velocity (GV) and postnatal growth failure for infants born from 2000 to 2013 weighing 501 to 1500 g at birth in the Vermont Oxford Network database.

## METHODS

Vermont Oxford Network member hospitals submitted deidentified data for infants weighing 401 to 1500 g at birth or at 22 to 29 weeks of gestation, who were born at their hospitals or transferred to them within 28 days of birth. Local staff collected data using uniform definitions.[20] No protected health care information was collected. The Committee on Human Research at the University of Vermont approved the use of the database for research.

### Subjects

The study included infants born at North American centers weighing 501 to 1500 g without major birth defects who survived to discharge from the hospital or transfer to another hospital between 15 and 175 days after birth. Infants with extreme values for GV (>4 interquartile ranges above the third quartile or 4 interquartile ranges below the first quartile) were excluded.

### Growth Measures

Average GV (g/kg per day) was computed for each infant on the basis of Patel et al's 2-point exponential model.[21,22] The 2 points were birth weight and discharge weight. The Fenton growth charts were used to calculate the percentage of infants with postnatal growth failure, defined as a discharge weight less than the 10th percentile for postmenstrual age, and severe postnatal growth failure, defined as a discharge weight less than the third percentile for postmenstrual age.[23]

### Statistical Analyses

Mixed-model analysis of variance was used to evaluate changes in average GV over the study period. Generalized estimating equations (GEEs) were used to evaluate changes in the percentage of infants with postnatal growth failure and severe postnatal growth failure. Birth year was included as a categorical fixed factor in all models, whereas birth hospital represented a random factor in mixed linear models and a clustering variable in GEE models. All outcomes were analyzed unadjusted, adjusted for infant characteristics, and adjusted for infant characteristics, any ventilation, and any major neonatal morbidity.

Infant characteristics included the following: race and ethnicity (Hispanic, black [non-Hispanic], white [non-Hispanic], other [non-Hispanic]); gender, gestational age, gestational age squared, multiple birth (yes/no), small size for gestational age (yes/no), 1-minute Apgar score, and exposure to any antenatal maternal steroid treatment. Small size for gestational age was defined within categories of gender, race, and ethnicity and multiple birth as birth weight below the 10th percentile on the basis of smoothed curves constructed by using the US Natality Dataset.[24] Infants were classified as having a major neonatal morbidity if they had ≥1 of the following conditions before discharge from the reporting hospital: early bacterial infection in blood or cerebrospinal fluid within 3 days of birth, late bacterial (including coagulase-negative *Staphylococcus*) or fungal infection in blood or cerebrospinal fluid ≥3 days after birth, necrotizing enterocolitis (bilious gastric aspirate or emesis, abdominal distension, gross or occult blood in the stool and pneumatosis intestinalis, hepatobiliary gas, or pneumoperitoneum), chronic lung disease (supplemental oxygen at 36 weeks' postmenstrual age or oxygen status at discharge for infants discharged before 36 weeks), cystic periventricular leukomalacia, severe intraventricular hemorrhage,[25] or severe retinopathy of prematurity.[19,20,26]

Descriptive analyses were performed within strata defined by birth weight categories, gestational age, initial disposition, and length of stay. Changes in demographic characteristics from 2000 to 2013 were evaluated by using mixed-model analyses of variance and GEE logistic models. Length of stay was log transformed before analysis; geometric means are presented. To evaluate the potential effect of changes in participating hospitals over time, primary analyses were repeated for the 254 hospitals that participated for all 14 years. All statistical analyses were performed by using SAS Statistical Software version 9.3 (SAS Institute, Cary, NC).

## RESULTS

From 2000 to 2013, 736 North American hospitals participated in Vermont Oxford Network (Supplemental Table 5). Of these, 85% were members for ≥4 years, 64% for ≥8 years, and 35% for all 14 years. Fourteen percent of the hospitals performed ventilation without restriction and major surgery including cardiac surgery, 44% performed ventilation without restriction and major surgery except for cardiac surgery, and 42% had restrictions on ventilation or surgery. The median annual number of VLBW infants at the hospitals was 63 (interquartile range: 34–111).

From 2000 to 2013, 390 801 eligible infants were born at participating hospitals without major birth defects and survived until discharge from the hospital or transfer to another hospital. Of these, 364 917 had lengths of stay between 15 and 175 days. The exclusion of 1356 cases with extreme values for GV and 728 cases who were missing data needed to calculate GV resulted in a final sample size of 362 833.

From 2000 to 2013, the percentage of black (28.2% to 30.0%; $P < .001$), Hispanic (13.7% to 17.2%; $P < .001$), and infants of other races (4.9% to 7.5%; $P < .001$) increased, whereas the percentage of white infants decreased (53.2% to 45.3%; $P < .001$) (Table 1). The percentage of infants exposed to antenatal steroids increased (80.9% to 88.4%; $P < .001$), as did the percentage of infants with an Apgar score <4 at 1 minute

**TABLE 1** Characteristics of 362 833 Infants Weighing 501 to 1500 g Without Congenital Malformations Who Were Inborn at Vermont Oxford Network North American Member Centers, Stayed 15 to 175 Days, and Survived to Initial Disposition

| | *n* | % |
|---|---|---|
| Birth weight | | |
| 501–750 g | 49 524 | 13.6 |
| 751–1000 g | 84 854 | 23.4 |
| 1001–1250 g | 102 715 | 28.3 |
| 1251–1500 g | 125 740 | 34.7 |
| Gestational age | | |
| ≤23 weeks | 6261 | 1.7 |
| 24–26 weeks | 78 223 | 21.6 |
| 27–29 weeks | 145 513 | 40.1 |
| 30–32 weeks | 109 080 | 30.1 |
| ≥33 weeks | 23 756 | 6.5 |
| Maternal race and ethnicity | | |
| Hispanic | 59 344 | 16.4 |
| Black non-Hispanic | 104 561 | 28.9 |
| White non-Hispanic | 175 444 | 48.5 |
| Other non-Hispanic | 22 620 | 6.2 |
| Size for gestational age | | |
| Appropriate for gestational age | 290 624 | 80.1 |
| Small for gestational age | 72 197 | 19.9 |
| Male | 179 381 | 49.4 |
| Multiple birth | 106 550 | 29.4 |
| Apgar at 1 minute <4 | 71 313 | 19.7 |
| Antenatal steroids | 303 786 | 83.7 |
| Length of stay | | |
| 15–37 days | 92 710 | 25.6 |
| 38–54 days | 91 780 | 25.3 |
| 55–77 days | 88 399 | 24.4 |
| 78–175 days | 89 944 | 24.8 |
| Initial disposition | | |
| Home | 322 418 | 88.9 |
| Transferred | 40 415 | 11.1 |
| Major morbidity | | |
| Yes | 140 061 | 40.4 |
| No | 206 867 | 59.6 |

(18.3% to 22.5%; $P < .001$). The percentage of infants with a major morbidity decreased (44.2% to 34.9%; $P < .001$). Geometric mean length of stay increased from 48.5 days in 2000 to 53.0 days in 2013 ($P < .001$).

From 2000 to 2013, average GV, both unadjusted and adjusted for infant characteristics, increased (Fig 1) from 11.8 g/kg per day in 2000 to 12.9 g/kg per day in 2013. Changes in growth over time are shown for specific subgroups of infants in Table 2. Increases were observed across all infant subgroups. The rate of increase diminished with time with most of the gain occurring before 2005. Additional adjustment for exposure to assisted ventilation and major morbidity produced nearly identical estimates of changes in average GV, 11.9 g/kg per day in 2000 and 12.9 g/kg per day in 2013.

From 2000 to 2013 the percentage of infants with postnatal growth failure decreased from 64.5% to 50.3%; the percentage of infants with severe postnatal growth failure decreased from 39.8% to 27.5% (Fig 2). The changes observed in postnatal growth failure over the time period were not unique to any subgroup (Tables 3 and 4). Adjusting for infant characteristics produced similar estimates (65.4% in 2000 and 49.3% in 2013 for postnatal growth failure; 40.6% and 26.7% for severe postnatal growth failure) as did adding adjustment for exposure to assisted ventilation and major morbidity (64.3% in 2000 and 49.6% in 2013 for postnatal growth failure; 39.3% and 26.9% for severe postnatal growth failure).

Interquartile ranges at the 648 hospitals with data in 2013 were 12.3 to 13.4 g/kg per day for average GV, 41.1% to 61.7% for postnatal growth failure, and 19.4% to 36.0% for severe postnatal growth failure. For the 254 hospitals that participated in the analysis for all 14 years, average GV increased by 1.1 g/kg per day, whereas postnatal growth failure decreased by 14.8%, on average, and severe postnatal growth failure decreased by 12.3%, on average.

## DISCUSSION

We observed that GV during the initial hospitalization after birth for infants weighing 501 to 1500 g increased from 2000 to 2013 with associated decreases in the percentages of infants with postnatal growth failure and severe postnatal growth failure defined as discharge weights less than the 10th and third percentiles for postmenstrual age, respectively. The increase of 1.1 g/kg per day in average GV was

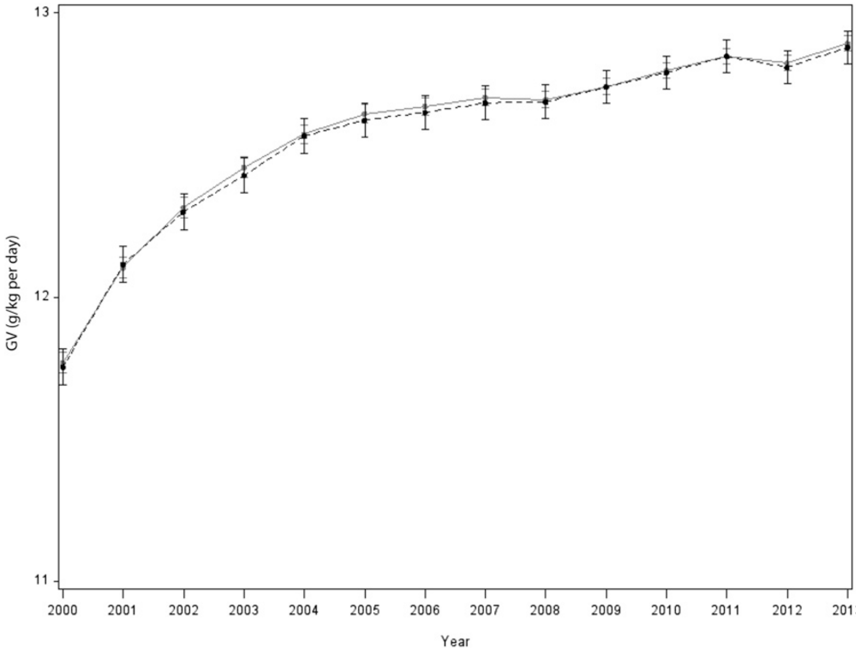


**FIGURE 1**
Average GV for infants weighing 501 to 1500 g, 2000 to 2013. The gray line with circle markers represents unadjusted estimates. The black dashed line with circle markers represents adjusted estimates. Error bars represent 95% confidence intervals.

**TABLE 2** Average GV (g/kg per day) of Infants Weighing 501 to 1500 g Without Congenital Malformations Who Were Inborn at Vermont Oxford Network North American Member Centers, Stayed 15 to 175 Days, and Survived to Initial Disposition: 2000 and 2013

| | 2000 | | | 2013 | | | Δ | |
|---|---|---|---|---|---|---|---|---|
| | *n* | Mean | (95% CI) | *n* | Mean | (95% CI) | Mean | (95% CI) |
| Birth weight | | | | | | | | |
| 501–750 g | 2524 | 12.8 | (12.7–12.9) | 4181 | 13.6 | (13.6–13.7) | 0.8 | (0.7–1.0) |
| 751–1000 g | 4584 | 12.4 | (12.3–12.4) | 6963 | 13.4 | (13.3–13.4) | 1.0 | (0.9–1.1) |
| 1001–1250 g | 5189 | 11.9 | (11.9–12.0) | 8453 | 13.1 | (13.0–13.1) | 1.1 | (1.1–1.2) |
| 1251–1500 g | 6185 | 10.8 | (10.7–10.8) | 10 613 | 12.1 | (12.1–12.2) | 1.4 | (1.3–1.5) |
| Gestational age | | | | | | | | |
| ≤23 weeks | 308 | 12.2 | (12.0–12.5) | 572 | 12.8 | (12.6–13.0) | 0.6 | (0.2–0.9) |
| 24–26 weeks | 4049 | 12.1 | (12.1–12.2) | 6539 | 13.0 | (13.0–13.1) | 0.9 | (0.8–1.0) |
| 27–29 weeks | 7532 | 11.7 | (11.7–11.8) | 11 873 | 12.9 | (12.8–12.9) | 1.1 | (1.1–1.2) |
| 30–32 weeks | 5384 | 11.5 | (11.5–11.6) | 9168 | 12.8 | (12.8–12.9) | 1.3 | (1.2–1.4) |
| ≥33 weeks | 1209 | 11.8 | (11.6–12.0) | 2058 | 13.0 | (12.8–13.1) | 1.1 | (0.9–1.4) |
| Size for gestational age | | | | | | | | |
| Appropriate for age | 14 830 | 11.6 | (11.6–11.6) | 23 986 | 12.7 | (12.7–12.7) | 1.1 | (1.0–1.1) |
| Small for gestational age | 3652 | 12.5 | (12.4–12.6) | 6218 | 13.7 | (13.6–13.8) | 1.2 | (1.1–1.3) |
| Gender | | | | | | | | |
| Male | 9332 | 11.7 | (11.7–11.8) | 14 914 | 12.9 | (12.9–13.0) | 1.2 | (1.1–1.3) |
| Female | 9149 | 11.8 | (11.8–11.9) | 15 296 | 12.9 | (12.8–12.9) | 1.0 | (1.0–1.1) |
| Length of stay | | | | | | | | |
| 15–37 days | 4939 | 11.0 | (10.9–11.1) | 6786 | 12.3 | (12.3–12.4) | 1.4 | (1.3–1.5) |
| 38–54 days | 4750 | 11.9 | (11.8–12.0) | 7402 | 13.1 | (13.0–13.1) | 1.2 | (1.1–1.3) |
| 55–77 days | 4489 | 12.3 | (12.3–12.4) | 7647 | 13.2 | (13.2–13.2) | 0.9 | (0.8–1.0) |
| 78–175 days | 4304 | 12.0 | (11.9–12.0) | 8375 | 12.9 | (12.9–12.9) | 0.9 | (0.9–1.0) |
| Initial disposition | | | | | | | | |
| Home | 16 416 | 12.0 | (12.0–12.0) | 27 110 | 13.0 | (13.0–13.0) | 1.0 | (1.0–1.1) |
| Transferred | 2066 | 10.0 | (9.8–10.2) | 3100 | 11.8 | (11.7–11.9) | 1.8 | (1.6–2.0) |
| Major morbidity | | | | | | | | |
| Yes | 7853 | 11.8 | (11.8–11.9) | 10 038 | 12.8 | (12.7–12.8) | 1.0 | (0.9–1.0) |
| No | 9906 | 11.8 | (11.8–11.9) | 18 700 | 13.0 | (13.0–13.0) | 1.2 | (1.1–1.3) |

CI, confidence interval.

accompanied by a 14% decrease in the proportion of infants with postnatal growth failure and a 12% decrease in the percentage with severe postnatal growth failure. Improvements in GV and growth failure were observed across all infant subgroups.

Despite these improvements, we observed variation among hospitals. In 2013, the interquartile ranges were 12.3 to 13.4 g/kg per day for average GV, 41.1% to 61.7% for postnatal growth failure, and 19.4% to 36.0% for severe postnatal growth failure. Although we do not have data on hospitals' nutrition practices, prospective attention to optimizing postnatal growth in VLBW infants is an important policy issue that deserves attention.

We used the 2-point exponential model for calculating average GV described and validated by Patel et al.[21,22] They compared calculating GV on the basis of the interval from birth to discharge as was done in the current study, with GV calculated by on the basis of the interval from the day on which birth weight was regained to discharge. Calculations based on the entire birth to discharge interval produced estimates of average GV that were ~3 g/kg per day lower than values generated by using the day on which birth weight was regained as the starting point.

GV varies over the NICU stay.[27,28] The 2-point exponential model that we used calculates the average GV from birth to discharge. It is nearly equivalent to the average of the individual daily GVs one would obtain by dividing the daily weight gain on a day by the mean weight in kilograms of that day and the preceding day. This equivalence holds as long as the daily weight gains are small relative to the daily weights (Supplemental Information).

Measures of postnatal growth failure, also referred to as extrauterine growth restriction or extrauterine

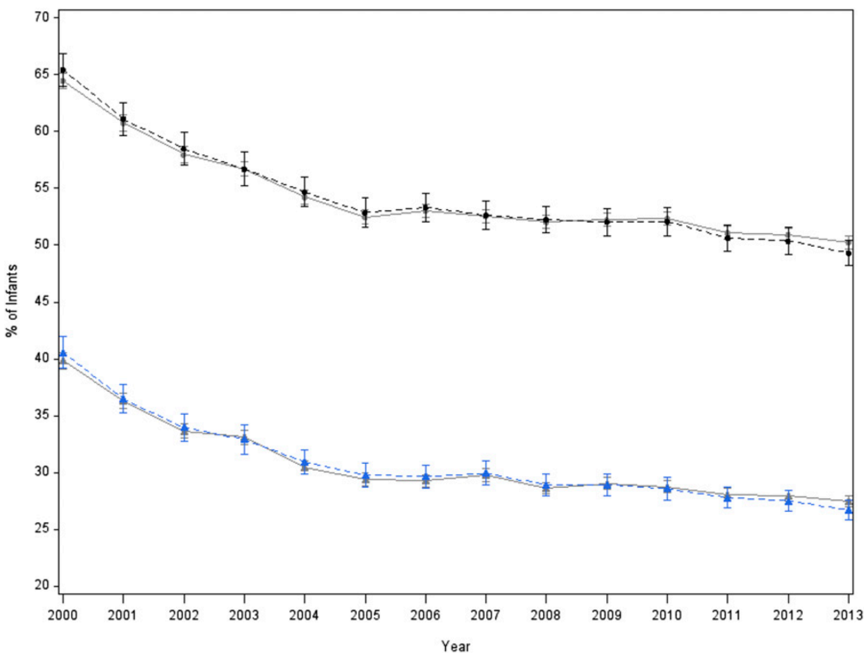


**FIGURE 2**
Percentage of infants weighing 501 to 1500 g who were discharged below the third or 10th percentiles of the Fenton growth chart, 2000 to 2013. The gray line with circle markers represents unadjusted percentages below the 10th percentile. The black dashed line with circle markers represents adjusted percentages below the 10th percentile. The gray line with triangle markers represents unadjusted percentages below the third percentile. The blue dashed line with triangle markers represents adjusted percentages below the third percentile. Error bars represent 95% confidence intervals.

growth retardation by some authors, have varied among studies. Measures based on percentiles have included a weight for age below the 10th percentile at 36, 37, and 40 weeks' postmenstrual age,[7,29–31] at the time of hospital discharge,[32,33] or at 28 days after birth.[34] Measures based on *z* scores at discharge and the differences between these scores at birth and discharge have also been used.[8,10,35,36]

Clark et al[31] evaluated 23 371 infants discharged from 114 NICUs from 1997 to 2000. The percentage of infants discharged weighing less than the 10th percentile for postmenstrual age decreased from 71% for infants born at 23 weeks to 23% for those born at 34 weeks. Radmacher et al[32] studied 221 infants with birth weights of ≤1000 g or gestational ages of ≤29 weeks born from 1997 to 2000. They found that 59% of these infants had a discharge weight less than the 10th percentile for postmenstrual age. Lemons et al[7] studied 4438 infants at the 14 NICUs in the National Institute of Child Health and Human Development Neonatal Research Network with birth weights of 401 to 1500 g born in 1995 or 1996. Ninety-seven percent of these infants had weights less than the 10th percentile at 36 weeks' postmenstrual age. Fenton et al[27] studied growth in 977 infants with gestational ages of 23 to 31 weeks born from 2001 to 2010. They found that 65% of the infants had weights less than the 10th percentile at 37 weeks' postmenstrual age and 55% had weights less than the 10th percentile at 40 weeks' postmenstrual age. Although differences in definitions of poor growth, reference standards used, and the populations studied make comparison between studies difficult, it is clear that poor postnatal growth is a serious and nearly universal problem for VLBW infants.[7,8]

We found that postnatal growth failure declined by 14% (from 64.5% to 50.3%) and severe postnatal growth failure by 12% (from 39.8% to 27.5%) from 2000 to 2013. We are aware of 1 other study that evaluated growth trends over time. Ofek Shlomai et al,[36] in a report based on 13 531 infants with gestational ages at birth of 24 to 32 weeks in the Israel National VLBW database, found that the percentage of infants discharged with a weight at discharge >2 *z* scores below that at birth decreased from 1995 to 2010.

Impaired growth at critical stages of fetal and neonatal development may have serious consequences well beyond the neonatal period.[9,11,12] Ehrenkranz et al[9] assessed GV and neurodevelopmental outcomes for 490 infants weighing 501 to 1000 g at birth born in 1994 and 1995. They found that GV during the NICU hospitalization exerts a significant and possibly independent effect on neurodevelopmental and growth outcomes at 18 to 22 months' corrected age. As GV increased, the incidence at 18 to 22 months of cerebral palsy, scores <70 on the Bayley II Mental Development and Psychomotor Development Indices, abnormal neurologic examinations, neurodevelopmental impairment, and need for rehospitalization decreased significantly. Sammallahti et al[12] evaluated 103 VLBW infants born from 1978 to 1985 who were followed to a mean age of 25 years. For each SD of faster growth in weight from birth to term, performance IQ improved by 5 points and verbal flexibility, visual memory, and visual flexibility composite scores increased by 0.23 to 0.30 SDs. Although the goals for nutrition management of preterm infants are to achieve a growth rate and a composition of weight gain similar to those of a normal fetus,[1] the optimal rate of growth is unknown. Higher GV during the postnatal period for preterm infants may increase the risk of health problems in adulthood.[37,38] Longer-term follow-up studies are required to

TABLE 3 Percentage of Infants Discharged Below the 10th Percentile of the Fenton Growth Chart Weighing 501 to 1500 g Without Congenital Malformations Who Were Inborn at Vermont Oxford Network North American Member Centers, Stayed 15 to 175 Days, and Survived to Initial Disposition: 2000 and 2013

| | 2000 | | | 2013 | | | Δ | |
|---|---|---|---|---|---|---|---|---|
| | *n* | % | (95% CI) | *n* | % | (95% CI) | % | (95% CI) |
| Birth weight | | | | | | | | |
| 501–750 g | 2511 | 84.0 | (82.5–85.4) | 4152 | 63.6 | (62.2–65.1) | −20.3 | (−22.4 to −18.3) |
| 751–1000 g | 4571 | 71.5 | (70.2–72.8) | 6928 | 51.9 | (50.7–53.1) | −19.6 | (−21.3 to −17.8) |
| 1001–1250 g | 5179 | 60.1 | (58.8–61.5) | 8443 | 47.2 | (46.1–48.2) | −13.0 | (−14.7 to −11.3) |
| 1251–1500 g | 6182 | 55.0 | (53.7–56.2) | 10 602 | 46.4 | (45.5–47.4) | −8.5 | (−10.1 to −7.0) |
| Gestational age | | | | | | | | |
| ≤23 weeks | 308 | 69.5 | (64.3–74.7) | 572 | 43.9 | (39.8–48.0) | −25.6 | (−32.2 to −19.0) |
| 24–26 weeks | 4049 | 64.7 | (63.2–66.1) | 6522 | 40.0 | (38.8–41.2) | −24.6 | (−26.5 to −22.7) |
| 27–29 weeks | 7505 | 52.0 | (50.9–53.2) | 11 830 | 36.7 | (35.8–37.5) | −15.4 | (−16.8 to −13.9) |
| 30–32 weeks | 5374 | 73.4 | (72.3–74.6) | 9149 | 64.6 | (63.6–65.6) | −8.9 | (−10.4 to −7.3) |
| ≥33 weeks | 1207 | 99.8 | (99.5–100.0) | 2052 | 99.2 | (98.8–99.6) | −0.5 | (−1.0 to −0.1) |
| Size for gestational age | | | | | | | | |
| Appropriate for age | 14 809 | 56.0 | (55.2–56.8) | 23 939 | 38.3 | (37.7–39.0) | −17.7 | (−18.7 to −16.7) |
| Small for gestational age | 3634 | 98.7 | (98.4–99.1) | 6180 | 96.4 | (96.0–96.9) | −2.3 | (−2.9 to −1.7) |
| Gender | | | | | | | | |
| Male | 9310 | 66.0 | (65.0–66.9) | 14 862 | 49.9 | (49.0–50.7) | −16.1 | (−17.4 to −14.9) |
| Female | 9132 | 62.9 | (61.9–63.9) | 15 263 | 50.7 | (49.9–51.5) | −12.2 | (−13.5 to −11.0) |
| Length of stay | | | | | | | | |
| 15–37 days | 4939 | 65.3 | (63.9–66.6) | 6786 | 67.1 | (66.0–68.2) | 1.9 | (0.1 to 3.6) |
| 38–54 days | 4750 | 55.6 | (54.2–57.0) | 7402 | 46.4 | (45.3–47.6) | −9.2 | (−11.0 to −7.4) |
| 55–77 days | 4489 | 61.7 | (60.3–63.2) | 7647 | 42.6 | (41.5–43.8) | −19.1 | (−20.9 to −17.3) |
| 78–175 days | 4265 | 76.2 | (75.0–77.5) | 8290 | 46.9 | (45.8–48.0) | −29.3 | (−31.0 to −27.7) |
| Initial disposition | | | | | | | | |
| Home | 16 381 | 65.3 | (64.5–66.0) | 27 046 | 50.9 | (50.3–51.5) | −14.4 | (−15.4 to −13.5) |
| Transferred | 2062 | 58.0 | (55.8–60.1) | 3079 | 45.0 | (43.2–46.7) | −13.0 | (−15.7 to −10.2) |
| Major morbidity | | | | | | | | |
| Yes | 7814 | 67.9 | (66.8–68.9) | 9963 | 47.1 | (46.1–48.1) | −20.8 | (−22.2 to −19.3) |
| No | 9906 | 61.6 | (60.7–62.6) | 18 690 | 50.4 | (49.6–51.1) | −11.3 | (−12.5 to −10.1) |

CI, confidence interval.

assess variation in GV and the risk of metabolic syndrome, hypertension, and cardiovascular disease in adulthood.

Experts have recommended a variety of nutritional practices to enhance growth in preterm infants, including early initiation of parenteral nutrition, increased protein administration, early initiation of enteral feedings, and a focus on human milk and breastfeeding.[13–17] Other factors may improve weight gain such as exposure to biological maternal sounds[39] or single-family room care.[40] Although the optimal nutritional strategy for preterm infants is unknown, the high rates of postnatal growth failure and the wide variation in rates among NICUs suggest that quality improvement efforts related to nutritional management may have a role to play in improving nutritional support and growth for preterm infants. Using a Delphi process and expert panel, Profit et al[41] identified GV as 1 of 9 key measures included in the Baby-MONITOR, a composite indicator of NICU quality. Several quality improvement collaboratives have focused their efforts on improving nutrition and growth.

Kuzma-O'Reilly et al,[42] in a quality improvement collaborative sponsored by the Vermont Oxford Network, identified, tested, and implemented a series of potentially better practices[43] designed to improve nutrition and growth. The potentially better practices included consistent and comprehensive monitoring of growth and nutritional intake, the early initiation of enteral and parenteral nutrition, consistent systematic advancement of enteral feedings with clear guidelines for withholding feedings, and human milk as the preferred nutritional substrate for premature infants. Implementation of these practices was associated with improved nutrient intake, better growth, and reduced length of stay. Bloom et al[44] identified meaningful differences in nutritional practices for VLBW infants among units in a private neonatology group by comparing sites with high and low weight gains during the first 28 days after birth. Providing performance feedback and education regarding these practices resulted in an increase in the average daily weight gain during the first 28 days after birth. Lee et al,[45] in a quality improvement collaborative sponsored by the California Perinatal Quality Care Collaborative, tested a change package designed to increase human

**TABLE 4** Percentage of Infants Discharged Below the Third Percentile of the Fenton Growth Chart Weighing 501 to 1500 g Without Congenital Malformations Who Were Inborn at Vermont Oxford Network North American Member Centers, stayed 15 to 175 Days, and Survived to Initial Disposition: 2000 and 2013

| | 2000 | | | 2013 | | | Δ | |
|---|---|---|---|---|---|---|---|---|
| | *n* | % | (95% CI) | *n* | % | (95% CI) | % | (95% CI) |
| Birth weight | | | | | | | | |
| 501–750 g | 2511 | 65.0 | (63.1–66.9) | 4152 | 40.6 | (39.1–42.1) | −24.4 | (−26.8 to −22.0) |
| 751–1000 g | 4571 | 46.2 | (44.8–47.7) | 6928 | 28.9 | (27.8–30.0) | −17.3 | (−19.1 to −15.5) |
| 1001–1250 g | 5179 | 34.0 | (32.7–35.3) | 8443 | 23.9 | (23.0–24.8) | −10.1 | (−11.7 to −8.6) |
| 1251–1500 g | 6182 | 29.8 | (28.6–30.9) | 10 602 | 24.3 | (23.5–25.1) | −5.5 | (−6.9 to −4.1) |
| Gestational age | | | | | | | | |
| ≤23 weeks | 308 | 48.4 | (42.8–54.0) | 572 | 22.6 | (19.1–26.0) | −25.8 | (−32.4 to −19.3) |
| 24–26 weeks | 4049 | 41.3 | (39.8–42.8) | 6522 | 19.2 | (18.2–20.1) | −22.1 | (−23.9 to −20.3) |
| 27–29 weeks | 7505 | 27.6 | (26.6–28.6) | 11 830 | 17.0 | (16.3–17.7) | −10.6 | (−11.8 to −9.4) |
| 30–32 weeks | 5374 | 43.0 | (41.7–44.3) | 9149 | 32.8 | (31.8–33.7) | −10.2 | (−11.8 to −8.6) |
| ≥33 weeks | 1207 | 95.0 | (93.8–96.3) | 2052 | 92.2 | (91.0–93.3) | −2.9 | (−4.6 to −1.2) |
| Size for gestational age | | | | | | | | |
| Appropriate for age | 14 809 | 28.1 | (27.4–28.8) | 23 939 | 14.3 | (13.9–14.8) | −13.8 | (−14.6 to −12.9) |
| Small for gestational age | 3634 | 87.7 | (86.7–88.8) | 6180 | 78.4 | (77.4–79.4) | −9.3 | (−10.8 to −7.8) |
| Gender | | | | | | | | |
| Male | 9310 | 41.0 | (40.0–42.0) | 14 862 | 27.3 | (26.5–28.0) | −13.7 | (−15.0 to −12.5) |
| Female | 9132 | 38.7 | (37.7–39.7) | 15 263 | 27.7 | (27.0–28.4) | −11.0 | (−12.2 to −9.8) |
| Length of stay | | | | | | | | |
| 15–37 days | 4939 | 39.7 | (38.4–41.1) | 6786 | 41.0 | (39.9–42.2) | 1.3 | (−0.5 to 3.1) |
| 38–54 days | 4750 | 29.1 | (27.8–30.4) | 7402 | 22.5 | (21.6–23.5) | −6.6 | (−8.2 to −5.0) |
| 55–77 days | 4489 | 34.8 | (33.4–36.2) | 7647 | 20.8 | (19.9–21.7) | −13.9 | (−15.6 to −12.3) |
| 78–175 days | 4265 | 57.2 | (55.7–58.7) | 8290 | 26.9 | (26.0–27.9) | −30.3 | (−32.1 to −28.5) |
| Initial disposition | | | | | | | | |
| Home | 16 381 | 40.7 | (40.0–41.5) | 27 046 | 28.0 | (27.5–28.5) | −12.7 | (−13.6 to −11.8) |
| Transferred | 2062 | 32.8 | (30.8–34.9) | 3079 | 22.9 | (21.4–24.4) | −9.9 | (−12.4 to −7.4) |
| Major morbidity | | | | | | | | |
| Yes | 7814 | 44.4 | (43.3–45.5) | 9963 | 25.7 | (24.9–26.6) | −18.6 | (−20.0 to −17.2) |
| No | 9906 | 36.0 | (35.0–36.9) | 18 690 | 26.9 | (26.2–27.5) | −9.1 | (−10.3 to −8.0) |

CI, confidence interval.

milk feedings for preterm infants. Implementation of the change package resulted in a sustained increase in breast-milk feeding and a decrease in necrotizing enterocolitis. The effects on postnatal growth were not reported.

There are several limitations to our study. We did not have data on nutritional practices over the study period and thus cannot associate the changes in growth we observed with specific changes in nutritional practice. However, our findings that the changes in growth cannot be explained by changes in patient characteristics or major morbidities over the study period suggest that changes in medical practices likely play a role. Length of stay increased significantly during the study time period, which could have influenced the improvement in weight gain velocity. However, because average GV increased across all lengths of stay, we do not feel that it is responsible for the observed increase. Although nearly 20% of the cohort was small for gestational age at birth and might be expected to continue to be growth restricted at discharge, after controlling for size for gestational age we observed virtually identical estimates.

Our growth data were limited to weights at birth and at discharge. We used these weights to calculate an average GV over the NICU stay for each infant using the 2-point exponential model.[21,22] It is known that weight GV changes over the NICU stay.[27,28] Differences in the patterns of GV over the stay that would not be reflected in the average may be important. However, the association between average GV and neurodevelopmental outcome and its simplicity suggest that this measure is a reasonable summary indicator of growth for identifying the nutritional performance of an NICU. Another limitation of our study is the lack of follow-up data on neurodevelopmental and growth outcomes. How the increased GV and decreased rate of growth failure we observed will affect these longer-term outcomes is unknown.

The hospitals included in our study changed over the study period. Because nearly identical results were obtained when the sample was restricted to hospitals participating for the entire period, this finding suggests that the changes we observed were not due to changes in the hospital sample over time. Finally, our study includes only infants cared for at centers participating in the Vermont Oxford Network. Because the Vermont Oxford Network now enrolls 90% of all VLBW infants born in the United States each year, it is likely that our results are generalizable.

## CONCLUSIONS

For infants weighing 501 to 1500 g at birth, average GV increased and the percentage with postnatal growth failure decreased from 2000 to 2013. However, in 2013, half of these infants still demonstrated postnatal growth failure and one-quarter demonstrated severe postnatal growth failure. Further improvements in growth for VLBW infants will require NICU teams to accept that postnatal growth failure is a serious morbidity amenable to prevention and to engage in quality improvement initiatives designed to implement nutritional practices supported by currently available evidence.

### ABBREVIATIONS

CI: confidence interval
GEE: generalized estimating equation
GV: growth velocity
VLBW: very low birth weight

**FINANCIAL DISCLOSURE:** Dr Horbar, Dr Soll, and Ms Morrow are employees of Vermont Oxford Network; Dr Buzas, Dr Edwards, and Mr Badger receive salary support from Vermont Oxford Network; the other authors have indicated they have no financial relationships relevant to this article to disclose.

**FUNDING:** No external funding.

**POTENTIAL CONFLICT OF INTEREST:** The authors have indicated they have no potential conflicts of interest to disclose.

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**Weight Growth Velocity and Postnatal Growth Failure in Infants 501 to 1500 Grams: 2000–2013**

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*Pediatrics* 2015;136;e84
DOI: 10.1542/peds.2015-0129 originally published online June 22, 2015;