Early Weight Loss Nomograms for Formula Fed Newborns

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abstract

OBJECTIVES: To develop nomograms depicting percentiles of weight loss by hour of age for both vaginal and cesarean-delivered newborns who are exclusively formula fed.

METHODS: Data regarding delivery mode, race/ethnicity, feeding type, and weights were extracted from electronic medical records of the birth hospitalization at 14 Kaiser Permanente Northern California hospitals between 2009 and 2013. Newborns whose first feeding was formula from a cohort of 161 471 healthy, term, singleton neonates born at ≥36 weeks' gestation between 2009 and 2013 were identified. Quantile regression was used to create nomograms stratified according to delivery mode; percentiles of weight loss were estimated as a function of time among formula-fed neonates. Weights measured subsequent to any breast milk feeding were excluded. Percentiles were determined through 48 and 72 hours of age for those born vaginally and via cesarean delivery, respectively.

RESULTS: A total of 7075 formula-fed newborns had weights recorded; 4525 were delivered vaginally, and 2550 were born via cesarean delivery. The median weight loss was 2.9% at 48 hours after vaginal delivery; weight loss >7% was rare. For cesarean-delivered neonates, median weight losses at 48 and 72 hours were 3.7% and 3.5%, respectively; weight loss >8% was rare.

CONCLUSIONS: For newborns who are formula fed, these results provide nomograms depicting percentiles of weight loss according to mode of delivery. These plots can be used to classify early weight loss according to percentile and may enable early identification of feeding difficulties or other neonatal morbidities.

According to the Centers for Disease Control and Prevention, ~19% of neonates in the United States in 2011 were supplemented with or exclusively fed formula in the first 2 days after birth.[1] It has been well established that among exclusively breastfed neonates, initial postnatal weight loss is nearly universal,[2–4] and this loss has been attributed both to diuresis and to relatively low initial enteral intake; little research has focused on weight loss for those who are formula fed. Although formula-fed infants have a somewhat larger, more measurable intake than those who breastfeed,[5] feeding habits for formula-fed newborns are often inconsistent in the immediate postnatal period.[6] Common causes of significant weight loss among formula-fed neonates may include fluid diuresis, poor initial intake due to infant somnolence, inadequate provision of formula, and disruption of bonding as parents master the feeding techniques.[7] In addition, weight loss may signify systemic abnormality or illness, even when feeding is presumed to be going well.

To monitor for potential morbidity, weight is routinely evaluated daily during the birth hospitalization. A nomogram published in 1999 depicting bilirubin levels by hour of age[8] has gained wide acceptance as a standard tool for evaluating trajectories of neonatal hyperbilirubinemia.[9,10] Recently, we constructed newborn weight loss nomograms among a sample of >109 000 exclusively breastfed newborns.[11] However, similarly detailed hour-specific values and trajectories for newborn weight loss among formula-fed newborns have not been previously reported. Therefore, our goal was to develop a graphical depiction of weight loss in a population of newborns who were exclusively formula fed. Such a weight loss nomogram may aid in the identification of those with early feeding issues and their related morbidities that might not otherwise be identified during the brief neonatal hospital stay. It could further identify need for feeding support and influence the timing and type of newborn follow-up.[12,13]

METHODS

Participants and Outcomes

The initial cohort included 161 471 newborns who were born at ≥36 weeks' gestation at 1 of 14 Kaiser Permanente Northern California hospitals between January 1, 2009, and December 31, 2013, who survived to discharge from the hospital and who did not receive intensive care. For these newborns, data were extracted on all weights obtained during the birth hospitalization as well as on gestational age, method of delivery, length of stay, hospital of birth, maternal race/ethnicity, and timing (hour of age) and type (breast milk or formula) of all inpatient feedings. Newborns were excluded if they had missing data on type of delivery, weight, or feeding; birth weight <2000 g or >5000 g; multiple birth; reported birth weights that were discrepant between data sources; or no weight documented after 6 hours of age and before initiation of formula feeding.

Weight change was defined as the difference between birth weight and each weight recorded subsequently, calculated as a percentage of birth weight (as is typically performed daily in clinical practice). Newborns with implausible weight loss or weight gain values (>10% loss in the first 24 hours, >15% loss during the measurement period before 72 hours, >10% gain during the measurement period before 72 hours) were excluded. Because length of stay varies naturally by method of delivery, and because neonates are usually weighed once daily during the birth hospitalization but not usually within 6 hours of birth, weight loss percentiles were determined from 6 to 48 hours for vaginal births and from 6 to 72 hours for cesarean deliveries. This method reflects the respective national average length of stay by delivery mode

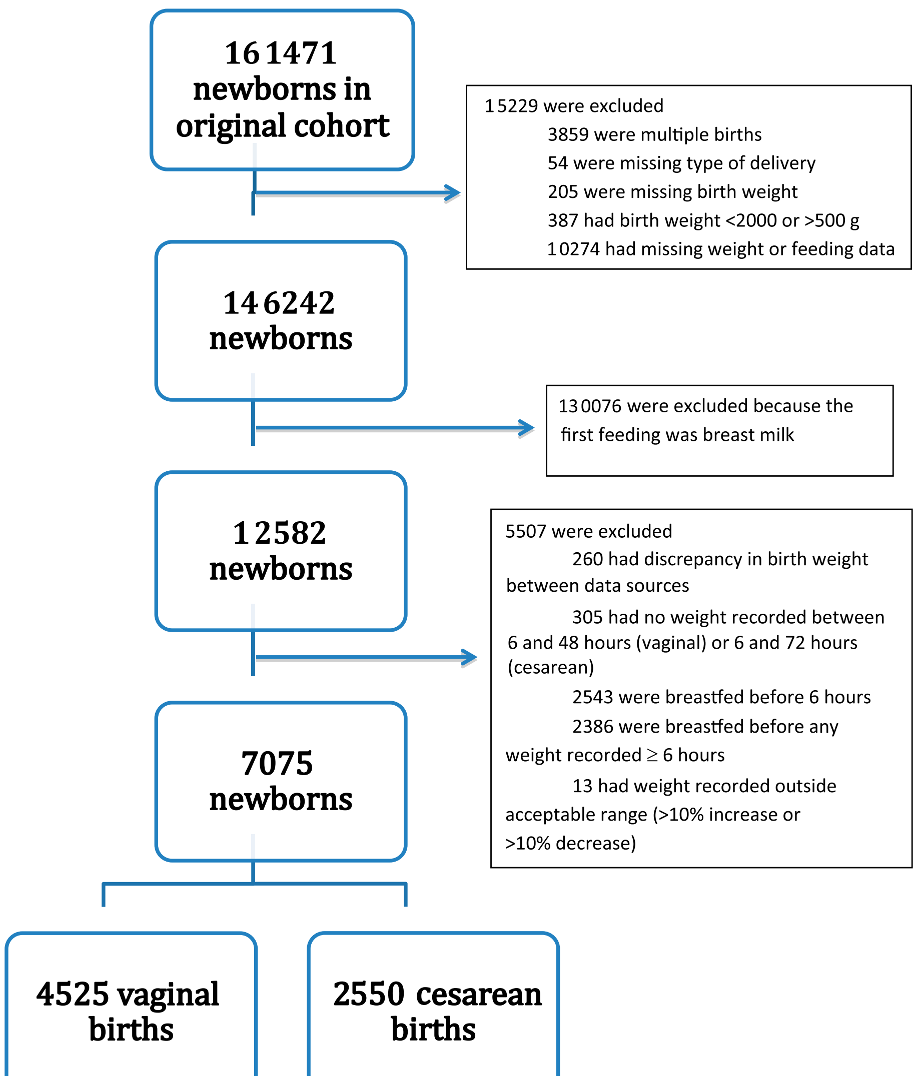

FIGURE 1 Derivation of the final analytic cohort.

and the corresponding variation in availability of weight measurements between vaginally delivered newborns and those born via cesarean delivery.[14]

For the present analysis, a newborn was included in the final cohort if the first feeding in the hospital was formula and a weight was recorded after 6 hours of age and before any breastfeeding. Record of any newborn weights that occurred after the time of the first breastfeeding were excluded, as were any weights that occurred after discharge from the birth hospitalization.

This study was approved by the University of California San Francisco Committee on Human Research and by the institutional review boards of Penn State Medical College and Kaiser Permanente Northern California.

Analyses

The statistical methods used in this study of formula-fed newborns were nearly the same as those used in our previous analysis of exclusively breastfed newborns.[11] Briefly, the same penalized fixed effects quantile regression model appropriate for repeated measures[15] was used to estimate percentile curves as a function of time after birth. The regularization parameter for the model was set equal to 5. However, natural splines[16] were used with 3 degrees of freedom to generate nonlinear curves due to the small number of weights recorded near the boundaries (48 hours for vaginal deliveries; 72 hours for cesarean deliveries) in this analysis. Bootstrapping with 500 resamples and the percentile method were used to estimate 95% confidence intervals for each percentile curve.[17]

As in the previous study,[11] we also conducted a sensitivity analysis to determine whether the exclusion of weights that occurred after breastfeeding may have substantially affected the final estimated percentile curves. Briefly, we matched newborns with censored weights to newborns without censored weights by using a greedy matching algorithm[18] on the basis of 3 variables: time of most recent weight included before breastfeeding, actual weight at that time point, and gestational age. The actual weights from the uncensored newborn were then imputed as weights for the censored newborn, and the models for each delivery mode were re-fit.

RESULTS

From 161 471 newborns in the cohort, 7075 were first fed formula in the hospital and included in the final analysis (Fig 1); 4525 (64%) of these infants were delivered vaginally, and 2550 (36%) were born via cesarean delivery. Data were available on race/ethnicity for 99% of mothers. The cohort was racially diverse: 27.5% of mothers were Hispanic, 25.8% were Asian, 12.8% were black non-Hispanic, and 31.0% were white non-Hispanic (Table 1).

A total of 5699 weights subsequent to birth weight were recorded for neonates delivered vaginally (1.26 per newborn) and 4782 for those delivered born via cesarean delivery (1.9 per newborn). A majority of newborns delivered vaginally (75.4%) had only 1 weight recorded between 6 and 48 hours, whereas a majority of newborns born via cesarean delivery (64.4%) had

TABLE 1 Demographic and Clinical Characteristics of Included Newborns According to Type of Delivery

Characteristic	Vaginal (*n* = 4525)	Cesarean (*n* = 2550)
Birth weight, g		
Mean ± SD	3390.4 ± 470.3	3483.7 ± 545.1
Median	3380	3470
Interquartile range	3060–3700	3120–3835
Range	2000–4950	2000–5000
Gestational age, wk		
No. (%) of weeks		
36	196 (4.3%)	158 (6.2%)
37	414 (9.1%)	256 (10%)
38	883 (19.5%)	457 (17.9%)
39	1458 (32.2%)	1140 (44.7%)
40	1154 (25.5%)	356 (14%)
41	407 (9%)	176 (6.9%)
42	13 (0.3%)	7 (0.3%)
Mean ± SD	38.9 ± 1.3	38.7 ± 1.2
Median	39	39
Interquartile range	38–40	38–39
Range	36–42	36–42
Maternal race/ethnicity		
Hispanic	1258 (27.8%)	687 (26.9%)
American Indian/Eskimo	16 (0.4%)	13 (0.5%)
Asian	1141 (25.2%)	681 (26.7%)
Black, non-Hispanic	585 (12.9%)	318 (12.5%)
White, non-Hispanic	1415 (31.3%)	780 (30.6%)
Unknown	57 (1.3%)	23 (0.9%)
Other	53 (1.2%)	48 (1.9%)
Newborn, hospital length of stay, d[a]		
Mean ± SD	1.9 ± 1.8	3.0 ± 1.7
Median	1.5	2.8
Interquartile range	1.2–2.0	2.1–3.3
Range	0.6–58.3	1.0–29.9

[a] There were missing length of stay data for 41 vaginally delivered and 39 Cesarean-delivered newborns.

TABLE 2 Number of Weights Used in the Final Analysis

No. of Weight Measurements	Vaginal (*n* = 4525)	Cesarean (*n* = 2550)
1	3410 (75.4%)	909 (35.6%)
2	1057 (23.4%)	1083 (42.5%)
3	57 (1.3%)	526 (20.6)
4	1 (<0.1%)	31 (1.2%)
5	—	1 (<0.1%)

≥2 weights recorded between 6 and 72 hours (Table 2). The difference reflects the longer average length of stay for cesarean delivery newborns.

Figure 2 presents percentile curves and 95% confidence intervals for vaginally delivered newborns. Median percent weight loss for these neonates was 2.9% at 48 hours of age. By 48 hours, <5% of vaginally delivered newborns had lost at least 7% of their birth weight. Figure 3 presents percentile curves and 95% confidence intervals for newborns born via cesarean delivery. Median percent weight losses among these neonates at 48 and 72 hours were 3.7% and 3.5%, respectively; weight loss >8% occurred in <5% of newborns.

In our main analysis depicted in Fig 2, a total of 432 newborns delivered vaginally (10%) and 888 newborns born via cesarean delivery (35%) had at least 1 weight censored from the analysis because it was obtained after the first time of breastfeeding. In the sensitivity analyses, weights were imputed for newborns with censored weights based on matching to newborns with no censored weights. Ninety-five percent of censored newborns had exact matches for time and gestational age, and >80% had a match of percent weight loss within 0.20 percentage point (Table 3). Percentile curves estimated from the original data plus the imputed data for censored weights were similar to the curves of the original data for each method of delivery.

DISCUSSION

These results provide the first graphical depiction of hourly weight loss for formula-fed newborns. Because weight changes steadily throughout the birth hospitalization and is measured at varied intervals from the hour of birth, these new nomograms may aid medical management by allowing clinicians and other providers to categorize newborn weight loss and calibrate decision-making to reflect hour of age. They may contribute to earlier identification of feeding difficulties. In turn, because feeding difficulties or unexpected weight loss may be a subtle first sign of significant neonatal illness or anatomic abnormalities,[7,19] identification of these issues during the birth hospitalization could lead to earlier identification of significant causes of morbidity. Similar to www.bilitool.org, a new Web site (ie, www.newbornweight.org) was developed by the study team to allow clinicians to compare individual newborns and their weight loss against our large sample.

Differences were noted between formula-fed infants who were delivered vaginally versus those with a cesarean delivery. At 48 hours of postnatal life, median percent weight loss for formula-fed infants delivered vaginally was 2.9%. For those born via cesarean delivery, it was 3.7%. These findings suggest that predelivery factors such as maternal hydration status may modestly affect postnatal weight loss in formula-fed infants.[3]

Compared with nomograms previously developed for breastfeeding newborns,[11] these results clearly identify that mode of feeding dramatically affects weight loss. For example, weight loss >10% was common among newborns who were exclusively breastfed and born via cesarean delivery. For formula-fed newborns, there were only 7 (0.1%) infants with >10% weight loss at any time.

The detailed data according to hour of life from a large, diverse population is a major strength of this study, particularly because data were available on type and timing of all feedings. Moreover, the similarity between the

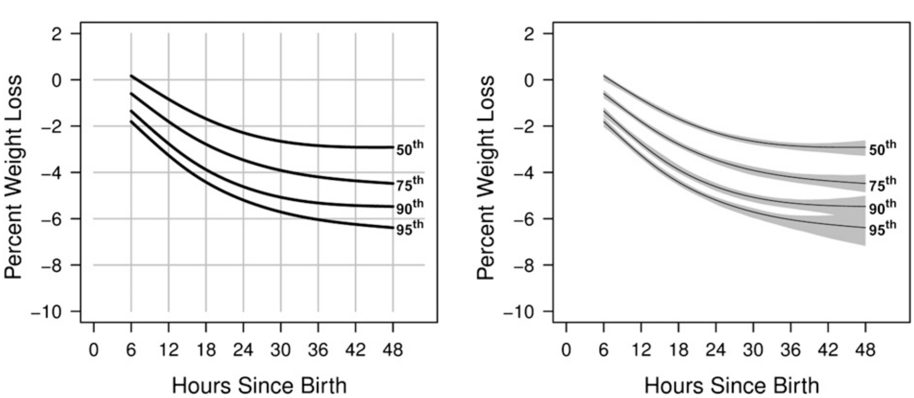

FIGURE 2 Estimated percentile curves of percent weight loss and 95% confidence intervals (gray region) according to time after birth for vaginal deliveries.

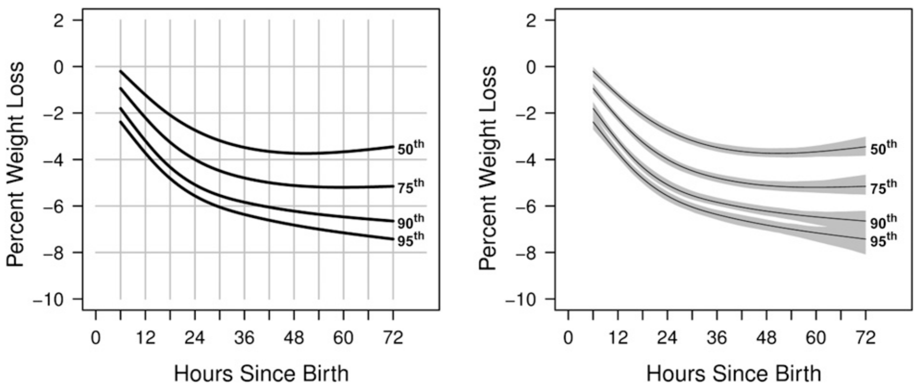

FIGURE 3 Estimated percentile curves of percent weight loss and 95% confidence intervals (gray region) according to time after birth for cesarean deliveries.

results presented in the main analysis and the results of the sensitivity analysis (in which weights were imputed for weights censored due to breastfeeding) offers evidence of the robust nature of the findings.

These analyses share similar limitations, as reported in the previous analysis of exclusively breastfed newborns.[11] First, weights for the study were obtained in the course of routine care, with various scales calibrated according to the guidelines of individual institutions. Second, feeding reports in this study were obtained from the electronic medical record maintained by the nursing staff, and the staff may not have been aware of or documented all feedings. Third, the northern California population studied was racially diverse, with only 43% being white non-Hispanic. Results could be different for populations with other racial and ethnic compositions. Finally, infants included in this study represented the typical distribution of patients in a nursery and likely included a small number of infants with comorbid conditions who were not ill enough to require intensive care. It is possible that infants with such diagnoses may have influenced our data.

The detailed data on weight and feeding available for this large cohort allow the study to present the first graphical depiction of hourly weight loss for formula-fed newborns. Similar to the widely used bilirubin nomogram by Bhutani et al,[8] which has been incorporated into the American Academy of Pediatrics' guidelines as well as our recent report for breastfed newborns,[11] our findings offer the potential for wide clinical applicability and may be generalized to other populations because the data are from a large, racially diverse cohort delivered at multiple hospitals.

Weight loss of ≥7% of birth weight is uncommon at any time in the formula-fed neonate, regardless of mode of delivery. Because poor feeding can be a subtle symptom of underlying neonatal illness or congenital malformation,[19] the data in the accompanying nomograms could be used to guide potential feeding interventions in the hospital and the timing of follow-up assessments. Future research should examine the ability of these nomograms (available at www.newbornweight.org) to predict newborn morbidity and how these data compare with that of other populations.

TABLE 3 Summary of Matched Variables for Newborns With Censored Weights

Variable	Vaginal (*n* = 432)	Cesarean (*n* = 888)
Time, h		
Exact match	420 (97.2%)	834 (93.9%)
1 h difference	11 (2.5%)	42 (4.7%)
2 h difference	1 (0.2%)	9 (1%)
3 h difference	–	3 (0.3%)
Percent weight loss		
<0.05 percentage point	229 (53%)	353 (39.8%)
Between 0.05 and 0.20 percentage point	155 (35.9%)	368 (41.4%)
Between 0.20 and 0.50 percentage point	41 (9.5%)	146 (16.4%)
Between 0.50 and 1 percentage point	7 (1.6%)	16 (1.8%)
>1 percentage point	–	5 (0.6%)
Gestational age		
Exact match	341 (78.9%)	624 (70.3%)
1 wk difference	81 (18.8%)	201 (22.6%)
2 wk difference	8 (1.9%)	50 (5.6%)
3 wk difference	2 (0.5%)	12 (1.4%)
4 wk difference	–	1 (0.1%)

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