Weight Change Nomograms for the First Month After Birth

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abstract

OBJECTIVE: Clinicians expect newborns to surpass birth weight by age 10 to 14 days, yet few studies have examined the natural history of weight change in the weeks after birth. We sought to determine the distribution of weight loss and subsequent regain during the first month, the proportion not surpassing birth weight by 14 and 21 days, and whether findings differed by delivery mode.

METHODS: For 161 471 singleton neonates delivered at ≥36 weeks' gestation at Kaiser Permanente Northern California Medical Centers between 2009 and 2013 and weighing 2000 to 5000 g at birth, we extracted daily weights from inpatient electronic records and weights from outpatient visits in the first month. Quantile regression appropriate for repeated measures was used to estimate percentiles of weight change as a function of time after birth, stratified by delivery mode.

RESULTS: After exclusions, weight data were analyzed from 143 889 newborns (76% born vaginally). Based on percentile estimates, 50% of newborns were at or above birth weight at 9 and 10 days after vaginal and cesarean delivery, respectively. Among those delivered vaginally, 14% and 5% were not back to birth weight by 14 and 21 days, respectively. For those delivered by cesarean, 24% and 8% were not back to birth weight by 14 and 21 days, respectively.

CONCLUSIONS: It is not uncommon for newborns to be below birth weight 10 to 14 days after delivery. A larger percentage of newborns delivered by cesarean had yet to regain birth weight at every time point through 1 month.

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Dr Paul conceptualized the study and analysis, oversaw the data analysis, drafted the initial manuscript, and participated in critical revision of the manuscript; Mr Schaefer led the data management, performed the data analyses, and participated in critical revision of the manuscript; Drs Miller, Kuzniewicz, and Flaherman contributed to the study design, participated in data analysis, and critically revised the manuscript for important scientific content; Ms Li contributed to the study design, carried out preliminary analyses, and critically revised the manuscript for important scientific content; Ms Walsh participated in study design and data analysis, coordinated data collection, and critically revised the manuscript for important scientific content; and all authors approved the final manuscript as submitted.

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WHAT'S KNOWN ON THIS SUBJECT: Guidance from the American Academy of Pediatrics suggests that most newborns should surpass their birth weight by age 7 to 10 days, with weekly gains of 4 to 7 ounces for the first several months.

WHAT THIS STUDY ADDS: The majority of newborns are below birth weight at 7 days. Indeed, only 50% are above birth weight at 9 and 10 days after vaginal and cesarean delivery, respectively, with some taking 2 to 3 weeks or longer to surpass the birth weight milestone.

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Nearly all newborns lose weight during the first days after birth regardless of whether they are breastfed or formula fed, with neonates typically reaching their weight nadir within 3 to 4 days of delivery.[1,2] After discharge from the birth hospitalization, weight change is commonly used as a strong indicator of feeding success, and common anticipatory guidance to parents is that infants should gain 4 to 7 ounces per week for the first several months.[3] Although anecdotally, most clinicians expect newborns to regain their initial weight and surpass birth weight by age 10 to 14 days, *Bright Futures: Nutrition,* published by the American Academy of Pediatrics (AAP), indicates that newborns "usually regain their birth weight within 7 days."[3] Furthermore, the *Guidelines for Perinatal Care,* published by the AAP and the American College of Obstetricians and Gynecologists, instructs that "failure to regain birth weight by 2 weeks of age in the term infant requires careful evaluation of the feeding techniques being used and the adequacy of breastfeeding."[4]

Surprisingly few data exist to support these statements because few studies have examined the natural history of newborn weight loss and the amount of time it takes for well newborns to regain this weight and surpass their birth weight. Studies that have examined this question have been limited by factors including small sample size, single center, lack of stratification by delivery mode, and frequent weights obtained outside of routine clinical care, which can lead to a biased result.[5–11] Since our development of nomograms to describe weight loss during the birth hospitalization,[2,12] which are publicly available at www.newbornweight.org, newborn care providers have asked for similar data for the outpatient setting after the birth hospitalization. Therefore, from this same large sample of well newborns, we sought to determine the distribution of weight loss and subsequent regain during the first month, the proportion of newborns not surpassing birth weight by 14 and 21 days, and whether these findings differed by delivery mode.

METHODS

Participants and Outcomes

The analysis included 161 471 newborns 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 level II or level III care. From this cohort, newborns were excluded if they had missing data on type of delivery, missing weight data after birth, birth weight <2000 g or >5000 g, multiple birth, discrepantly reported birth weights between data sources, no weight documented after 6 hours of age during the birth hospitalization, or prolonged birth hospitalizations (>96 or >120 hours after vaginal or cesarean delivery, respectively). Newborns with implausible weight loss or weight gain values during the birth hospitalization (>10% loss in the first 24 hours, >15% loss at any time thereafter, gain >5% at any time) were also excluded because these were considered data collection or entry errors. The final analytic cohort contained 143 889 newborns (Fig 1).

Data were extracted on all weights obtained during the birth hospitalization (≥6 hours after birth) and on gestational age, method of delivery, length of stay, hospital of birth, and maternal race or ethnicity. Weights were also extracted from all outpatient and inpatient visits through age 30 days after discharge from the birth hospital. 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 done daily in clinical practice. Implausible weights recorded in outpatient or inpatient visits after discharge (≥20% weight loss at any time point, ≥50% weight gain in first 14 days, and ≥75% weight gain in first month) were excluded (N = 138/668 799 weights = <0.01%). This study was approved by the institutional review boards at Penn State College of Medicine, the University of California San Francisco, and Kaiser Permanente Northern California.

Analyses

Quantile regression methods appropriate for data with repeated measures were used to estimate fifth, 10th, 25th, 50th (median), 75th, 90th, and 95th percentiles of weight change as a function of time after birth. The penalized fixed-effects model in the R package "Regression Quantiles for Panel Data" was used to estimate the percentile curves.[13] The model is an extension of ordinary quantile regression[14] to longitudinal settings in which newborns may be weighed at multiple time points and was used in previous analyses to create nomograms for the birth hospital setting.[1,2] The model accounts for multiple (or repeated) weights from a newborn by including a separate intercept parameter for each newborn, with regularization used to estimate these intercepts by shrinking them toward a common value. The amount of regularization is controlled by a tuning parameter, which was set equal to 5 as in the previous analysis. A natural spline with 4 degrees of freedom was used to generate nonlinear percentile curves.[15] All weights recorded from 6 to 720 hours (30 days) after birth were included. The value of 0% weight change at birth was also included for all newborns to ensure that all curves started at 0% at birth. For this reason, an overall intercept term was not included in the model. Nonparametric bootstrapping with 500 resamples

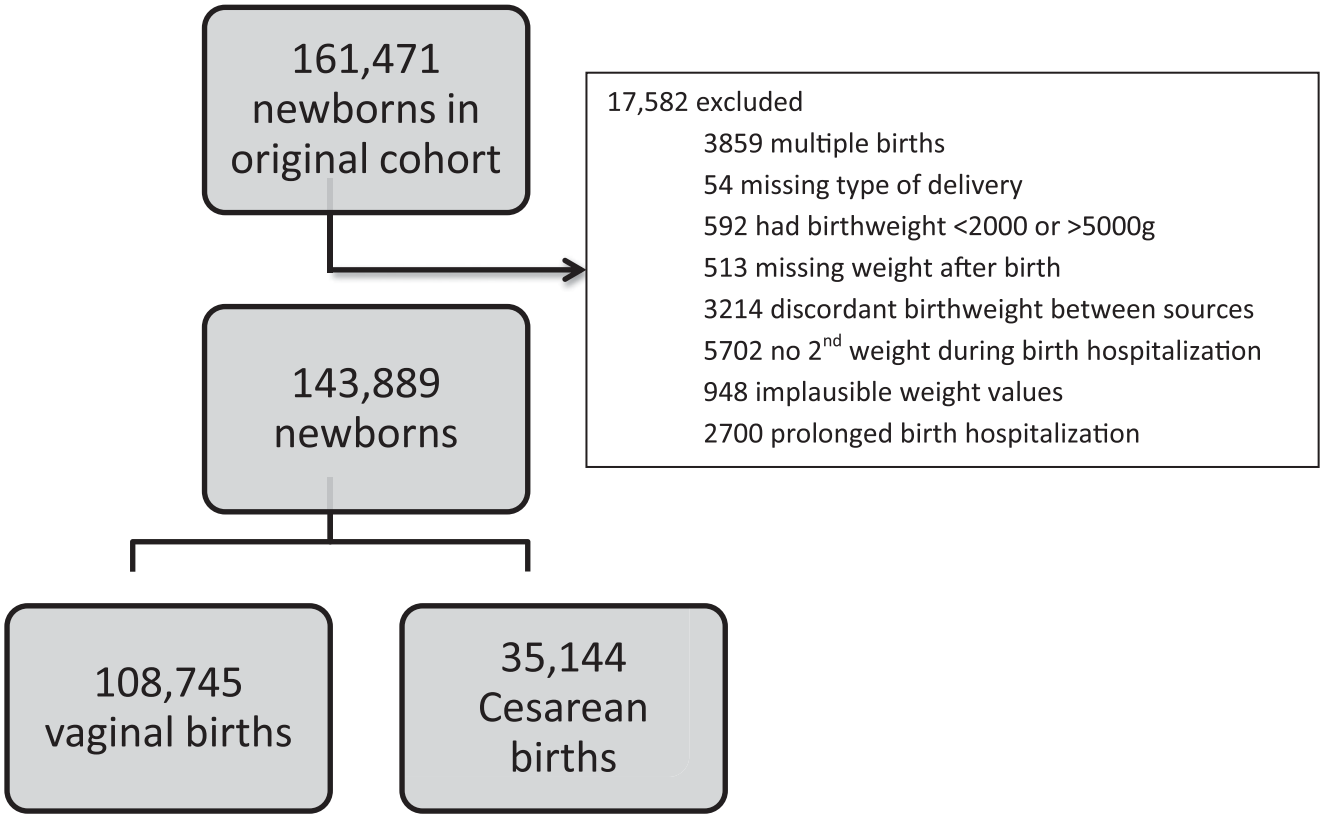

FIGURE 1
Derivation of final analytic cohort.

and the percentile method were used to obtain confidence intervals for each percentile curve.[16] We also examined whether percentile estimates differed by gestational age (36–38, 39–40, and 41–43 weeks) and birth weight (2000–2999, 3000–3999, and 4000–5000 g) groups. The same model as above was fit separately for each gestational age and birth weight group for each delivery mode.

RESULTS

Among the cohort of 143 889 who met all inclusion criteria and were included in this analysis, 108 745 (75.6%) were delivered vaginally and 35 144 (24.4%) were delivered by cesarean (Table 1). Mean (SD) birth weight was 3435 g (458 g) for these neonates delivered at a median gestational age of 39 weeks. Approximately 40% of mothers were self-described as white, non-Hispanic, with ~25% being each Asian and Hispanic. Exclusive breastfeeding during the maternity stay occurred in 63% of newborns, with only 4% exclusively feeding formula. The median newborn lengths of stay were 1.5 and 2.6 days after vaginal and cesarean delivery, respectively.

During the first month after birth, infants delivered vaginally had 480 491 weights subsequent to birth weight recorded, with a median (interquartile range) of 5 (4–6) weights recorded across all settings (birth hospital, outpatient visit, inpatient visit). Infants delivered by cesarean had 188 170 weights subsequent to birth weight recorded, with a median of 6 (5–7) weights recorded through age 30 days. After the birth weight measurement, weights were most commonly obtained during the newborn hospital stay, with additional clustering during the first days after discharge and at ~14 days of age (Fig 2).

Percentile curves of weight change after birth are shown in Fig 3 separately for vaginal and cesarean deliveries. Differences in percentile estimates between vaginal and cesarean deliveries occurred early and persisted through 30 days. The nadir for the 50th percentiles was −5.9% (61 hours) and −7.1% (68 hours) after vaginal and cesarean delivery, respectively; subsequent increases of weight gain for the 50th percentile occurred at a rate of ~1.17 and ~1.11 percentage points per day through the end of the first month, respectively. Averaging differences between cesarean and vaginal curves across all integer time points separately for each percentile, cesarean curves were a mean 1.2 percentage points lower (5th percentile) to 2.1 percentage points lower (50th and 75th percentiles). After vaginal delivery, ~50% of newborns surpassed birth weight by age 9 days, although 14% and 5% had not achieved this milestone by ages

TABLE 1 Demographic and Clinical Characteristics of Included Newborns by Type of Delivery

	Vaginal, *N* = 108 745	Cesarean, *N* = 35 144
Birth weight, g		
Mean (SD)	3415 (443)	3495 (496)
2000–2999, *N* (%)	18 508 (17.0)	5412 (15.4)
3000–3999, *N* (%)	79 651 (73.2)	24 235 (69.0)
4000–4999, *N* (%)	10 586 (9.7)	5497 (15.6)
Gestational age, wk		
Median (interquartile range)	39 (38–40)	39 (38–40)
36–38, *N* (%)	30 361 (27.9)	9212 (26.2)
39–40, *N* (%)	66 085 (60.8)	21 739 (61.9)
41–43, *N* (%)	12 299 (11.3)	4193 (11.9)
Maternal race or ethnicity, *N* (%)		
Hispanic	27 551 (25.3)	8619 (24.5)
American Indian or Eskimo	444 (0.4)	144 (0.4)
Asian	26 436 (24.3)	8734 (24.9)
Black, non-Hispanic	7368 (6.8)	2830 (8.1)
White, non-Hispanic	44 056 (40.5)	13 832 (39.4)
Other or unknown	2890 (2.7)	985 (2.8)
Newborn hospital stay in days, median (interquartile range)	1.5 (1.2–2.0)	2.6 (2.1–3.1)
Weights recorded per child, median (interquartile range)		
Total[a]	5 (4–6)	6 (5–7)
Birth hospital	1 (1–2)	2 (2–3)
Outpatient	3 (2–4)	2 (2–3)

[a] Subsequent inpatient data not presented because only 4% and 2% were readmitted for any reason after vaginal and cesarean delivery, respectively.

14 and 21 days, respectively. After cesarean delivery, ~50% of newborns exceeded their birth weight at day 10; 24% and 8% were below birth weight at days 14 and 21, respectively.

To examine whether percentile curves differed by key demographic features, we fit models separately by gestational age (36–38, 39–40, and 41–43 weeks) and birth weight (2000–2999, 3000–3999, and 4000–5000 g) groups. For both delivery modes, percentage weight change was similar for gestational age groups for each percentile during the first 14 days after birth, and from 14 to 30 days after birth, neonates with shorter gestations had slightly higher percentage weight gains. In contrast, for both delivery modes percentage weight change was notably different between birth weight groups for all percentiles. Starting at ~3 days after birth, smaller birth weight groups had increasingly higher estimates of percentage weight change over time. Figure 4 shows 50th percentile estimates by birth weight group for each delivery mode (all percentiles showed a similar pattern). Figure 4 also shows the 50th percentiles by

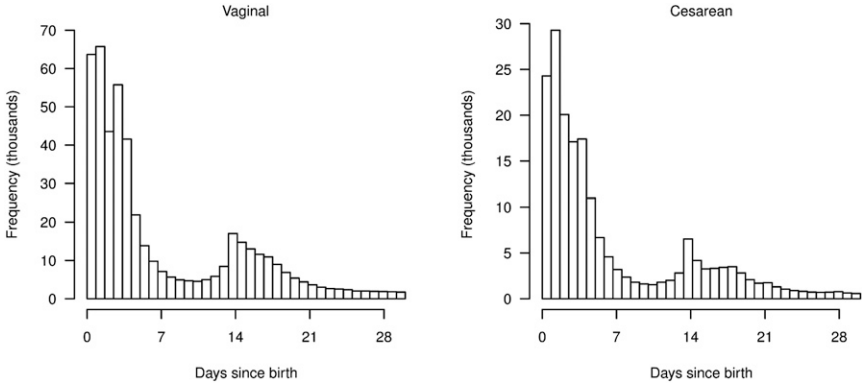

FIGURE 2
Timing and frequency of weights subsequent to birth weight.

birth weight group based on actual weights (as opposed to percentage weight change) for each delivery mode, which help explain the differences observed: Similar weight gain after the nadir of each curve corresponded to larger percentage increases for smaller birth weight groups. For example, focusing on the 50th percentile for cesarean deliveries, the actual amount of weight loss to the nadir differed between the birth weight groups (median losses of 202 g, 252 g, and 305 g for smallest to largest birth weight groups, respectively), but these differences corresponded to approximately the same percentage (losses of 7.2%) relative to the median birth weight for each group. After the nadir, the curves showed daily increases in weight for each group that were similar (38, 39, and 35 g/day), but these increases corresponded to larger percentage increases for smaller birth weight groups (1.4%, 1.1%, and 0.8%). The percentile estimates indicated that ~50% of neonates with birth weights between 2000 and 2999 g had surpassed birth weight by age 8 days for vaginal deliveries and 9 days for cesarean deliveries, whereas ~50% of

neonates with birth weights between 4000 and 5000 g had achieved this milestone by age 10 and 12 days, respectively.

DISCUSSION

These analyses represent the most detailed assessment of weight change among well newborns in the first month after birth to date and provide data for several aspects of newborn anticipatory guidance that previously lacked sufficient evidence. Whereas AAP-published texts suggest that newborns should surpass birth weight by age 7 days and that failure to do so by 14 days suggests feeding difficulties, our data suggest that the majority of newborns take more than a week to achieve this milestone, sometimes weeks longer. Those delivered by cesarean on average take longer to regain their birth weight than those delivered vaginally. After they reach their weight nadir, weekly weight gain on average exceeds the 4 to 7 ounces cited by AAP texts, with on average a 35 to 40 g daily gain that varies slightly by birth weight and delivery mode.

Each of these new findings has important implications for newborn care, particularly among those who are breastfeeding. Mothers with newborns still below birth weight 10 to 14 days after delivery may feel anxious about their milk supply as a result of providers holding them to a non–evidence-based norm.[12,17] Using these new nomograms to understand normal newborn weight trends may reduce the need for clinicians to recommend formula supplementation for breastfed newborns who have not regained their birth weight by 10 to 14 days after birth. Our new nomograms may also provide reassurance to parents of infants who are still below birth weight at 10 to 14 days after birth. Because newborn weight can affect maternal milk supply concern,[12,18] a common contributor to breastfeeding cessation,[19–21] it is possible that use of these new nomograms may even reduce the risk of breastfeeding cessation by reassuring mothers about normal newborn weight trends. Similarly, some office visits and medical evaluations may be avoided.

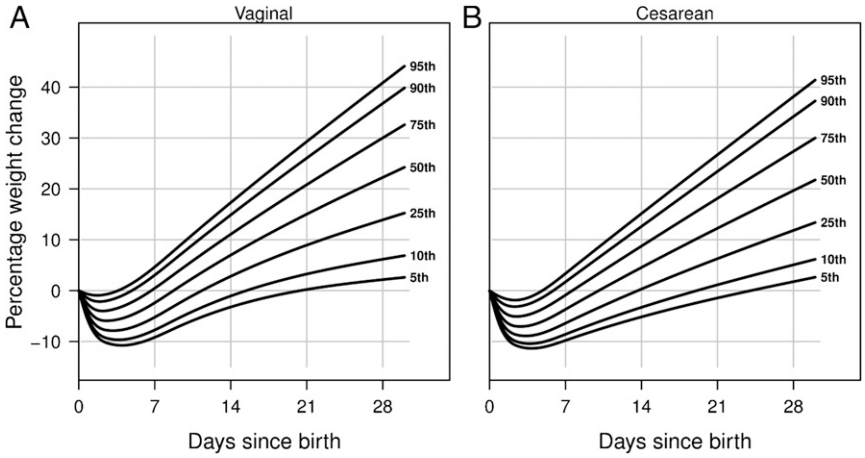

FIGURE 3
Estimated percentile curves of percentage weight change by time after birth. A, Vaginal delivery. B, Cesarean delivery.

The data presented here are similar to those described previously with smaller samples. For example, Crossland et al[6] studied 111 exclusively breastfed women and found that ~50% and 25% were below birth weight at 8 and 12 days, respectively. Macdonald et al[5] similarly reported a median time to surpass birth weight among 395 breastfeeding newborns of 8.3 days, although ~5% took ≥19 days. Times were shorter for formula-fed newborns in that study. In addition to the small sample sizes, these 2 studies and others are limited by describing the experience at a single center with research designs that involved frequent weights and contact with study or clinical personnel that differ from real-world practice. These previous studies also failed to stratify by delivery mode, which we have shown to be an important factor for weight change during the first days and weeks after birth.

We were concerned that newborns with a large number of weights and newborns who were weighed only within the first week may have substantially influenced our estimated curves. We examined these scenarios by fitting separate models after randomly selecting only 1 weight for each newborn in the data set, and after using matching to impute data for newborns with last recorded weight at ≤7 days. Estimates were in accordance with the final models (not shown), indicating that our final estimates were robust to these potential issues.

As opposed to our nomograms constructed for the birth hospitalization,[1,2] the differences in percentage weight change as a function of birth weight may limit broad application of a single weight change nomogram to the outpatient setting. Stated most simply, because actual daily weight gain is similar irrespective of birth weight, those with lower birth weights have faster percentage weight gain, whereas larger newborns gain a smaller percentage per day. These larger newborns therefore on average take longer to get back to birth weight than those with lower birth weights.

Our study has additional limitations. As opposed to our previous publications describing the birth hospitalization,[1,2] we did not have

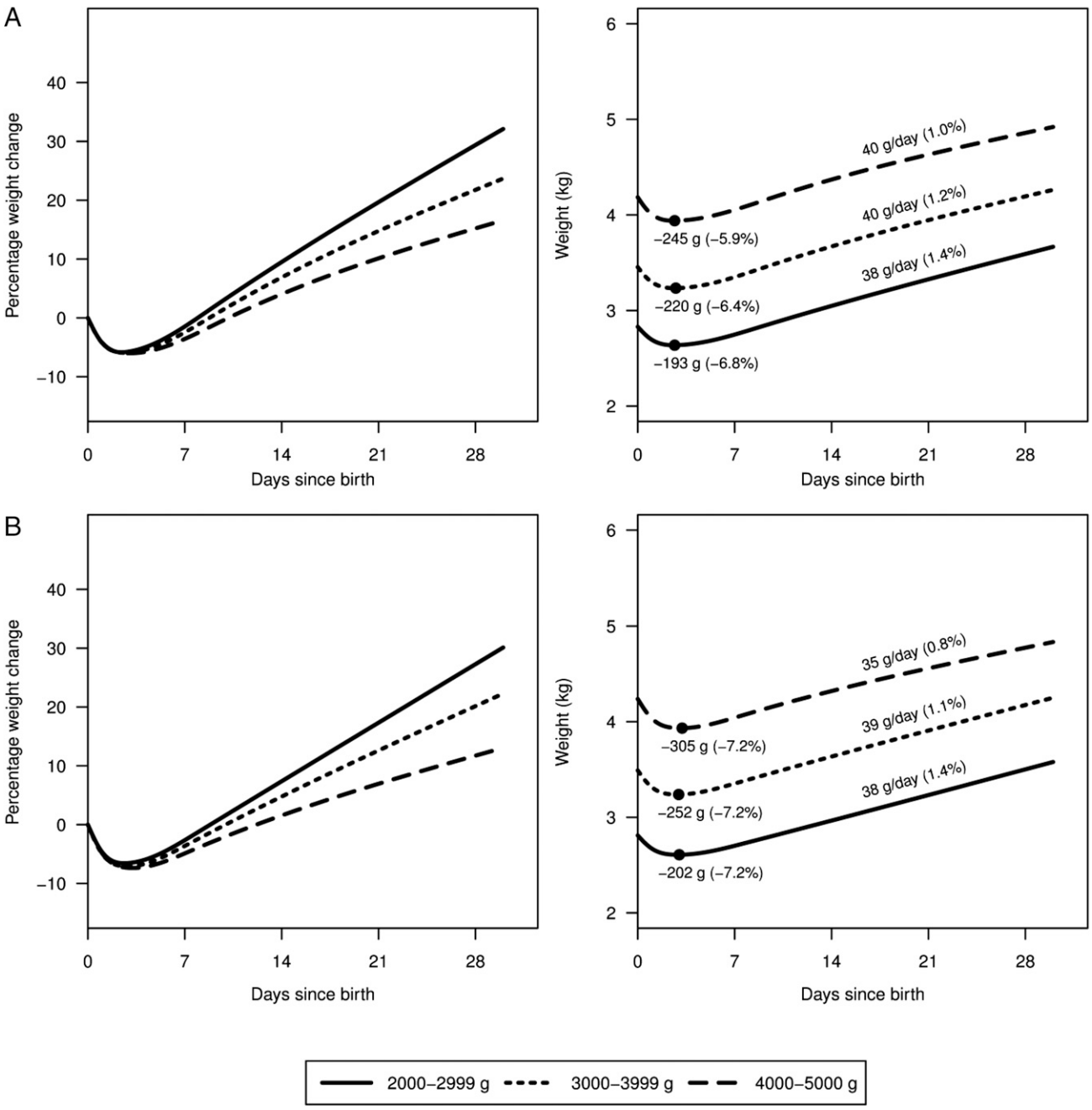

FIGURE 4
Median percentage weight change (left panels) and median weight (right panels) by birth weight groups as a function of time after (A) vaginal delivery and (B) cesarean delivery. The decrease in median weight in grams (%) from birth at nadir for each group is listed followed by daily rate of gain.

precise data on infant feeding mode in the outpatient setting. Therefore, data on weight change through age 1 month does not account for infant feeding mode. Furthermore, weights obtained for this study were obtained as part of routine clinical care, and calibration of these scales is subject to individual institutional guidelines.

In summary, these data demonstrate that it is not uncommon for newborns to be below birth weight 10 to 14 days after delivery regardless of delivery mode. This is especially true for those delivered by cesarean, who lose more weight on average in the first few days. Although ensuring adequate feeding and weight gain remains an important part of well newborn care, advice based on anecdote can now be replaced with hard data.

ABBREVIATION

AAP: American Academy of Pediatrics

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