Length of Stay and Readmission Among Late Preterm Infants: An Instrumental Variable Approach

OBJECTIVE: Evidence to guide safe discharge for late preterm infants (34–36 weeks’ gestation) is lacking. Previous studies have demonstrated the increased risk of neonatal readmission for these infants compared with those born at term (≥37 weeks’ gestation). The purpose of this study was to estimate the effect of length of stay (LOS) on 7-day readmissions in this population.

METHODS: This was a retrospective study using hospital discharge data linked with vital records for late preterm infants delivered vaginally in California from 1993 to 2005. Exclusion criteria included complications likely requiring neonatal intensive care. The effect of LOS was assessed by using birth hour as an instrumental variable to account for unmeasured confounding. By using a matching algorithm, we created pairs of infants with different LOS based on birth hour but otherwise matched on known confounders for readmission risk, including birth year, hospital, and clinical and demographic covariates such as gestational age, birth weight, race, and insurance.

RESULTS: We produced 80,600 matched pairs of infants with different LOS based on birth hour. In 122 pairs, both infants were readmitted within 7 days, and in 75,362 pairs, neither infant was readmitted. Of the remaining 5,116 matched pairs in which only 1 infant was readmitted, 2,456 infants with long LOS and 2,660 infants with short LOS were readmitted. We found no evidence that longer LOS reduces the odds of readmission (1-sided P value = .99).

CONCLUSIONS: By using an instrumental variable approach and matching algorithm, longer LOS was not associated with decreased readmission within 7 days of discharge for these late preterm infants.

Of all pediatric hospitalizations in the United States, the majority (4 million annually) are for neonates ≤30 days of age.1 Although most neonatal hospitalizations are for births during that hospital stay, readmissions in the first 30 days of life, particularly for potentially preventable causes such as jaundice and poor feeding, account for >100,000 hospitalizations each year.1 Neonatal readmissions have a significant impact on new families and may be decreased by appropriate hospital care and follow-up.2–4 Given the volume of neonatal hospitalizations and their contribution to pediatric health care spending, this represents an important area for potential improvements in hospital care quality.5,6

One group at particular risk for neonatal readmission is late preterm infants, delivered at 34 to 36 weeks’ gestation, comprising >70% of infants born preterm.7 Several studies have described the morbidity and mortality risks associated with this group compared with term infants delivered at ≥37 weeks’ gestation8–12; specific complications include higher risks of hyperbilirubinemia, poor feeding, and temperature instability. In the neonatal period, they are more likely
to be readmitted for jaundice as well as non–jaundice-related diagnoses.\textsuperscript{13–15} Despite these known risks, current gaps in knowledge include evidence-based recommendations for discharge care to minimize readmissions.\textsuperscript{12}

Although policy statements from the American Academy of Pediatrics assert that late preterm infants are unlikely to meet eligibility criteria for early discharge (before 48 hours of life), previous research suggests that early discharge of these infants is common.\textsuperscript{12,16,17} The implications of this practice are unclear. Previous studies of healthy term infants suggest a minimal, if any, association between length of stay (LOS) and neonatal readmissions.\textsuperscript{18–20} However, given the known risks of complications in late preterm infants, further research is necessary to understand the effect of LOS on neonatal readmissions in this population.

One methodologic challenge in studying the association between LOS and readmission is unmeasured confounding. An infant requiring prolonged LOS may have more complications, such as feeding inadequacy, and also may be more likely to be readmitted than an infant discharged before 48 hours. Alternatively, there could be unmeasured reasons for early discharge, such as parental attitudes and competence in caregiving, which may be associated with reduced readmission risk. We therefore used an instrumental variable (IV) approach, an increasingly recognized alternative to standard statistics when the association between primary predictor and outcome is confounded by unmeasured factors.\textsuperscript{21,22} An IV is a variable correlated with the primary predictor (ie, LOS) but does not belong in the causal pathway with the outcome (ie, readmission). The purpose of the current study was to use birth hour as an IV in an attempt to mimic a randomized assignment of LOS to late preterm infants to test the hypothesis that longer LOS reduces 7-day readmissions within a population otherwise matched on clinical and sociodemographic characteristics.

**METHODS**

**Data Set**

We used statewide discharge data on birth hospitalizations in California from 1993 to 2005, available from the California Office of Statewide Health Planning and Development. Each hospital record contains information from the UB-92 form (ie, demographic data, admission source, dates of admission and discharge), principal diagnoses, and procedures; these data have been linked to birth certificate data with a 98\% match rate as described previously, as well as to maternal hospital records.\textsuperscript{23,24} In addition, hospitalizations up to 1 year after birth are matched to infant birth certificates. The resulting data set is a powerful tool to evaluate an expansive group of maternal–infant factors, including demographic characteristics, pregnancy-related health conditions, medical treatments during hospitalization, and readmission outcomes in a population-based sample (~8.7 million births in total over 13 years). This project was approved by the institutional review boards of the California Department of Health and The Children’s Hospital of Philadelphia.

**Study Population**

Our study evaluated live-born infants delivered vaginally at 34 to 36 weeks’ gestation and discharged from the hospital. Gestational age was identified by using birth certificate data from the best obstetric estimate. *International Classification of Diseases, Ninth Revision, Clinical Modification* (ICD-9-CM) codes and birth certificate data were used to exclude infants delivered via cesarean delivery because they are usually hospitalized at least 72 hours’ postpartum. Of the 322,904 vaginally delivered late preterm infants, 66,641 with maternal postpartum LOS >2 days were excluded because infants remained in the hospital while awaiting maternal discharge. By using ICD-9-CM codes, we also excluded those likely to require neonatal intensive care: major congenital anomalies (n = 3335), surgeries (n = 107), or complications such as respiratory distress syndrome or sepsis (n = 8153). We also excluded 12,837 infants with LOS >5 days because prolonged hospitalization likely reflects significant complications and possible need for neonatal intensive care and thus ineligibility for early discharge. The resulting sample (before infant matching) comprised 231,831 infant–maternal pairs delivered at 310 hospitals.

**Birth Hour as an IV**

Based on previous studies, we used birth hour as an IV due to its correlation with infant LOS.\textsuperscript{25,26} For this approach to be valid, the IV must meet 3 criteria: (1) strength: how well the IV is associated with LOS; (2) independence: lack of additional unmeasured confounding; and (3) no association with readmission except through its effect on LOS.\textsuperscript{21} Previous research has described how reimbursement patterns for birth hospitalizations, which are generally billed in number of midnights, may contribute to the association between birth hour and LOS.\textsuperscript{26} As an example, infant
A delivered late in the evening will be billed for that first midnight, whereas infant B delivered after midnight, at 01:00, will have almost a full 24 hours of care before being billed for the first hospital day. As a result, infant A may be less likely than infant B to be discharged from the hospital after only 1 night of observation in the hospital. As such, birth hour may essentially randomize infants to differing LOS. Because birth hour should only affect an infant’s readmission risk through this association with LOS, it can be used to estimate the impact of LOS on readmissions.

To calculate each infant’s actual LOS, we used previously reported data on infant discharge timing, because hour of discharge was not available in our data set. For infants born and discharged from the hospital within the same calendar day, we assumed a discharge time of 17:00; for all others staying at least 1 night, we assumed a discharge time of 13:00. For each birth hour (0:00 to 23:00), we then calculated a median LOS; as an example, the median LOS for infants born at 18:00 was 43 hours. Thus, birth hour can be transformed into an expected LOS, which is the IV for each infant’s actual LOS based on his or her birth hour.

Strength of the IV was assessed by its association with LOS by using an F statistic in the first stage of a 2-stage least squares regression testing the null hypothesis that birth hour has no effect on actual LOS; an F statistic <10 suggests a weak correlation between birth hour and actual LOS. Independence of the IV from confounding variables was assessed by using the standardized difference in means for each covariate. The association between the IV and primary outcome variable was assessed by using a \( \chi^2 \) test for difference in the proportion readmitted.

**Matched Study Design**

Although often calculated by using a 2-stage least squares method, an IV estimator is a Wald estimator that can be calculated by using other approaches. Recent studies have demonstrated that the use of a matched study design, as an alternative to a 2-stage least squares model, yields a nonparametric approach that helps strengthen the instrument and avoid overextrapolation of the data.

We therefore used an algorithm to match pairs of infants with similar clinical and demographic characteristics but different IV values. Within each pair, 1 infant had a long expected LOS and 1 infant had a short expected LOS. As an example, an infant born at 11:00, IV of 26 hours, might be paired with an infant born at 18:00, IV of 43 hours. To maximize strength of the instrument, we restricted analysis to pairs of infants who were far apart in expected LOS, and the algorithm preferentially created pairs of infants with a short expected LOS between 21 and 27 hours and a long expected LOS between 38 and 44 hours. For every pair, the difference in expected LOS was at least 12 hours; on average, it was 14 hours.

We identified, a priori, several covariates for matching that may be important potential measured confounders. To account for temporal trends in both early discharge and readmission, we exactly matched infants on birth year. We also exactly matched on hospital to account for hospital-level variability. Gestational age, gender, race, insurance, education, parity, and single versus multiple gestation were

---

### TABLE 1 Number of Infant Pairs According to Birth Hour With Corresponding Mean Difference in Expected LOS

<table>
<thead>
<tr>
<th>Longer Expected LOS Infants</th>
<th>16:00</th>
<th>15:00</th>
<th>14:00</th>
<th>13:00</th>
<th>12:00</th>
<th>11:00</th>
<th>10:00</th>
<th>9:00</th>
<th>8:00</th>
<th>7:00</th>
<th>6:00</th>
<th>5:00</th>
</tr>
</thead>
<tbody>
<tr>
<td>17:00</td>
<td>180 (23)</td>
<td>272 (22)</td>
<td>325 (21)</td>
<td>414 (20)</td>
<td>469 (19)</td>
<td>501 (18)</td>
<td>600 (17)</td>
<td>788 (16)</td>
<td>924 (15)</td>
<td>1151 (14)</td>
<td>1662 (13)</td>
<td>2537 (12)</td>
</tr>
<tr>
<td>18:00</td>
<td>238 (22)</td>
<td>289 (21)</td>
<td>373 (20)</td>
<td>471 (19)</td>
<td>550 (18)</td>
<td>623 (17)</td>
<td>767 (16)</td>
<td>996 (15)</td>
<td>1227 (14)</td>
<td>1537 (13)</td>
<td>2127 (12)</td>
<td></td>
</tr>
<tr>
<td>19:00</td>
<td>259 (21)</td>
<td>358 (20)</td>
<td>460 (19)</td>
<td>584 (18)</td>
<td>683 (17)</td>
<td>758 (16)</td>
<td>951 (15)</td>
<td>1176 (14)</td>
<td>1560 (13)</td>
<td>1994 (12)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>20:00</td>
<td>290 (20)</td>
<td>386 (19)</td>
<td>542 (18)</td>
<td>685 (17)</td>
<td>846 (16)</td>
<td>917 (15)</td>
<td>1195 (14)</td>
<td>1403 (13)</td>
<td>2023 (12)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>21:00</td>
<td>409 (19)</td>
<td>500 (18)</td>
<td>615 (17)</td>
<td>787 (16)</td>
<td>963 (15)</td>
<td>1255 (14)</td>
<td>1494 (13)</td>
<td>1924 (12)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>22:00</td>
<td>444 (18)</td>
<td>588 (17)</td>
<td>780 (16)</td>
<td>981 (15)</td>
<td>1255 (14)</td>
<td>1495 (13)</td>
<td>1925 (12)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>23:00</td>
<td>510 (17)</td>
<td>719 (16)</td>
<td>928 (15)</td>
<td>1191 (14)</td>
<td>1676 (13)</td>
<td>1859 (12)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0:00</td>
<td>491 (16)</td>
<td>692 (15)</td>
<td>952 (14)</td>
<td>1308 (13)</td>
<td>1746 (12)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1:00</td>
<td>708 (15)</td>
<td>997 (14)</td>
<td>1412 (13)</td>
<td>1997 (12)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2:00</td>
<td>987 (14)</td>
<td>1486 (13)</td>
<td>2176 (12)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3:00</td>
<td>1612 (13)</td>
<td>2501 (12)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4:00</td>
<td>3176 (12)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Vertical axis represents infants with birth hours conferring longer LOS; horizontal axis represents infants with birth hours conferring shorter LOS. Table values are the number of infant pairs for each birth hour combination. Values in parentheses indicate the mean difference in expected LOS between paired infants for each birth hour combination.
finely balanced to yield an exactly equal covariate distribution between the long-IV group and the short-IV group, even if individual pairs of infants were not exactly matched on these covariates. For birth weight, multiple approaches were used to ensure optimal matching. More than 97% of pairs were exactly matched on an indicator variable for low birth weight (ie, <2500 g). Mean birth weights between short-IV and long-IV infants were also constrained to be similar (~3065 g in both groups). Finally, an effort was made to pair infants with similar birth weights. Additional clinical covariates were near-finely balanced in the algorithm, so that their distributions between short-IV and long-IV infants were permitted to differ but only slightly. These variables were constructed from ICD-9-CM codes and included oligohydramnios, cord and placental abnormalities, chorioamnionitis, premature rupture of membranes, and birth injury (Appendix).

**Outcome Definition**

Readmission was defined as any hospitalization within 7 days of discharge because readmission beyond the first week may be more influenced by decisions in the primary care office rather than the hospital. By using the IV to control for unmeasured confounding, the odds ratio and the confidence interval for 7-day readmission were assessed among matched infants.
with longer versus shorter expected LOS. A 1-sided test of the null hypothesis was conducted that longer LOS does not reduce readmission risk. As a sensitivity analysis, we also stratified this test on year of birth (data not shown).

RESULTS
Evaluation of Birth Hour as an IV
We produced 80,600 pairs of late preterm infants matched on clinical and demographic characteristics but with different IV values. Table 1 depicts birth hours for paired infants and the mean difference in expected LOS for each pairing.

IV Strength
Table 2 depicts the distribution of covariates according to birth hour. Overall, these were evenly distributed, with only small differences in means across blocks of time.

7-Day Readmissions
Unadjusted Analysis
Among the matched sample of 161,200 infants, 3.3% were readmitted within 7 days of discharge. As seen in Fig 1, the percentage of readmitted infants increased during the study time frame from 3.0% in 1993 to 3.8% in 2005; this trend is statistically significant (Cochran-Armitage $P$ value <.001). However, there was no unadjusted association between the IV and readmission status, with 16% and 17% of readmitted and non-readmitted infants, respectively, having an expected LOS <24 hours ($P = .66$).

Matched Pairs Analysis
Table 4 depicts readmission status among pairs of infants with longer and shorter expected LOS after matching on all other covariates. In 122 matched pairs, both the longer LOS and shorter LOS infants were readmitted within 7 days, and in 75,362 pairs, neither was readmitted. Among the remaining 5,116 matched pairs in which only 1 infant was readmitted, the odds ratio for readmission for infants with longer versus shorter expected LOS was estimated to be 1.08 (95% confidence interval: 1.02–1.14). By using a 1-sided test of the null hypothesis, there was no evidence that longer LOS reduces readmissions ($P = .99$). When we stratified this analysis on birth year, results were similar.

DISCUSSION
This study evaluated the relationship between LOS and readmissions for late preterm infants. We demonstrated the utility of an IV approach to account for unmeasured factors that may contribute to differences in readmission risk, and we extended previous approaches by using a novel matching algorithm. Trend data suggest an increase in the percentage of late preterm infants readmitted over
Results of our analysis suggest that longer LOS does not reduce readmissions in this population. Our results are consistent with previous studies of LOS and readmissions for term infants. Much of this literature focuses on state and federal legislation from the 1990s, which mandated insurers to cover hospital stays of ≥48 hours for vaginal deliveries and ≥96 hours for cesarean deliveries.

Many studies have demonstrated a higher readmission rate among late preterm infants compared with term infants. This literature emphasizes the risks associated with late preterm birth and underscores the need for parental counseling regarding these infants, who may appear more mature than they are. Our current finding that longer LOS has no effect on reducing neonatal readmissions in this population may have useful implications for hospitals seeking to improve late preterm infant care; discharge appropriateness criteria may need to focus less on LOS and more on clinical and social factors.

### Table 3

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Readmitted (N = 5360)</th>
<th>Not Readmitted (N = 155840)</th>
<th>P Value (χ²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Actual LOS</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;24 h</td>
<td>21.7 (1165)</td>
<td>25.6 (3964)</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>24–48 h</td>
<td>62.6 (3354)</td>
<td>58.8 (9157)</td>
<td></td>
</tr>
<tr>
<td>&gt;48 h</td>
<td>15.7 (840)</td>
<td>15.6 (24317)</td>
<td></td>
</tr>
<tr>
<td>IV, h&lt;sup&gt;a&lt;/sup&gt;</td>
<td></td>
<td></td>
<td>.66</td>
</tr>
<tr>
<td>&lt;24</td>
<td>16.3 (874)</td>
<td>16.5 (25781)</td>
<td></td>
</tr>
<tr>
<td>24–48</td>
<td>83.7 (4486)</td>
<td>83.5 (130059)</td>
<td></td>
</tr>
</tbody>
</table>

Gestational age, wk

34 11.2 (599) 13.9 (21667) <.001

35 28.9 (1548) 28.2 (43364) <.001

36 59.9 (3213) 57.9 (90209) <.001

LBW <2500 g

12.7 (679) 10.0 (15521) <.001

Mean birth weight, gb

297759 3068.01 <.001

Female

41.1 (2204) 47.4 (73898) <.001

Race

Hispanic 38.1 (2043) 50.5 (78641) <.001

White 40.9 (2192) 29.5 (45942) <.001

Asian 13.5 (726) 9.6 (15016) <.001

Black 4.0 (217) 7.6 (11801) <.001

Other 3.4 (182) 2.8 (4440) <.001

Insurance

Medicaid 42.7 (2291) 52.5 (81381) <.001

HMO 48.8 (2614) 38.7 (60308) <.001

Fee-for-service 5.5 (297) 4.5 (6993) <.001

Uninsured 2.0 (109) 3.6 (5651) <.001

Other 0.9 (49) 0.7 (1040) <.001

High school degree

73.1 (3920) 59.5 (92270) <.001

Nulliparous 53.1 (2844) 373 (58066) <.001

Multiple gestation

12 (97) 2.2 (3429) <.001

Birth injury

2.1 (111) 1.1 (1697) <.001

Oligohydramnios

0.7 (37) 0.9 (1394) <.001

Cord abnormality

3.5 (188) 3.4 (5336) <.001

Placental disorders

1.3 (72) 1.0 (1525) <.001

Eclampsia

0.15 (10) 0.0 (42) <.001

Chorioamnionitis

1.7 (93) 1.3 (2055) <.001

Postpartum fever

0.2 (12) 0.2 (237) <.001

Gestational diabetes

5.2 (276) 3.3 (5146) <.001

Diabetes mellitus

0.7 (38) 0.4 (612) <.001

PROM

16.4 (880) 7.9 (12344) <.001

Data are presented as % (n) unless otherwise indicated. HMO, health maintenance organization; LBW, low birth weight; PROM, premature rupture of membranes.

<sup>a</sup> Although some infants had an actual LOS >48 hours, the IV was calculated as a median LOS based on birth hour. Because the IV represents an expected, not actual, LOS, the range of IV values does not exceed 48 hours.

<sup>b</sup> P value for difference in mean birth weights represents the F statistic P value.

<sup>c</sup> The P values in this table were also calculated with a Bonferroni correction for multiple comparisons. The P values that changed from being statistically significant at the 5% percent level to not being significant are denoted.
more systematically focused on issues such as feeding and parental readiness, this would again suggest that specific processes of care during hospitalization are more important than LOS alone in affecting readmissions.

Although the focus of the current study was to determine whether longer LOS is associated with reduced readmissions in this population, a 2-sided confidence interval actually suggested evidence of slightly increased odds of readmission among infants with longer LOS. This unanticipated finding raises a potential concern that the birth hour instrument is still confounded with risk factors for readmission, despite our attempts to account for observed covariates. An alternative possibility is that differences in care for infants discharged early, such as early primary care follow-up or home nursing visits, resulted in improved care coordination and decreased readmissions compared with those discharged after longer LOS. Future research may focus on these aspects of postdischarge care, including home visits, that may be more directly associated with readmissions as well as other important outcomes (ie, discontinuation of breastfeeding).14,15,20

One limitation of this study was our inability to precisely determine LOS in hours, which we estimated by using birth hour, number of hospital nights, and assumptions about discharge timing. For this estimation, we repeated the approach of Malkin et al, by using median discharge times from a Rand survey conducted in 2000 of 2447 infants born in California and Iowa; among the population surveyed, >70% of infants had an actual discharge within 3 hours of the median.26,27 Another limitation was our use of administrative data, which may result in misclassification bias if undercoded or overcoded. Although we adjusted for observable characteristics, there may still be residual unmeasured confounding based on birth hour. However, this is unlikely given previous research demonstrating no difference in mortality or short-term morbidity in preterm infants by birth hour after adjustment for maternal and infant characteristics.40 Finally, an additional limitation was our focus on readmission rather than more specific health outcomes such as breastfeeding failure. Readmission is relatively infrequent, and it may be influenced by other processes of care such as home visits and other outpatient follow-up factors. However, readmission is widely used as an indicator of adverse health outcomes; it is costly, it reflects morbidity, and it can be systematically measured.

CONCLUSIONS
Neonatal readmissions have a significant impact on new families and may be decreased by appropriate hospital care and follow-up.2–4 Given the high volume of neonatal hospitalizations, readmissions represent an important area for potential improvement in hospital care quality. Although late preterm infants are particularly vulnerable to complications, including readmission, our study demonstrated no reduction in 7-day readmissions associated with longer LOS for this population. Further research is needed to validate and extend these findings for late preterm infant cohorts in other regions of the country. These results underscore the importance of focusing attention on other aspects of care, particularly postdischarge management, that may improve outcomes for this population.

ACKNOWLEDGMENTS
The authors thank Corinne Ahlberg, MS, and Kristin Ray, MD, for their assistance with data management.

REFERENCES


## APPENDIX ICD-9-CM Diagnosis Codes Used to Identify Maternal Comorbidities

<table>
<thead>
<tr>
<th>Condition</th>
<th>ICD-9-CM Codes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Birth injury</td>
<td>7672–7679</td>
</tr>
<tr>
<td>Placental disorders</td>
<td>641.0x, 641.1x, 641.2x</td>
</tr>
<tr>
<td>Eclampsia</td>
<td>642.6x</td>
</tr>
<tr>
<td>Chorioamnionitis</td>
<td>658.4x, 659.2x, 659.3x</td>
</tr>
<tr>
<td>Diabetes mellitus</td>
<td>250.x, 3572, 362.0x, 366.41, 648.0x</td>
</tr>
<tr>
<td>Premature rupture of membranes</td>
<td>658.1x, 658.2x</td>
</tr>
<tr>
<td>Oligohydramnios</td>
<td>658.0x</td>
</tr>
<tr>
<td>Cord abnormalities</td>
<td>663.0x, 663.1x, 663.5x</td>
</tr>
<tr>
<td>Maternal postpartum fever</td>
<td>672.x</td>
</tr>
</tbody>
</table>