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Original Article

Birth Weight and Gestational Age as Modifiers of Rehospitalization after Neonatal Intensive Care Unit Admission

Tatiana Moreno, BS[1] Louis Ehwerhemuepha, PhD[1] Joan Devin, BS[2] William Feaster, MD[1] Michel Mikhael, MD[1]

[1] Children's Hospital of Orange County, Orange, California
[2] School of Pharmacy and Biomolecular Sciences, Royal College of Surgeons in Ireland, Dublin, Ireland

Address for correspondence Tatiana Moreno, BS, Children's Hospital of Orange County, 505 Main Street, 10th Floor, Orange, CA 92868-3874 (e-mail: tatiana.moreno@choc.org).

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Abstract

Objective This study aimed to assess interaction effects between gestational age and birth weight on 30-day unplanned hospital readmission following discharge from the neonatal intensive care unit (NICU).

Study Design This is a retrospectivestudy that uses the study site's Children's Hospitals Neonatal Database and electronic health records. Population included patients discharged from a NICU between January 2017 and March 2020. Variables encompassing demographics, gestational age, birth weight, medications, maternal data, and surgical procedures were controlled for. A statistical interaction between gestational age and birth weight was tested for statistical significance.

Results A total of 2,307 neonates were included, with 7.2% readmitted within 30 days of discharge. Statistical interaction between birth weight and gestational age was statistically significant, indicating that the odds of readmission among low birthweight premature patients increase with increasing gestational age, whereas decrease with increasing gestational age among their normal or high birth weight peers.

Conclusion The effect of gestational age on odds of hospital readmission is dependent on birth weight.

Keywords
- gestational age
- hospital readmission
- neonatal intensive care unit
- neonatology
- birth weight

Key Points

- Population included patients discharged from a NICU between January 2017 and March 2020.
- A total of 2,307 neonates were included, with 7.2% readmitted within 30 days of discharge.
- The effect of gestational age on odds of hospital readmission is dependent on birth weight.

Hospital readmission is a leading cause of health care costs and high resource utilization.[1–3] Some unplanned hospital readmissions (UHR) are preventable, and reducing UHR rates is a critical priority.[4–8] A reduction in UHR has been shown to circumvent patient and parental dissatisfaction, limit increasing health care expenditures, and reduce mortality.[9–12] UHR is a measure of health care quality, and the identification of risk factors related to readmission provides clinical

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insight into mitigation strategies aimed at reducing this risk.[13,14]

Risk factors and readmission rates have been widely reported in older adults[7,15–18] and pediatric patient groups[2,12,19] including diagnosis-specific pediatric models examining the impact of pulmonary hypertension[20] and lower respiratory tract infections[21] on readmission rates. However, these models are not accurate reflections of hospital performance in neonates and younger infants.

Neonatal patients discharged from a neonatal intensive care unit (NICU) may be at increased risk of UHR, with those born prematurely more likely to be admitted than those born at term.[22,23] It is difficult to accurately predict risk in this population as NICU patients are a relatively heterogeneous group in relation to reasons for NICU hospitalization, such as gestational age and diagnoses. Moreover, neonates have different physiological parameters than pediatric and adult patients.[24] NICU patients generally will not have the history of health care utilization that most readmission models depend on for high model performance[2,18] and may transfer between facilities or get readmitted to other areas in the hospital; therefore, health records may be fragmented.[25]

Previous studies on neonatal readmission risks have centered around specific newborn populations stratified by birth weight (e.g., <1,500 g),[26,27] prematurity,[28] or diagnosis-specific encounters such as bronchopulmonary dysplasia or respiratory syncytial virus.[29,30] In this study, we hypothesize that the effect of prematurity (gestational age < 37 wk) on UHR is dependent on birth weight. Therefore, we set out to examine statistical interactions between gestational age and birth weight while controlling for potential confounders.

Materials and Methods

This study was approved by the Institutional Review Board of the corresponding author's institution with Institutional Review Board number: 2008107.

Data Source

We retrieved and combined retrospective neonatal encounter data from our local Children's Hospitals Neonatal Database (CHND)[31] and the electronic health records (EHR) databases. CHND provided perinatal, neonatal, and maternal data, whereas the EHR database provided other clinical data captured on the patients.

Patients and Variables

Neonates (aged 28 days or less) who were admitted to the NICU between January 2017 and March 2020 were selected. The status of 30-day readmission was calculated, and all planned readmissions were excluded using data on preregistration.[2] Patients that died before initial discharge were also excluded. The 30-day readmission metric was selected a priori.

Data on neonatal demographics, maternal data, hospital resource utilization variables, medications, infections, and surgical complications were retrieved as measured confounders to control for.

Statistical Considerations

The level of multicollinearity[32] (correlation) among the predictors was assessed by estimating the generalized variance inflation factor (GVIF) across the candidate variables.[32,33] Variables with a GVIF of greater than 4 were excluded in a stepwise manner to reduce the negative impact of highly correlated variables and statistical separation.[34,35]

A full model consisting of all variables and a two-way statistical interaction between gestational age and birth weight was built and used for inference. Analyses were conducted using the R Statistical Programming Language.[36]

Results

A total of 2,307 neonates met the inclusion criteria of which 165 (7.2%) had unplanned readmission within 30 days of discharge. Median day of life (age) at NICU admission was 2 days (interquartile range [IQR], 3 d). Other patient demographics include 42.70% female, 23.58% Caucasian, 36.63% non-White Hispanic, 9.28% Asian, 1.82% African American/Black, and 28.70% other or unknown race/ethnicity. There are statistically significantly greater odds of hospital readmission among neonates that had one or more surgical procedures during the initial NICU admittance as displayed in ►Table 3. Low birthweight (LBW) patients (birth weight <2.5 kg) were 37.62% of the overall population, whereas the median gestational age of all patients was 38 weeks (IQR, 5 wk). Median length of stay was 10 days (IQR, 21 d). Maternal information indicates that of all mothers 57.74% were on public/governmental insurance plans; 81.71% had documented prenatal care; 10.75% had multiple gestation; and 27.05% received antenatal steroids. Summary statistics on all variables by readmission status are shown in ►Table 1.

Statistical interaction between gestational age and birth weight was significant at an alpha level of 0.05 ($p = 0.001$). Corresponding effect sizes are shown in ►Table 2 with a graphical exposition of the interaction shown in ►Fig. 1. Odds ratios and 95% confidence intervals for all variables controlled for are shown in ►Table 3. The interaction indicates that the odds of readmission increase with gestational age among LBW neonates. In other words, higher gestational age with LBW is a risk factor for readmission, whereas lower gestation among non-LBW or normal weight neonates is a risk factor for readmission in this cohort.

Discussion

Growth, development, and changes to physiology occur rapidly during the first year of life.[24] Consequently, gestational age and birth weight are key to neonatal outcomes. We rejected the null hypothesis that an interaction between gestational age and birth weight is not associated with odds of readmission after NICU stay.

Table 1 Summary statistics

Variable	Level	Readmitted	Not readmitted
		n (%) or median (IQR)	
Neonatal demographics			
Gender	Female	926 (43.23)	59 (35.76)
	Male	1,216 (56.77)	106 (64.24)
Day of life (DOL)		2.00 (3.00)	2.00 (3.00)
Gestational age (wk)		37.40 (4.80)	37.00 (5.00)
Race	Caucasian	512 (23.90)	32 (19.39)
	African American	39 (1.82)	3 (1.82)
	Asian or Pacific Islander	202 (9.43)	12 (7.27)
	Hispanic	775 (36.18)	70 (42.42)
	Other or multiple	614 (28.66)	48 (29.09)
Other neonatal data			
Birth weight (kg)	<2.5	803 (37.49)	65 (39.39)
	≥2.5	1,339 (62.51)	100 (60.61)
Length of stay	–	9.00 (19.00)	20.00 (39.00)
Focal intestinal perforation	None	2,128 (99.35)	164 (99.39)
	Present	14 (0.65)	1 (0.61)
NICU referral	No	1,525 (71.20)	93 (56.36)
	Yes	617 (28.80)	72 (43.64)
Endotracheal tube ventilation	None	1,685 (78.66)	128 (77.58)
	Done	149 (6.96)	12 (7.27)
	Unknown	308 (14.38)	25 (15.15)
Gastrointestinal anomalies	None	2,092 (97.67)	158 (95.76)
	Present	50 (2.33)	7 (4.24)
Infections	None	902 (42.11)	66 (40.00)
	Present	1,240 (57.89)	99 (60.00)
Neonatal hospital interventions			
Surgical procedure(s)	None	1,786 (83.38)	95 (57.58)
	One or more	356 (16.62)	70 (42.42)
Ileostomy/colostomy	No	2,122 (99.07)	159 (96.36)
	Yes	20 (0.93)	6 (3.64)
Feeding ostomy	No	2,031 (94.82)	138 (83.64)
	Yes	111 (5.18)	27 (16.36)
Tracheostomy	No	2134 (99.63)	160 (96.97)
	Yes	8 (0.37)	5 (3.03)
Maternal data			
Assisted reproductive technology	None	2,055 (95.94)	159 (96.36)
	Present	87 (4.06)	6 (3.64)
Group B *Streptococcus* colonization	No	1,831 (85.48)	143 (86.67)
	Yes	311 (14.52)	22 (13.33)
Antenatal steroids	None	1,566 (73.11)	117 (70.91)
	One or more	576 (26.89)	48 (29.09)
Prenatal care	No	73 (3.41)	4 (2.42)
	Yes	1,750 (81.70)	135 (81.82)
	Unknown	319 (14.89)	26 (15.76)

(*Continued*)

Table 1 (*Continued*)

Variable	Level	Readmitted	Not readmitted
		n (%) or median (IQR)	
Multiple gestation	No	1,908 (89.08)	151 (91.52)
	Yes	234 (10.92)	14 (8.48)
Insurance at time of discharge from NICU	Private	907 (42.34)	68 (41.21)
	Public	1,235 (57.66)	97 (58.79)
Substance use history	No	1,719 (80.25)	136 (82.42)
	Yes	80 (3.73)	2 (1.21)
	Unknown	343 (16.01)	27 (16.36)
Medications (neonatal) administered during hospitalization and/or discharge			
Analgesic	No	1,445 (67.46)	72 (43.64)
	Yes	697 (32.54)	93 (56.36)
Antiarrhythmics	No	1450 (67.69)	79 (47.88)
	Yes	692 (32.31)	86 (52.12)
Anticonvulsants	No	1,944 (90.76)	131 (79.39)
	Yes	198 (9.24)	34 (20.61)
Benzodiazepines	No	1861 (86.88)	121 (73.33)
	Yes	281 (13.12)	44 (26.67)
Bronchodilators	No	1,856 (86.65)	115 (69.70)
	Yes	286 (13.35)	50 (30.30)
Cephalosporins	No	1,598 (74.60)	87 (52.73)
	Yes	544 (25.40)	78 (47.27)
Diuretics	No	1,900 (88.70)	124 (75.15)
	Yes	242 (11.30)	41 (24.85)
Inhaled corticosteroids	No	2,057 (96.03)	148 (89.70)
	Yes	85 (3.97)	17 (10.30)
Proton pump inhibitors	No	2,072 (96.73)	147 (89.09)
	Yes	70 (3.27)	18 (10.91)

Abbreviations: IQR, interquartile range; NICU, neonatal intensive care unit.

Table 2 Two-way statistical interaction between gestational age and birth weight

Variable/term	Coefficient/logit log OR (95% CI)	*p*-Value
Gestational age	0.10 (0.006, 0.19)	0.04
Birth weight (kg)	8.52 (3.18, 13.75)	0.002
Gestational age–birth weight interaction	−0.23 (−0.38, −0.09)	0.001

Abbreviations: CI, confidence interval; OR, odds ratio.

The results of this study indicate that premature neonates with normal or high birth weight for their gestation admitted to the NICU generally have increased odds of readmission compared with their LBW counterpart (who survive the NICU). A cross-over effect takes place at a gestational age of 37 weeks where LBW patients tend to have greater odds of readmission.

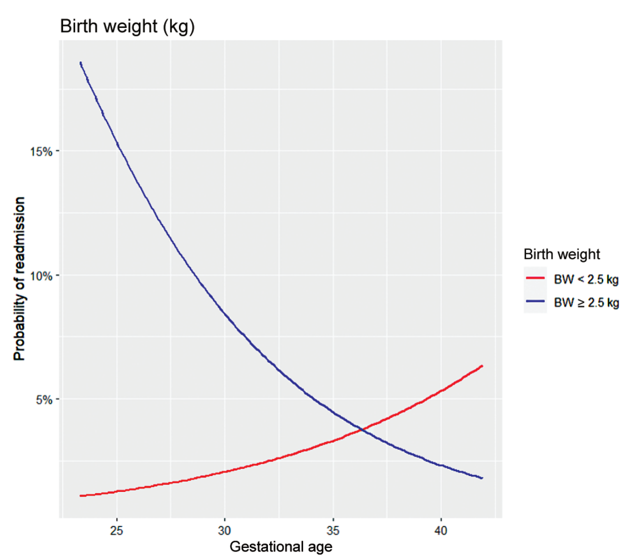

Fig. 1 Interaction between gestational age and birth weight.

Table 3 Variables controlled for in multivariable model

Variable	Levels	30-d readmission OR (95% CI)	*p*-Value
Neonatal demographics			
Sex	Male	1.36 (0.97, 1.92)	0.08
Day of life (DOL)	–	1.01 (0.98, 1.04)	0.44
Race	White	Reference	
	African American	1.08 (0.30, 3.87)	0.90
	Asian or Pacific Islander	0.91 (0.45, 1.83)	0.78
	Hispanic	1.50 (0.94, 2.39)	0.09
	Other or multiple	1.31 (0.80, 2.16)	0.29
Other neonatal data			
Length of stay	–	1.00 (0.99, 1.01)	0.95
NICU referral	–	1.16 (0.79, 1.72)	0.45
Endotracheal tube ventilation	–	0.65 (0.32, 1.32)	0.24
Gastrointestinal anomalies	–	0.68 (0.28, 1.64)	0.39
Infections	–	0.93 (0.64, 1.35)	0.69
Neonatal hospital interventions			
Surgical procedure	–	2.16 (1.18, 3.95)	0.01
Maternal data			
Group B *Streptococcus* colonization	–	0.96 (0.59, 1.57)	0.87
Antenatal steroids	–	1.28 (0.76, 2.16)	0.35
Multiple gestation	–	0.84 (0.46, 1.56)	0.59
Health insurance/payer	Public/governmental	0.90 (0.63, 1.29)	0.57
Medications			
Analgesic	–	1.33 (0.76, 2.31)	0.32
Antiarrhythmics	–	1.31 (0.86, 2.01)	0.21
Anticonvulsants	–	1.25 (0.71, 2.22)	0.44
Benzodiazepines	–	0.77 (0.43, 1.38)	0.37
Bronchodilators	–	1.02 (0.60, 1.73)	0.94
Cephalosporins	–	1.12 (0.65, 1.93)	0.69
Diuretics	–	1.24 (0.72, 2.14)	0.44
Proton pump inhibitors	–	1.37 (0.69, 2.73)	0.37

Abbreviations: CI, confidence interval; NICU, neonatal intensive care unit; OR, odds ratio.

Among LBW babies, the risk of 30-day UHR increases as gestational age increases. This identifies the clinical vulnerabilities in infants with intrauterine growth restriction (IUGR). Various studies have found infants with IUGR are at higher risk of mortality, respiratory distress syndrome,[37] chronic lung disease,[38] and necrotizing enterocolitis[39] in comparison to normally grown infants of the same gestational age.[40,41] Small for gestational age neonates when compared with appropriate for gestational age neonates had significantly increased risk in respiratory failure or death.[37] Thus, the increased odds of readmission for neonates with lower birth weight as gestational age increases are evidence of greater generalized risk in this LBW neonatal population. Consequently, term babies with LBW should be provided interventions to reduce readmission including postdischarge services and access to primary care resources.

Limitations

There were several limitations to this study. First, this is a single-center retrospective study (from a large tertiary pediatric health system) that captures only portions of the broad heterogenous neonatal population in the United States. Multicenter studies would ensure that more diverse and larger samples of the population are captured for model development. Second, the maternal, perinatal, and neonatal variables used for this study were selected based on availability within CHND and the hospital's EHR. Lastly, these variables were captured as part of routine care and may not contain the robustness of data captured specifically for research.

Conclusion

Future studies will focus on the use of machine learning and artificial intelligence to predict and flag high-risk patients for readmission on discharge from the NICU, including strategies for deployment of corresponding models and corresponding interventions.[42] The findings of this study suggest postdischarge interventions and more comprehensive assessments targeted at LBW infants and normal to high birth weight premature infants as these may reduce neonatal readmission. Further research on the interaction between gestational age and birth weight on neonatal readmission is required, as existing studies are limited on this topic. This study has identified a need for targeted discharge interventions on these high risk for readmission neonates.

Conflict of Interest
None declared.

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