ARTICLE

Nurse Staffing and NICU Infection Rates

Jeannette A. Rogowski, PhD; Douglas Staiger, PhD; Thelma Patrick, PhD, RN; Jeffrey Horbar, MD; Michael Kenny, MS; Eileen T. Lake, PhD, RN

Importance: There are substantial shortfalls in nurse staffing in US neonatal intensive care units (NICUs) relative to national guidelines. These are associated with higher rates of nosocomial infections among infants with very low birth weights.

Objective: To study the adequacy of NICU nurse staffing in the United States using national guidelines and analyze its association with infant outcomes.

Design: Retrospective cohort study. Data for 2008 were collected by web survey of staff nurses. Data for 2009 were collected for 4 shifts in 4 calendar quarters (3 in 2009 and 1 in 2010).

Setting: Sixty-seven US NICUs from the Vermont Oxford Network, a national voluntary network of hospital NICUs.

Participants: All inborn very low-birth-weight (VLBW) infants, with a NICU stay of at least 3 days, discharged from the NICUs in 2008 (n=5771) and 2009 (n=5630). All staff-registered nurses with infant assignments.

Exposures: We measured nurse understaffing relative to acuity-based guidelines using 2008 survey data (4046 nurses and 10 394 infant assignments) and data for 4 complete shifts (3645 nurses and 8804 infant assignments) in 2009-2010.

Main Outcomes and Measures: An infection in blood or cerebrospinal fluid culture occurring more than 3 days after birth among VLBW inborn infants. The hypothesis was formulated prior to data collection.

Results: Hospitals understaffed 31% of their NICU infants and 68% of high-acuity infants relative to guidelines. To meet minimum staffing guidelines on average would require an additional 0.11 of a nurse per infant overall and 0.34 of a nurse per high-acuity infant. Very low-birth-weight infant infection rates were 16.4% in 2008 and 13.9% in 2009. A 1 standard deviation–higher understaffing level (SD, 0.11 in 2008 and 0.08 in 2009) was associated with adjusted odds ratios of 1.39 (95% CI, 1.19-1.62; $P<.001$) in 2008 and 1.40 (95% CI, 1.19-1.65; $P<.001$) in 2009.

Conclusions and Relevance: Substantial NICU nurse understaffing relative to national guidelines is widespread. Understaffing is associated with an increased risk for VLBW nosocomial infection. Hospital administrators and NICU managers should assess their staffing decisions to devote needed nursing care to critically ill infants.

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Neonatal intensive care units (NICUs) care for the most critically ill infants. Neonatal intensive care unit stays are among the most expensive hospitalizations[1] and require high levels of nursing resources. Very little is known about the adequacy of staffing in US NICUs. Acuity-based staffing guidelines for neonatal nursing[2] were recently reaffirmed by national medical and nursing bodies,[3,4] although definitions of infant acuity levels do not exist. It is not known how well the guidelines are followed or how guideline adherence relates to infant outcomes.

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The guidelines specify ranges of nurse to patient ratios across infant acuity levels, as well as requisite nurse training and experience. For instance, infants with the lowest acuity levels have a recommended nurse to patient ratio of 1 to 3 or 4. In contrast, the highest acuity infants have recommended ratios of 1 or more nurses per patient. Furthermore, the guidelines also address the level of education and experience of the nurses, noting that "registered nurses in the NICU should have specialty certification or advanced training. They also should be experienced in caring for unstable

Author Affiliations are listed at the end of this article.

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Table 1. Definitions for Infant Acuity Levels

Level	Care Provided per Newborn Requirement According to Guideline[3,4]	Definition
1	Continuing care	Infant only requiring PO or NG feedings, occasional enteral medications, basic monitoring (may or may not have a hep lock for medications)
2	Intermediate care	Stable infant with established management plan, not requiring significant support Eg, room air, supplemental oxygen or low-flow nasal cannula, several medications
3	Intensive care	Infant is stabilized, although requires frequent treatment and monitoring to assure maintenance of stability Eg, ventilator, CPAP, high-flow nasal cannula, multiple intravenous needs via central or peripheral line
4	Multisystem support	Infant requires continuous monitoring and interventions Eg, conventional ventilation, stable on HFV, continuous drug infusions, several intravenous fluid changes via central line
5	Unstable, requiring complex critical care	Infant is medically unstable and vulnerable, requiring many simultaneous interventions Eg, ECMO, HFV, nitric oxide, frequent administration of fluids, medication

Abbreviations: CPAP, continuous positive airway pressure; ECMO, extracorporeal circulation membrane oxygenation; HFV, high-frequency ventilation; NG, nasogastric; PO, by mouth.

neonates with multi-organ system problems and in specialized care technology."[3(p32)]

One patient outcome that has been directly linked to nurse staffing in critical care is infection.[5,6] Most NICU infants have central venous lines. Nurse understaffing could result in lapses in aseptic technique that increase infants' risk for infection.[7,8] A study of 2 New York NICUs found that higher nurse staffing was associated with significantly lower infection risk in one NICU but not the other.[9] Several other single-site NICU studies have shown that infection spread is associated with nurse staffing.[10-13] A large British study found no association between nurse staffing and infection among all NICU infants.[14] However, another British study in 6 NICUs showed that more than half of shifts fell short of British guidelines and that understaffing led to delays in essential treatment and reduced clinical care.[15]

The Affordable Care Act established the Center for Medicare and Medicaid Innovation to improve quality and reduce costs in health care through improvements in health system delivery and payment innovation. The Centers for Medicare and Medicaid Services has already reformed payments for hospital-associated infections under Medicaid. For hospitals to respond effectively to these incentives, they must have access to evidence about the health systems factors, such as nurse staffing, that contribute to adverse patient outcomes such as infection.

We developed definitions for the national NICU staffing guidelines and studied guideline adherence and its association with hospital-associated infection in very low-birth-weight (VLBW) infants. We hypothesized that nurse understaffing would be positively associated with nosocomial infection. Very low-birth-weight infants are the highest-risk pediatric population, accounting for half of infant deaths in the United States each year.[16] They are highly susceptible to infection due to an underdeveloped immune system, more transparent and penetrable skin barrier, and high prevalence of central lines.[17-19] Hospital-associated infections in this population have been associated with poor neurodevelopmental and growth outcomes in early childhood, increased mortality, and longer hospital stay.[20-22] Medicaid is the largest payer for the care of these infants.[23]

METHODS

STUDY DESIGN AND DATA

This retrospective cohort study was conducted in the Vermont Oxford Network (VON), a national voluntary hospital network dedicated to improving the quality and safety of NICU care. The VON database contains detailed uniform clinical and treatment information on all VLBW infants. By 2008, the US network comprised 578 hospitals, which included approximately 65% of NICUs and 80% of all VLBW infants. This study included 67 VON hospitals with inborn infants in 2008 and 2009, with nurse staffing data from 2 data collections.

The 2008 data were collected by web survey of staff nurses and included 4046 nurses assigned to 10 394 infants (response rate, 77%). Nurses reported on their last shift the infant assignment including infants' acuity levels and whether infants were coassigned. The 2009 data were collected on 4 complete shifts. Data were collected for 4 shifts in 4 calendar quarters (3 in 2009 and 1 in 2010): 1 day shift and 3 shifts that were randomized to day, night, and weekend shifts (3645 nurses assigned to 8804 infants). For simplicity, these data are referred to as the 2009 data. Interrater reliability of the acuity levels was measured for 258 infants in 9 hospitals in 2009.

This project was approved by the institutional review boards of the University of Medicine and Dentistry of New Jersey, the University of Pennsylvania, the University of Vermont, Ohio State University, Dartmouth College, and the study hospitals.

VARIABLES

Definition of Infant Acuity Levels

The national guidelines that have existed since 1992 comprise 5 categories of infants. Infant acuity definitions were developed to represent mutually exclusive categories of infant need for nursing resources (**Table 1**). An expert panel that included a neonatologist, a perinatal nurse specialist, and a representative from the National Association of Neonatal Nurses

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Table 2. Characteristics of the NICUs and Infants

Variable	No. (%) 2008	No. (%) 2009
NICUs		
No. of NICUs	67	67
NICU levels		
A	7 (10)	9 (13)
B	41 (61)	40 (60)
C	19 (28)	18 (27)
Annual volume of VLBW admissions, mean (SD)	108 (63)	105 (64)
VLBW infants (eligible for nosocomial infection)		
No. of VBLW infants	5713	5558
Nosocomial infection	938 (16.4)	775 (13.9)
Birth weight, mean (SD), g	1077 (277)	1072 (278)
Gestational age, mean (SD), wk	28.4 (2.8)	28.4 (2.8)
1-min Apgar score, mean (SD)	5.5 (2.5)	5.4 (2.4)
Small for gestational age	1134 (19.9)	1118 (20.1)
Multiple birth	1701 (29.8)	1600 (28.8)
Congenital malformation	200 (3.5)	209 (3.8)
Vaginal delivery	1631 (28.5)	1526 (27.5)
Had prenatal care	5468 (95.7)	5341 (96.1)
Male	2878 (50.4)	2770 (49.8)
Race/ethnicity, %		
Non-Hispanic white	2905 (50.8)	2757 (49.6)
Non-Hispanic black	1641 (28.7)	1702 (30.6)
Other[a]	1167 (20.4)	1099 (19.8)

Abbreviations: NICU, neonatal intensive care unit; VLBW, very low birth weight.
[a] All other races/ethnicities, including Hispanic.

developed the definitions. These were refined through focus groups and feedback from a broad range of neonatal nurses.

Nurse Staffing Measures

Guidelines for the nurse to patient ratio by acuity level were available from medical and nursing specialty societies.[3(p29)4(p33)] Nurse to patient ratios by acuity were calculated for all infants in each NICU (adjusted for coassignments). Compliance was defined as meeting the minimum threshold. For 3 acuity levels (1, 2, and 3), the guideline specifies a range, and the maximum number of infants per nurse was used as the threshold. For acuity level 5, where the guideline indicates 1 or more nurses per infant, the threshold was set to 1 nurse per infant. When another nurse was coassigned, we assumed that the additional nurse was entirely available to care for the infant. This approach created a conservative estimate of understaffing. There were few coassignments (3.3% in 2008 and 1.5% in 2009). Two measures of understaffing were created: the percentage of infants staffed below guidelines and the mean fraction of a nurse per infant needed to meet guidelines. Because the 2009 data were based on a census of all infants and nurses on a shift and the 2008 data were based on a nurse survey, the latter data were subject to measurement error. In the survey, nurses reported caring for 6% more infants and a slightly higher average infant acuity level, and there was more variation across nurses in patient load. Thus, survey-based measures are expected to be biased toward larger understaffing compared with complete shift data. The results based on the 2009 data were emphasized.

Infant characteristics, infection rates, and NICU-level measures were obtained from the VON database using standardized definitions. The VON risk-adjustment model[24] included gestational age in weeks (and its square); small for gestational age; 1-minute Apgar score; race and ethnicity (non-Hispanic black, non-Hispanic white, or other [including Hispanic]); sex; multiple birth; presence of a major birth defect; vaginal delivery; and whether the mother received prenatal care. This model had an area under the receiver operating characteristic curve of 0.76.

Risk-adjusted infection rates for all sites were computed for both years. Nosocomial infection was defined as an infection in blood or cerebrospinal fluid culture occurring more than 3 days after birth for 3 culture-proven infections: coagulase-negative staphylococcus, the most common bacterial infection in the NICU; other bacterial infections; and fungal infections. In 2009, very few infants (0.12%) were transferred, contracted an infection, and were readmitted to the birth hospital where the infection was attributed.

Two NICU-level variables were included, consistent with prior research[24-26]: volume (measured as the log of the mean number of VLBW admissions) and level according to VON classification (A: restriction on ventilation, no surgery; B: major surgery; and C: cardiac surgery, corresponding to high level II and level III units in the American Academy of Pediatrics classification). Hospital characteristics to describe the sample were derived from the American Hospital Association Annual Survey of Hospitals.[27,28]

DATA ANALYSIS

We estimated a logistic regression of infection on understaffing in each year, controlling for risk adjusters and NICU-level covariates. We estimated random-effect models by the maximum likelihood method, which adjusted for clustering of infants within hospitals. Predicted values were generated from these regressions. Interrater reliability was computed using the Kappa statistic. Estimations were performed in Stata version 10.1 (StataCorp), with a P value of .05 in 2-tailed tests.

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Table 3. Recommended Staffing Ratios, Infant Acuity Distribution, and Nurse Understaffing Relative to Guidelines[3,4]

	Mean (SD)[a]					
		Acuity Level				
	Overall	1	2	3	4	5
Recommended nurse to patient ratios according to guidelines	NA	1:3-4	1:2-3	1:1-2	1:1	≥1:1
Infants by acuity level, %						
2008	100	32	28	28	8	4
2009	100	33	33	26	6	2
Infants who were understaffed, %						
2008	47 (20)	34 (21)	46 (22)	53 (23)	89 (15)	63 (30)
2009	31 (19)	20 (19)	29 (21)	37 (26)	77 (33)	42 (40)
Fraction of a nurse/patient needed to achieve minimum recommended nurse to patient ratio						
2008	.19 (.11)	.10 (.08)	.15 (.09)	.23 (.11)	.52 (.19)	.37 (.24)
2009	.11 (.08)	.04 (.05)	.07 (.06)	.13 (.10)	.39 (.22)	.20 (.22)

Abbreviation: NA, not available.
[a] Statistics were calculated from 4046 nurses assigned to 10 394 infants in 2008 and 3645 nurses assigned to 8804 infants in 2009-2010.

RESULTS

HOSPITAL AND INFANT CHARACTERISTICS

Our sample comprised mostly higher level NICUs (87% were levels B and C) compared with the VON (66% were levels B and C and 34% were level A). Compared with the universe of US hospitals with a NICU, our sample contained more teaching hospitals (26% in the United States vs 51% in the study sample) and somewhat more not-for-profit hospitals (71% in the United States vs 85%), as well as larger units (a mean of 22 beds in the United States vs 33). Many of the participating hospitals had achieved recognition for nursing excellence through Magnet accreditation (40% vs 19% in the United States).[29]

Infants in our sample had mean birth weights of 1077 g in 2008 and 1072 g in 2009, as well as a mean gestational age of 28.4 weeks in both years. The racial and ethnic composition of the sample was approximately half non-Hispanic white, 30% non-Hispanic black, and 20% other (**Table 2**).

INFECTION RATES

The percentages of VLBW infants with hospital-associated infection were 16.4% in 2008 and 13.9% in 2009. This decline was consistent with a secular trend in nosocomial infections among VLBW infants, as reported by Horbar and colleagues.[30] The infection rates ranged from the 25th percentile of 10.0% in 2008 and 8.8% in 2009 to the 75th percentile of 20.3% in 2008 and 16.4% in 2009.

INFANT ACUITY DEFINITIONS

The infant acuity definitions developed for neonatal intensive care nursing are listed in Table 1. The definitions specify feeding, ventilation, medication, monitoring, and other differences across acuity levels. The classification had high interrater reliability ($\kappa = 0.79$). In 2009, there were few infants in the 2 highest acuity levels (8%), with most in the 2 lowest levels (66%). The proportions of the highest acuity infants were slightly greater in 2008 (12%).

COMPLIANCE WITH GUIDELINES

On average, each infant had 0.4 of a nurse (in the 2008 data, 4046 nurses were assigned to 10 394 infants; in the 2009-2010 data, 3645 nurses were assigned to 8804 infants). Relative to the guidelines, on average, hospitals understaffed 47% of all NICU infants in 2008 and 31% in 2009 (**Table 3**). Hospitals understaffed 80% of high-acuity infants (levels 4 and 5) in 2008 and 68% in 2009. Higher infant acuity was associated with more understaffing. For example, in 2009, 20% of acuity level 1 infants and 68% of high-acuity infants (levels 4 and 5) were understaffed. To meet guidelines, an additional 0.11 of a nurse per infant overall and an additional 0.34 of a nurse per high acuity infant (ie, levels 4 and 5) would have been needed in 2009. In 2008, the understaffing was higher. There was very little overstaffing. Hospitals overstaffed 4% and 6% of their infants in 2008 and 2009, respectively. The overstaffing provided a very small offset (0.01 and 0.02 of nurse per infant in 2008 and 2009, respectively) to counterbalance understaffing.

In 2009, 55% of units understaffed at least 25% of their infants and 16% understaffed at least 50% of their infants. Five units had no understaffing in 2009.

MULTIVARIATE REGRESSION RESULTS

As shown in **Table 4**, a 1 standard deviation increase in the amount of a nurse per infant needed to meet guidelines (0.11 of a nurse in 2008 and 0.08 of a nurse in 2009) was associated with higher odds of infection in 2008 (adjusted odds ratio, 1.39; 95% CI, 1.19-1.62; $P < .001$) and 2009 (adjusted odds ratio, 1.40; 95% CI, 1.19-1.65; $P < .001$).

The odds ratios for understaffing translate into predicted infection rates as displayed in the **Figure**. This represents the predicted risk for infection associated with

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Table 4. Risk for VLBW Infant Infection Associated With Nurse Understaffing and NICU Variables

	Odds Ratio (95% CI)[a]	
	2008	2009
Understaffing amount[b]	1.39 (1.19-1.62)	1.40 (1.19-1.65)
NICU level		
A	1.33 (0.65-2.70)	1.52 (0.84-2.75)
B	0.69 (0.50-0.96)	1.02 (0.70-1.48)
C	1 [Reference]	1 [Reference]
Natural log of annual volume of VLBW admissions	0.82 (0.61-1.09)	0.82 (0.63-1.07)

Abbreviations: NICU, neonatal intensive care unit; VLBW, very low birth weight.

[a] Odds ratios and CIs were derived from random-effects logistic regression models. The 2008 model had 5713 observations; the 2009 model had 5558 observations. Infant risk adjusters were gestational age, gestational age squared, 1-minute Apgar score, small for gestational age, multiple birth, congenital malformation, vaginal delivery, prenatal care, race/ethnicity, and sex.

[b] Fraction of a nurse per patient needed to achieve the minimum recommended nurse to patient ratio.

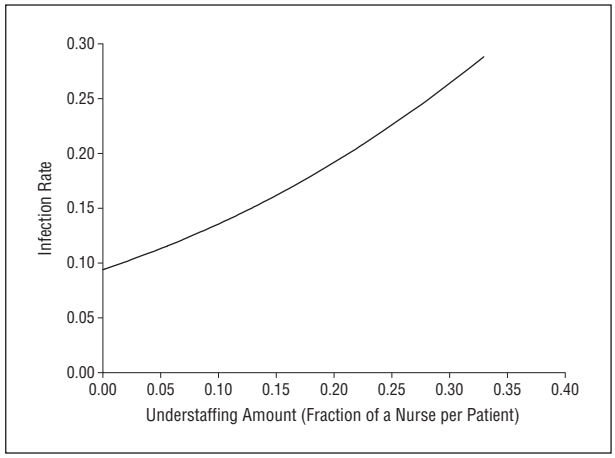

Figure. Predicted risk-adjusted infection rates by nursing unit understaffing amount.

understaffing for an infant who had average infection risk, based on estimates from the random-effects logit model. In a unit with no understaffing, the predicted infection rate was 9%. At the 2009 median understaffing level (0.11 of a nurse per infant), the predicted infection rate was 14%. At the 90th percentile of understaffing (0.22 of a nurse per infant), the infection rate was 21%.

COMMENT

The NICU provides care for critically ill infants and is a highly nurse-intensive setting. Yet, little is known about the adequacy of nurse staffing in US NICUs or the potential implications of understaffing for infant outcomes. Our results document widespread understaffing relative to guidelines: one-third of NICU infants were understaffed. Understaffing varies further across acuity levels, with the greatest fraction of understaffed infants (68% in 2009) requiring the most complex critical care (acuity levels 4 and 5). An additional tenth of a nurse per infant would be needed on average to meet current national guidelines; however, for the high-acuity infants, an additional third of a nurse per infant would be needed. This translates into a 25% increase in nurse staffing on average (ie, to increase from observed staffing of 0.4 of a nurse per infant by an additional 0.11 of a nurse per infant) or an additional nurse for every 9 infants. These are conservative estimates of understaffing because the measures are based on the guideline minimums.

The widespread understaffing is noteworthy in a hospital sample that was disproportionately recognized for nursing excellence. The overall registered nurse staffing in sample hospitals was higher than in US hospitals with a NICU (10.4 vs 9.4 hours/patient day; $P < .05$; authors' calculations from American Hospital Association data). Staffing levels in all US NICUs may be lower than those observed here. Sample NICUs may have better-trained nurses than other hospitals and this training composition may influence nurse staffing. However, the guidelines indicate that a specialized staff is the minimum expectation.

In VLBW infants, NICU nurse understaffing relative to guidelines was associated with a sizable increase in infection risk. A 1 standard deviation–higher amount of nurse understaffing per infant (ie, one-tenth of a nurse) was associated with 40% higher odds of infection. There are wide variations in infection rates across units, demonstrating that low infection rates are achievable: 9% of units in 2009 had infection rates below 5%. Quality improvement initiatives have been successful in reducing rates of infection in the NICU[31-34] and in other settings.[34-36] With a median length of stay in the NICU of 62 days (in the 2009 VON) for VLBW infants, exposure to understaffing should be minimized to reduce infection risk. The NICU caseload is heavily concentrated in the care of VLBW infants. In a subset of 30 hospitals with VON data on all infants, VLBW infants accounted for 1 in 5 admissions but half of patient days.

Very low-birth-weight infants are a high-risk population, accounting for half of infant deaths in the United States each year.[16] Their NICU stays are among the most expensive hospitalizations.[1] Hospital-associated infections are associated with higher mortality and costs for these vulnerable infants. The development of an infection more than doubles the mortality rate among VLBW infants.[20] In VON, among VLBW infants who survived 3 days, 13.8% of those with nosocomial infection died compared with 5.5% without infection. Very low-birth-weight infants who develop an infection have lengths of stay that are 4 to 7 days longer than those without, adjusted for infant risk.[21]

Medicaid is a principal payer for the hospital care of 42% of preterm and low-birth-weight infants.[23] The Center for Medicare and Medicaid Innovation was recently formed under the Affordable Care Act to foster value in health care through health systems and payment innovations. The Centers for Medicare and Medicaid Services has already focused on hospital-associated infection in its payment systems. Medicaid will no longer reimburse the additional hospital costs associated with vascular catheter-associated infection. For hospitals to

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respond effectively to these incentives, they require information on such factors as adequate nurse staffing. Previously, for nurse staffing, definitions for the national guidelines in NICUs that have existed since 1992 were not available. Definitions that have high interrater reliability are now available to guide such efforts. The guidelines can be reevaluated now that a reliable acuity classification is available.

In the decade since *Crossing the Quality Chasm*,[37] there have been numerous calls to improve the quality of the health care system. Improving the quality of care for VLBW infants was emphasized in the Institute of Medicine report on preterm birth,[1] which called for better measurement of the quality of care in NICUs and pointed to nurse staffing as a promising avenue for developing such measures. The focus on infants was reinforced by the recent March of Dimes volume, *Towards Improving the Outcomes of Pregnancy III*.[38] Our results demonstrate a sizable gap in the quality of care for these infants.

Our study had limitations. The VON hospitals do not fully represent all US hospitals with a NICU and our sample was disproportionately recognized for nursing excellence. The cross-sectional research design prevented causal inferences. The analyses presented here do not take into consideration other factors that may be important in NICU staffing decisions such as nonnursing personnel.

In conclusion, our findings suggest that the most vulnerable hospitalized patients, unstable newborns requiring complex critical care, do not receive recommended levels of nursing care. Even in some of the nation's best NICUs, nurse staffing does not match guidelines. Hospital administrators and NICU managers must assess their staffing decisions to devote needed nursing care to critically ill infants.

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Author Affiliations: Department of Health Systems and Policy, School of Public Health, University of Medicine and Dentistry of New Jersey, Piscataway, New Jersey (Dr Rogowski); Department of Economics, Dartmouth College, Hanover, New Hampshire, and National Bureau of Economic Research, Cambridge, Massachusetts (Dr Staiger); College of Nursing, Ohio State University, Columbus, Ohio (Dr Patrick); Department of Pediatrics, University of Vermont (Mr Kenny), Vermont Oxford Network (Dr Horbar), Burlington, Vermont; and Center for Health Outcomes and Policy Research, School of Nursing, Department of Sociology, Leonard Davis Institute of Health Economics, University of Pennsylvania, Philadelphia (Dr Lake).
Correspondence: Jeannette A. Rogowski, PhD, Department of Health Systems and Policy, School of Public Health, University of Medicine and Dentistry of New Jersey, 683 Hoes Lane W, Piscataway, NJ 08854 (rogowsje@umdnj.edu).
Author Contributions: *Study concept and design:* Rogowski, Staiger, Patrick, Horbar, and Lake. *Acquisition of data:* Rogowski, Patrick, Horbar, Kenny, and Lake. *Analysis and interpretation of data:* All authors. *Drafting of the manuscript:* Rogowski, Staiger, Patrick, Horbar, and Lake. *Critical revision of the manuscript for important intellectual content:* All authors. *Statistical analysis:* Rogowski, Staiger, and Kenny. *Obtained funding:* Rogowski, Staiger, Patrick, and Lake. *Administrative, technical, and material support:* Rogowski and Lake. *Study supervision:* Rogowski, Horbar, and Lake.
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Poetry in Pediatrics

The Reason I Am

I have forgotten the pain
I have forgotten the wounds
The pain of unsleeping nights
The wounds of failed exams;
I am a physician now
I am the patients' hope
Their teardrops move me.
I became a reason for the suffering children
I became a champion for my friends
A strange, tired but amazing child for my parents
An eternal busy mother
And, for sure, a hard-to-understand wife.
All of these because I chose to be a physician,
And I swore to be skilled in my job
Because I like my career, I like children
And I want to bring them back to health.
Please, forgive me for my neglect
Try to understand and let me be forthright
And I promise to be
A real mother, although eternally busy
A real wife, although sometimes hard to understand
A good, but strange, child for my parents
And also, a champion physician.

Simona Gurzu, MD, PhD

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