THE RELATION BETWEEN THE AVAILABILITY OF NEONATAL INTENSIVE CARE AND NEONATAL MORTALITY

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ABSTRACT

Background There is marked regional variation in the availability of neonatal intensive care in the United States. We conducted a study to determine whether a greater supply of neonatologists or neonatal intensive care beds is associated with lower neonatal mortality.

Methods We used the 1996 master files of the American Medical Association and the American Osteopathic Association and 1998 and 1999 surveys of neonatal intensive care units to calculate the supply of neonatologists and neonatal intensive care beds in 246 neonatal intensive care regions. We used linked birth and death records from the 1995 U.S. birth cohort to assess associations between the supply of both neonatologists and neonatal intensive care beds per capita (in quintiles) and the risk of death within the first 27 days of life.

Results Among 3,892,208 newborns with a birth weight of 500 g or greater, the mortality rate was 3.4 per 1000 births. After adjustment for neonatal and maternal characteristics associated with an increased risk of neonatal death, the rate was lower in the regions with 4.3 neonatologists per 10,000 births than in those with 2.7 neonatologists per 10,000 births (odds ratio for death, 0.93; 95 percent confidence interval, 0.88 to 0.99). Further increases in the number of neonatologists were not associated with greater reductions in the risk of death. There was no consistent relation between the number of neonatal intensive care beds and neonatal mortality.

Conclusions A minority of regions in the United States may have inadequate neonatal intensive care resources, whereas many others may have more resources than are needed to prevent the death of high-risk newborns. The effect of the availability of neonatologists on other health outcomes is not known. (N Engl J Med 2002;346:1538-44.)

NEONATAL intensive care has reduced the mortality rate among newborns as the result of both technological advances and the advent of neonatal intensive care units.[1,2] Advances in neonatology have been accompanied by a dramatic increase in the number of neonatal intensive care units and neonatologists.[3-5] Thirty years ago, these resources were scarce and were primarily confined to university medical centers. Now, they are widely distributed and are available at hospitals that are close to and compete directly with tertiary care centers.[6,7]

The benefits afforded by these increasing resource levels have not been established.[3] A larger supply of neonatologists and beds may increase accessibility and improve outcomes for high-risk infants in previously underserved areas.[8] The supply of neonatologists, however, appears to have grown beyond that needed solely for the care of ill newborns.[6,9-14] Oversupply may paradoxically lead to less effective care, as the number of severely ill newborns per neonatologist and per neonatal intensive care unit decreases.[15]

In previous studies we found that the number of neonatal intensive care beds and neonatologists per newborn varied by a factor of more than four across regions in the United States — a level of variation that is higher than that in other medical care resources.[16-18] It is not known whether this variation reflects regional differences in the needs of newborns or whether outcomes among newborns are better in areas with greater resources.[19,20] Therefore, we examined the relation between the availability of resources for neonatal intensive care and neonatal mortality.

METHODS

Study Population and Definition of Neonatal Intensive Care Regions

The study included the 1995 U.S. birth cohort as reflected by the linked birth and death data set of the National Center for Health Statistics.[21] Infants with a birth weight of less than 500 g were excluded from the analyses because such infants are not always classified as live births.[22,23]

As previously described,[17] we used traditional methods of small-area analysis[18,24] to identify 246 neonatal intensive care regions. Briefly, the assignation of a county to a neonatal care region was based on the travel patterns of mothers of low-birth-weight infants from the county of residence to the county of birth, with the use of the linked data of the National Center for Health Statistics.[21] Patients travel relatively infrequently outside these regions for neonatal intensive care and, therefore, these regions provide regional measures of neonatal intensive care resources per newborn that are unlikely to be biased by travel.

Measurement of Intensive Care Resources

We identified the practice sites of neonatologists using the January 1, 1996, master files of the American Medical Association and the American Osteopathic Association, which provide a census of U.S. physicians that is not limited to members. Of the 3199

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physicians (including 377 clinical fellows) who designated themselves as neonatologists, we excluded those who reported that they spent the majority of their time teaching (97 physicians), doing administrative work (100), or research (232) and those working less than 20 hours per week (118). We multiplied the total number of fellows by 0.35 to adjust for their less active clinical roles ($377\times0.35=132$).[25,26] Thus, the study included the equivalent of 2407 clinically active full-time neonatologists.

To validate these data, we used an independent 1998 survey of neonatologists conducted by the American Academy of Pediatrics Section on Perinatal Pediatrics.[27] The survey identified 3674 neonatologists but did not assess their professional activities and, therefore, included neonatologists with various levels of clinical activity. These two measures of neonatologists were closely correlated (Spearman's correlation coefficient, 0.65; $P<0.001$).

Because the existing data sets of hospitals are incomplete,[28] we also determined the numbers of neonatal intensive care beds (the primary measure) and intermediate care beds using a 1999 survey of directors of neonatal intensive care units that we conducted in collaboration with the American Academy of Pediatrics Section on Perinatal Medicine. This survey also identified 3628 nonphysicians who were providing intensive care, including neonatal nurse practitioners, neonatal nurse clinicians, and physician assistants. All units were contacted repeatedly by mail and by telephone; the final rate of response was 100 percent.

Statistical Analysis

The primary outcome was neonatal mortality, defined as death within the first 27 days of life. The 1995 data set included information on maternal and infant characteristics derived from birth and death certificates.[21] We assessed the frequency of characteristics such as low birth weight and young maternal age that are known to correlate with the need for intensive care resources.[29-33]

We used logistic regression[34] to model the relation between death within the first 27 days of life and the numbers of neonatologists and neonatal intensive care beds per 10,000 births. We divided these measures of the availability of resources into quintiles (very low, low, medium, high, and very high supply). We controlled for birth weight and other recognized risk factors that indicate the need for neonatal intensive care.[29-33] The resulting odds ratios were considered to approximate relative risks. Variables were excluded if they were related to the process of neonatal intensive care and were therefore potentially influenced by the availability of resources (e.g., Apgar scores and the use of intubation and assisted ventilation). All models controlled for the newborns' sex and type of birth (singleton or multiple) as well as for maternal age (<15, 15 to 19, 20 to 29, 30 to 34, or $\geqslant35$ years), parity (primiparous or multiparous), race (white, black, or other), level of education (<12, 12, 13 to 15, or $\geqslant16$ years), marital status (unmarried or married), and extent of prenatal care (none, beginning in first trimester, beginning after the first trimester, or unknown). In the main models, birth weight was modeled as a fourth-degree polynomial, since this mathematical form provides the best fit of the nonlinear relation between birth weight and neonatal mortality.[35] We also stratified newborns according to birth weight to assess whether the relation between the availability of neonatal intensive care and neonatal mortality varied according to birth weight. Although the models used births as the unit of analysis, we adjusted the models for the clustering of neonatal mortality within regions.[36] This correlation effectively reduced the sample size and increased the width of the confidence intervals by about 40 percent in the group of newborns with a birth weight of 500 to 999 g and by about 10 percent in the group of newborns with a birth weight of 1000 to 1499 g. The degree of clustering was negligible in the group with a birth weight of 1500 to 2499 g and in the group with a birth weight of 2500 g or more, as well as in the unstratified models.

RESULTS

The characteristics of the study population are listed in Table 1. For each 10,000 births, there were 6.2 clinically active neonatologists, 9.3 midlevel providers, 33.7 neonatal intensive care beds, and 17.7 intermediate care beds. The availability of neonatal intensive care per 10,000 births varied substantially across neonatal intensive care regions (Table 2). This was true even when the analyses were restricted to newborns with a birth weight of 500 to 999 g — the group with the greatest need for intensive care (Fig. 1). For each 10,000 newborns with a birth weight of 500 to 999 g, the ratio of the regional supply of neonatologists to the overall supply in the United States ranged from 0.15 to 4.51 (interquintile range, 0.56 to 1.51 [20th to 80th percentile]), and the ratio of the regional supply of intensive care beds to the overall supply in the United States ranged from 0.22 to 4.86 (interquintile range, 0.61 to 1.53). Regions with more intensive care beds per capita did not necessarily have more neonatologists per capita (Spearman's correlation coefficient, 0.32; $P<0.001$).

Relation between Availability of Resources and Perinatal Risk Factors

The numbers of neonatologists and beds were not consistently larger in areas where the need for neonatal intensive care was greatest (Table 2). For example, areas with a very high supply of neonatologists (11.6 per 10,000 births) had the highest rates of multiple births and primiparous mothers (indicative of an elevated risk of death among newborns) but the lowest rates of mothers with less than 12 years of education and mothers who delayed prenatal care (indicative of a decreased risk). Furthermore, differences in the availability of neonatal intensive care across regions were greater than could be explained by differences in the rates of high-risk neonates. Although there were 68 percent more black mothers in regions with a very high supply of neonatologists than in regions with a very low supply, these regions also had more than four times as many neonatologists.

Relation between Availability of Resources and Neonatal Mortality

After adjustment for infant and maternal factors associated with an increased risk of neonatal death, the odds ratio for death that was associated with a low supply of neonatologists, as compared with a very low supply, was 0.93 (95 percent confidence interval, 0.88 to 0.99) (Table 3). There was no further reduction in the risk of neonatal death, however, as the supply of neonatologists increased. There was no consistent association between the regional supply of neonatal intensive care beds and neonatal mortality. In secondary analyses, the risk of death between two

TABLE 1. CHARACTERISTICS OF THE 3,892,208 NEWBORNS IN THE 1995 U.S. BIRTH COHORT AND THEIR MOTHERS AND AVAILABILITY OF NEONATAL INTENSIVE CARE.

VARIABLE	VALUE
Newborns' characteristics	
Birth weight — %	
≥2500 g	92.8
1500–2499 g	6.0
1000–1499 g	0.7
500–999 g	0.5
Female sex — %	48.8
Multiple — %	2.6
Death by day 27 of life	
Total no.	13,241
No./1000 births	3.4
Death between day 28 and 6 mo of life	
Total no.	5,683
No./1000 births	1.5
Maternal characteristics — %	
Race	
Black	15.4
White	79.5
Other	5.1
Unmarried	32.1
Age	
<15 yr	0.3
15–19 yr	12.8
20–29 yr	52.1
30–34 yr	23.2
≥35 yr	11.6
Level of education	
<12 yr	22.2
12 yr	33.5
13–15 yr	21.7
≥16 yr	21.1
Unknown	1.5
Time of initiation of prenatal care	
No prenatal care	1.2
After first trimester	17.1
First trimester	79.4
Unknown	2.3
Parity	
Primiparous	41.3
Multiparous	58.0
Unknown	0.7
Availability of neonatal intensive care resources	
Clinically active neonatologists	
Total no. of full-time equivalents	2,407
No./10,000 births	6.2
Midlevel providers*	
Total no.	3,628
No./10,000 births	9.3
Intensive care beds	
Total no.	13,105
No./10,000 births	33.7
Intermediate care beds	
Total no.	6,905
No./10,000 births	17.7

*Midlevel providers were neonatal nurse practitioners, neonatal nurse clinicians, and physician assistants.

and six months after birth was not associated with the supply of either neonatologists or intensive care beds (data not shown).

Our findings were essentially unchanged when we used alternative measures to represent the supply of neonatologists, such as the neonatologists identified by the 1998 survey conducted by the American Academy of Pediatrics, the addition of neonatal nurse practitioners and other nonphysician care providers, and the exclusion of neonatal fellows (data not shown). The results of analyses of intensive care beds were also unchanged by the inclusion of intermediate care beds (data not shown). Inclusion of the supply of both neonatologists and neonatal intensive care beds in the same model did not affect the odds ratios for neonatal mortality. Finally, we found no relation between the percentage of neonatologists in a given neonatal intensive care region who were primarily teachers, researchers, or fellows and the availability of neonatal intensive care or the risk of neonatal death (data not shown).

When the data were analyzed according to birth weight, a low supply of neonatologists was associated with a significantly lower rate of neonatal death among newborns with a birth weight of 500 to 999 g than was a very low supply of neonatologists (Table 4). For newborns with a birth weight of 1000 to 1499 g, 1500 to 2499 g, or at least 2500 g, the rate did not decrease significantly as the supply of neonatologists increased. The supply of neonatal intensive care beds was not consistently related to the risk of death in any category of birth weight (data not shown).

DISCUSSION

The supply of neonatologists and intensive care beds varied substantially across regions, even after adjustment for regional differences in the numbers of severely premature infants with a birth weight of 500 to 999 g. Differences among areas in other risk factors, such as maternal marital status and race, also failed to account for the variation in supply. Our findings extend those of previous studies of geographic variation in neonatal care.[14,16,17,37] Using detailed measures of the availability of resources and risk factors associated with death within intensive care regions, we found that resources for neonatal intensive care were maldistributed.

We found little difference in the risk of neonatal death between the lowest and highest quintiles of bed supply. The risk was lower in regions with a low supply of neonatologists than in regions with a very low supply. However, little additional benefit in survival was seen with further increases in supply. Associations between a very low supply of neonatologists and an increased risk of death were limited to the infants with the lowest birth weights. These findings suggest that, in the case of infants with extremely

TABLE 2. CHARACTERISTICS OF 3,892,208 NEWBORNS AND THEIR MOTHERS ACCORDING TO THE SUPPLY OF NEONATAL INTENSIVE CARE ACROSS REGIONS.*

CHARACTERISTIC	REGIONAL SUPPLY OF NEONATOLOGISTS					REGIONAL SUPPLY OF INTENSIVE CARE BEDS				
	VERY LOW (2.7/10,000 BIRTHS)	LOW (4.3/10,000 BIRTHS)	MEDIUM (5.9/10,000 BIRTHS)	HIGH (7.5/10,000 BIRTHS)	VERY HIGH (11.6/10,000 BIRTHS)	VERY LOW (14.0/10,000 BIRTHS)	LOW (23.5/10,000 BIRTHS)	MEDIUM (32.4/10,000 BIRTHS)	HIGH (40.7/10,000 BIRTHS)	VERY HIGH (59.3/10,000 BIRTHS)
	percent									
Newborns' characteristics										
Birth weight										
500–999 g	0.5	0.5	0.5	0.6	0.6	0.5	0.5	0.6	0.5	0.6
1000–1499 g	0.6	0.7	0.7	0.7	0.7	0.6	0.6	0.7	0.7	0.8
1500–2499 g	5.8	6.1	5.8	6.1	6.2	5.7	5.7	6.1	5.9	6.6
Female sex	48.8	48.9	48.8	48.8	48.8	48.8	48.8	48.8	48.8	48.8
Multiple	2.5	2.5	2.5	2.7	2.8	2.5	2.5	2.6	2.6	2.7
Maternal characteristics										
Race										
Black	12.1	15.9	12.1	17.7	20.3	11.5	11.9	17.3	16.4	20.2
Other	6.0	4.3	4.3	5.9	5.0	5.1	6.8	4.1	5.2	4.1
Unmarried	32.6	31.3	32.6	32.5	31.6	29.8	30.4	32.4	33.2	34.8
Age										
<15 yr	0.3	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.4
≥35 yr	11.1	9.9	10.9	12.4	14.7	11.6	11.3	11.6	11.8	11.8
<12 yr of education	22.6	22.1	26.6	21.2	17.5	19.4	23.4	21.3	24.2	21.6
Time of initiation of prenatal care										
No prenatal care	1.2	1.3	1.2	1.1	1.2	1.1	1.1	1.2	1.1	1.7
After first trimester	18.6	17.7	17.2	16.7	14.8	16.6	18.0	17.2	16.4	17.7
Primiparous	40.6	41.6	41.5	41.1	41.8	41.3	41.2	41.1	41.2	41.9

*The chi-square test for trend was significant ($P<0.05$) for all risk factors except sex. Given the large sample (3,892,208), even small differences were statistically significant. The level of maternal education, extent of prenatal care, and parity were unknown in the case of 1.5 percent, 2.3 percent, and 0.7 percent of infants, respectively.

low birth weights, some neonatal intensive care units may have an inadequate supply of neonatologists, whereas most other regions have an adequate supply or a surplus.

Several potential limitations of this study merit comment. The study covariates are well-described measures of neonatal risk[29-33,38] but may not represent risk fully. We believe that it is unlikely that unmeasured risk factors could explain the findings, since the risk factors we measured were poorly correlated with the availability of intensive care. We intentionally excluded variables that we considered to be part of the causal pathway that links resource levels to mortality. Five-minute Apgar scores were not included in our models, for example, because they may reflect more effective resuscitation efforts in the delivery room as a result of the greater availability of neonatologists.

Our data on the number of neonatologists and neonatal intensive care beds were not from the same years as the birth cohort we studied. However, substantial changes were unlikely to have occurred during the interval between these measurements, and small differences would not be expected to affect the results materially.

We did not have data on health status in infancy other than mortality or on long-term outcomes. Infants may benefit from the greater availability of resources in ways that are not reflected in mortality rates. This may be particularly true for neonates with a birth weight of at least 1000 g, who have a low overall risk of death. Infants in regions with more neonatologists might receive more attentive care, resulting in a faster resolution of illness, lower rates of complications, and better subsequent health status, than infants in regions with fewer neonatologists.

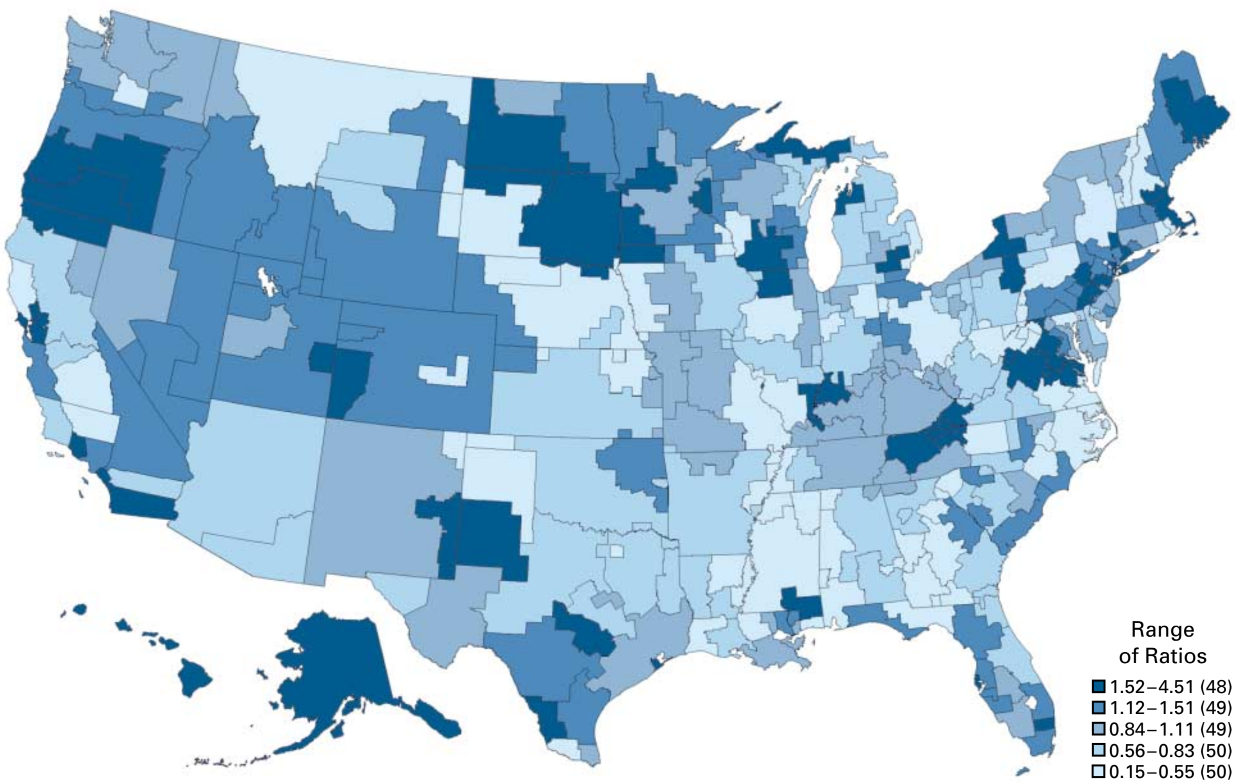
The alternative must also be considered: infants might be harmed by the availability of higher levels

Figure 1 (next page). Ratio of the Regional Supply of Neonatologists (Panel A) and Intensive Care Beds (Panel B) in 246 Neonatal Intensive Care Regions to the Overall Supply in the United States for Each 10,000 Newborns with a Birth Weight of 500 to 999 g.

Values in parentheses are the numbers of regions.

A

Neonatologists



B

Intensive Care Beds

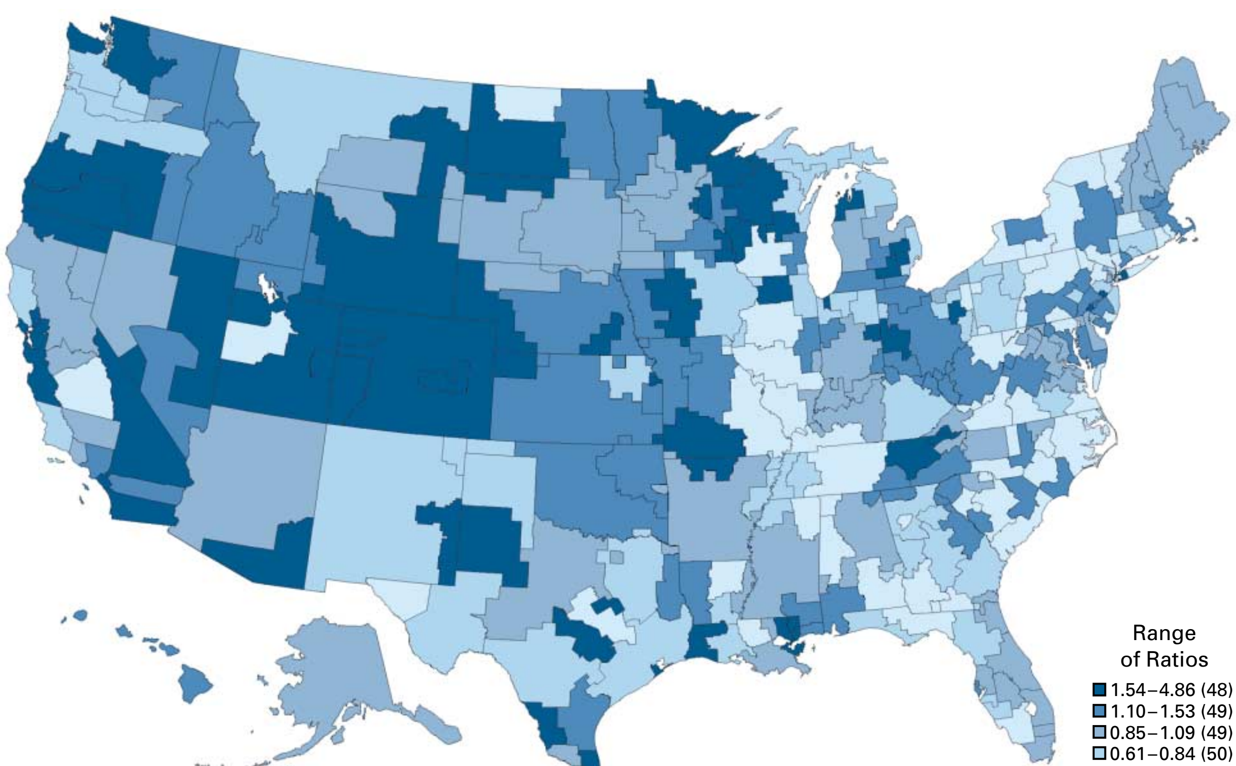


TABLE 3. ASSOCIATIONS BETWEEN THE REGIONAL SUPPLY OF NEONATAL INTENSIVE CARE AND NEONATAL MORTALITY.

SUPPLY		REGIONAL SUPPLY OF NEONATOLOGISTS	
		NO. OF DEATHS/ 1000 BIRTHS	ADJUSTED ODDS RATIO (95% CI)*
Neonatologists			
Very low	(2.7/10,000 births)	3.5	1.00†
Low	(4.3/10,000 births)	3.3	0.93 (0.88–0.99)
Medium	(5.9/10,000 births)	3.3	0.93 (0.88–0.99)
High	(7.5/10,000 births)	3.4	0.91 (0.86–0.97)
Very high	(11.6/10,000 births)	3.5	0.89 (0.83–0.95)
Intensive care beds			
Very low	(14.0/10,000 births)	3.4	1.00†
Low	(23.5/10,000 births)	3.2	0.92 (0.86–0.98)
Medium	(32.4/10,000 births)	3.7	1.02 (0.96–1.08)
High	(40.7/10,000 births)	3.2	0.93 (0.88–0.99)
Very high	(59.3/10,000 births)	3.7	0.95 (0.89–1.02)

*Odds ratios were adjusted for birth weight (as a fourth-degree polynomial), sex, type of birth (singleton vs. multiple), and maternal age, marital status, parity, race, level of education, and extent of prenatal care. The odds ratios are approximately equal to the relative risks. CI denotes confidence interval.

†The quintile with a very low supply served as the reference group.

TABLE 4. ASSOCIATION BETWEEN THE SUPPLY OF NEONATOLOGISTS AND NEONATAL MORTALITY, ACCORDING TO BIRTH WEIGHT.

BIRTH WEIGHT AND REGIONAL SUPPLY OF NEONATOLOGISTS*	NO. OF DEATHS	ADJUSTED ODDS RATIO (95% CI)†
Birth weight, 500–999 g		
Very low	31.7/100 births	1.00‡
Low	27.3/100 births	0.79 (0.69–0.91)
Medium	29.4/100 births	0.87 (0.75–1.01)
High	27.9/100 births	0.83 (0.70–0.99)
Very high	27.4/100 births	0.79 (0.68–0.92)
Birth weight, 1000–1499 g		
Very low	5.4/100 births	1.00‡
Low	4.8/100 births	0.94 (0.76–1.16)
Medium	4.7/100 births	0.91 (0.75–1.12)
High	4.3/100 births	0.85 (0.68–1.06)
Very high	4.4/100 births	0.86 (0.70–1.06)
Birth weight, 1500–2499 g		
Very low	10.1/1000 births	1.00‡
Low	9.6/1000 births	0.97 (0.85–1.11)
Medium	10.2/1000 births	1.05 (0.91–1.20)
High	9.8/1000 births	1.02 (0.88–1.17)
Very high	9.4/1000 births	0.97 (0.84–1.13)
Birth weight, ≥2500 g		
Very low	1.1/1000 births	1.00‡
Low	1.1/1000 births	1.02 (0.93–1.13)
Medium	1.0/1000 births	0.91 (0.82–1.00)
High	1.0/1000 births	0.94 (0.85–1.04)
Very high	1.0/1000 births	0.94 (0.84–1.05)

*A very low supply was defined as 2.7 neonatologists per 10,000 births, a low supply as 4.3 per 10,000 births, a medium supply as 5.9 per 10,000 births, a high supply as 7.5 per 10,000 births, and a very high supply as 11.6 per 10,000 births.

†Odds ratios were adjusted for birth weight, sex, type of birth (singleton vs. multiple), and maternal age, marital status, parity, race, level of education, and extent of prenatal care. The odds ratios are approximately equal to the relative risks except in the birth-weight category of 500 to 999 g. CI denotes confidence interval.

‡The quintile with a very low supply served as the reference group.

of resources. In regions with a greater supply of beds and neonatologists, infants with less serious illness might be more likely to be admitted to a neonatal intensive care unit and might be subjected to more intensive diagnostic and therapeutic measures, with the attendant risks of errors and iatrogenic complications, as well as impaired family–infant bonding.[39,40]

Because intensive care resources are measured at the regional level and we have no data on the processes of care, we cannot determine the actual causes of the higher mortality rates in the regions with the lowest supply of resources. The differences do not appear to be due to a relative lack of academic neonatal intensive care units. Other possible causes include differences in the volume of very sick infants cared for in neonatal intensive care units, the level of care provided to high-risk newborns, the specific treatments provided, and delays in initiating care because of the need to transfer neonates rather than treat them at the hospital where they were born.[41-46]

Will further growth in the U.S. supply of medical resources resolve regional disparities and improve outcomes? For many emerging medical specialties, an initially limited supply is coupled with a regionalization of care, in which services are available primarily in academic centers. In neonatology, the rapid growth in the numbers of neonatal intensive care units and neonatologists over the past 30 years was less the result of a plan to meet regional needs than a result of market forces, in particular the twin institutional interests of establishing prestigious birthing services and securing a large share of the health care market for young families.[7,47,48] The fact that state-run perinatal programs are no longer responsible for organizing and monitoring maternal and newborn care adds to the loss of public accountability for the total birth cohort in a region.[49] Information on the effect of the availability of medical resources on outcomes could help us identify areas where we should increase the numbers of clinical units and physicians and areas where we should use alternative approaches to improve public health.

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