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Mortality in Low Birth Weight Infants According to Level of Neonatal Care at Hospital of Birth

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ABSTRACT. *Objective.* In 1976, the Committee on Perinatal Health recommended that hospitals with no neonatal intensive care unit (NICU) or intermediate NICUs transfer high-risk mothers and infants that weigh <2000 g to a regional NICU. This standard was based on expert opinion and has not been validated carefully. This study evaluated the effect of NICU level and patient volume at the hospital of birth on neonatal mortality of infants with a birth weight (BW) of <2000 g.

Methods. Birth certificates of 16 732 singleton infants who had a BW of <2000 g and were born in nonfederal hospitals in California in 1992 and 1993 were linked to death certificates and to discharge abstracts. The hospitals were classified by the level of NICU: no NICU, no intensive care; intermediate NICU, intermediate intensive care; community NICU, expanded intermediate intensive care; and regional NICU, tertiary intensive care. A logistic regression model that controlled for demographic risks, diagnoses, transfer, average NICU census, and NICU level was estimated using death within the first 28 days or first year of life if continuously hospitalized as the main outcome measure.

Results. Compared with birth in a hospital with a regional NICU, risk-adjusted mortality of infants with BW of <2000 g was higher when birth occurred in hospitals with no NICU (odds ratio [OR]: 2.38; 95% confidence interval [CI]: 1.81–3.13), an intermediate NICU (OR: 1.92; 95% CI: 1.44–2.54), or a small (average census <15) community NICU (OR: 1.42; 95% CI: 1.14–1.76). Risk-adjusted mortality for infants who were born in hospitals with a large (average census ≥ 15) community NICU was not statistically different compared with those with a regional NICU (OR: 1.11; 95% CI: 0.87–1.43). Except for large community NICUs, all of these ORs are larger when the data are restricted to infants with BW of <1500 g or BW of <1250 g and smaller for BW between 1250 g and 1999 g and 1500 g and 1999 g. For large community NICUs, the results are similar for the smaller

BW intervals and significant only for the larger BW interval.

Conclusions. These results support the recommendation that hospitals with no NICU or intermediate NICUs transfer high-risk mothers with estimated fetal weight of <2000 g to a regional NICU. For infants with BW of <2000 g, birth at a hospital with a regional NICU is associated with a lower risk-adjusted mortality than birth at a hospital with no NICU, intermediate NICU of any size, or small community NICU. Subsequent neonatal transfer to a regional NICU only marginally decreases the disadvantage of birth at these hospitals. The evidence for the few hospitals with large community NICUs is mixed. Although the data point to higher mortality in large community NICUs, they are not conclusive and additional study is needed on the mortality effects of large community NICUs. Greater efforts should be made to deliver infants with expected BW of <2000 g at hospitals with regional NICUs. *Pediatrics* 2002;109:745–751; *infant, low birth weight, hospital mortality, vital statistics, health care surveys, intensive care units.*

ABBREVIATIONS. NICU, neonatal intensive care unit; BW, birth weight; OSHPD, Office of Statewide Health Planning and Development; ICD-9-CM, *International Classification of Diseases, Ninth Revision, Clinical Modification*; OR, odds ratio; CI, confidence interval; VLBW, very low birth weight.

The advent and diffusion of neonatal intensive care services during the late 1960s and 1970s resulted in a marked reduction in neonatal mortality.¹ To facilitate the availability of neonatal care to all high-risk infants and to use the country's neonatal resources efficiently, the Committee on Perinatal Health recommended a regionalized system of neonatal intensive care in 1976. These recommendations included the referral of high-risk mothers and infants to a hospital with a regional neonatal intensive care unit (NICU). Specifically, hospitals with no or intermediate NICUs were expected to refer all infants that weigh 2000 g or less to a regional NICU.² This standard was based on expert opinion, and the only population-based studies that support this standard are based on the limited data available from birth certificates. Because failure to control for important risk factors that are not available from birth certificate data can bias studies of neonatal mortality in either direction, this issue needs additional study.

During the late 1980s and 1990s, technology and clinical expertise disseminated outside the tertiary centers, resulting in a proliferation of intermediate

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NICUs and an expansion of their scope of practice. There has been an increase in the rate of high-risk infants who are born outside tertiary centers³⁻⁸ and a decrease in referrals to regional NICUs.³

In a previous study that examined high-risk births of all weights in California during 1990, we showed that there is an advantage of delivery in a hospital with a high-volume regional NICU.⁹ It is unclear whether this advantage is limited to certain birth weight (BW) groups. It is possible that because of the development of new technologies (eg, surfactant replacement therapy) and the diffusion of technology and clinical expertise that the 2000-g threshold set in the 1976 recommendation is too conservative and that some uncomplicated births below this weight limit can safely occur outside the tertiary care centers. The objective of this study was to examine the impact of the level of care provided at the hospital of birth on survival of infants of <2000 g over different BW strata.

METHODS

The 1992 and 1993 California birth-infant death cohort file linked to the California Office of Statewide Health Planning and Development (OSHPD) discharge abstracts for 1992 and 1993 were used for this study.¹⁰ These linkages were only for singleton births that occurred in nonfederal hospitals in California in 1992 and 1993; the linking could not distinguish among multiple births, and federal hospitals do not file discharge abstracts with the state. Ninety-nine percent of the maternal and singleton infant discharge abstracts were successfully linked with the birth certificates. These data were also successfully linked to the infant's discharge abstract from the receiving hospital for 99% of the infants who were transferred to another hospital. The advantages of these linked data include having information on the complete neonatal course of hospitalization for infants who are transferred and the diagnosis information from the *International Classification of Diseases, Ninth Revision, Clinical Modification (ICD-9-CM)* codes recorded on the hospital discharge abstracts. Although there are limitations to the ICD-9-CM code data, specifically a lack of severity information, validation studies have found a very high rate of coding accuracy.¹¹

The focus of this study was restricted to singleton infants who had a BW of <2000 g. Because the current standard in most California hospitals is that all infants with a BW of <2000 g be admitted to some level of neonatal intensive care (unless they die before they can be admitted), we did not impose any additional criteria for inclusion in this study. Infants with BW of <500 g were excluded to be consistent with previous research and because the overwhelming majority of these infants died before discharge from the hospital, most in the first day of life. A total of 16 732 singleton infants were born in 1992 or 1993 with a BW of <2000 g and had the discharge record linked to the birth certificate.

We used the 1993 California Association of Neonatologists' Survey of Directors of Neonatology¹² to assign the level of care provided by each hospital. Any uncertainty about appropriate classification was resolved by direct communication with the senior staff of the unit. Each hospital was assigned to 1 of the 4 categories used by the State of California.¹³ The criteria for level of care are as follows:

1. No NICU: Cared only for healthy neonates and those with minor medical problems.
2. Intermediate NICU: Cared for moderately sick infants but did not regularly provide assisted ventilation for more than 4 hours.
3. Community NICU: Provided long-term ventilatory support but not all other specialized services normally provided by regional NICUs.
4. Regional NICU: Provided a full range of specialized neonatal intensive care, including pediatric subspecialty consultants and surgery.

In addition to being based on the state criteria, these levels of care are very similar to those used by the Vermont-Oxford Network.

The OSHPD hospital data were used to determine total NICU patient days and to calculate average NICU daily census. These are regulatory data that all nonfederal hospitals in California must file annually with OSHPD. Following Phibbs et al,⁹ we classified community NICUs as small when they had an average census of <15 patient and large otherwise. Intermediate NICUs were not sorted by patient census as all of these units had an average patient census of <13, almost all of which had an average census of <10, and we had previously identified a mortality threshold at an average census of 15 patients. All of the regional NICUs had an average census of at least 15 patients. The 15 patient census cutoff from Phibbs et al was based on an empirical volume-outcome relationship.⁹

To risk-adjust hospital mortality rates, we repeated the general approach of the logistic regression analysis that we used previously to model neonatal death using only data for infants with a BW of <2000 g.⁹ The model controls for BW, gender, maternal demographic factors, and many clinical diagnoses. For infants who were transferred, diagnoses made at the referral centers were mapped back to the hospital of birth. The main difference in approach is that to prevent possible bias, we restricted the clinical variables considered for inclusion to those used by Phibbs et al⁹ that were present at birth. Only the clinical variables that were associated with mortality at the 5% significance level were retained in the multivariate model. Patient demographic and insurance variables, and hospital characteristics were retained in the models regardless of statistical significance. To allow for gender differences in BW-specific mortality, BW was specified separately for each gender. The model was also estimated with a variable added for neonatal transfer to examine the association between transfers and mortality.

The dependent variable was neonatal-related mortality, which we defined as neonatal mortality (28 days) or any other death that occurred in the first year of life if the infant remained hospitalized continuously since birth. These later deaths were included to prevent bias from the exclusion of cases where care in the NICU prolonged death past an age of 28 days. We tested the sensitivity of the analysis to the inclusion both of the late deaths and of out of hospital neonatal deaths. Since both of these types of deaths were not very common, their inclusion or exclusion had very little effect on the results; they were included for completeness.

To examine the effects of NICU patient volume and level of care at the hospital of birth, we added variables for each level of care and NICU census at the hospital of birth to the regression model (regional NICU was the reference category). These models were used to calculate relative odd ratios (OR) and 95% confidence intervals (CI) for mortality at each hospital level, controlling for the risk profile of the infant using the Stata statistical program (Stata Corp, College Station, TX). The standard errors of the hospital level variables were corrected for within-hospital correlation using the "cluster" option in Stata. The models were estimated for infants with BW of <2000 g, <1500 g, and <1250 g to determine whether there is a BW limit below which NICU level at the hospital of birth has a significant effect on mortality. To determine whether there were risk differences for moderately low BW infants, we also estimated models for the 1250 g to 1999 g and 1500 g to 1999 g intervals.

RESULTS

Of the 16 732 singleton infants with BW of <2000 g included in this study, 12% ($n = 2001$) were born in the 159 hospitals with no NICU, 13% ($n = 2217$) in the 49 hospitals with an intermediate NICU, 44% ($n = 7338$) in the 68 hospitals with a community NICU, and 31% ($n = 5176$) in the 22 hospitals with a regional NICU (Table 1). Of the 49 intermediate NICUs, only 8 had an average patient census of ≥ 5 patients. Twenty-four percent (530 of 2217) of the infants who were born at hospitals with intermediate NICUs were born in 1 of these 8 hospitals. The 18 community NICUs with an average census of ≥ 15 patients cared for 43% (3126 of 7338) of the infants

TABLE 1. Level of Neonatal Care at Hospital of Birth in Infants With BW of <2000 Grams

| BW (Grams) | No NICU (n = 159) n (%) | Intermediate NICU (n = 49) n (%) | Community NICU (n = 68) n (%) | Regional NICU (n = 22) n (%) | Total n (%) |
|------------|----------------------------|-------------------------------------|----------------------------------|---------------------------------|-------------|
| 500–749 | 160 (9.7) | 172 (10.5) | 732 (44.5) | 581 (35.3) | 1645 (100) |
| 750–999 | 148 (8.8) | 168 (10.0) | 737 (43.7) | 633 (37.5) | 1686 (100) |
| 1000–1249 | 158 (9.6) | 176 (10.7) | 736 (44.9) | 570 (34.8) | 1640 (100) |
| 1250–1499 | 185 (8.8) | 247 (11.7) | 994 (47.0) | 688 (32.5) | 2114 (100) |
| 1500–1749 | 410 (11.2) | 488 (13.4) | 1613 (44.2) | 1138 (31.2) | 3649 (100) |
| 1750–1999 | 940 (15.7) | 966 (16.1) | 2526 (42.1) | 1566 (26.1) | 5998 (100) |
| Total | 2001 (12.0) | 2217 (13.3) | 7338 (43.9) | 5176 (30.9) | 16732 (100) |

who were born in hospitals with community NICUs. Hospitals with a regional NICU had more deliveries of infants <2000 g (median: 224; range: 66–616; $P < .05$) than hospitals with no NICU (median: 9; range: 1–61), intermediate NICU (median: 33; range: 2–245), or community NICU (median: 99; range: 16–383). Of those infants who were <2000 g and born at a hospital with no NICU, 40% were transferred to a higher level of care during the first 24 hours after birth and 9% after 24 hours. Of those who were born at a hospital with an intermediate or community NICU, 23% and 2%, respectively, were transferred to a regional NICU during the first 24 hours and 10% and 2%, respectively, were transferred after the first day. Of the infants who had a BW of <2000 g and were not transferred from a hospital with no NICU or an intermediate NICU, virtually all of the infants either died or had a BW of at least 1500 g.

The ORs for the final set of risk factors included in the risk-adjusted model for infants with BW of <2000 g are shown in Table 2. The OR present the relative risk of mortality, compared with the reference group (OR = 1.0), infants with a BW between 1500 g and 1999 g, controlling for all of the other risk factors in the model. Infants who were small for gestational age had a 44% reduction in their mortality risk, compared with infants of normal BW. Similarly, cases that were complicated by placental hemorrhage had a 52% increase in their mortality risk, compared with similar infants without this complication. BW was strongly associated with mortality, with ORs for the lower BW stratum (500–749 g) of 151 and 83 for male and female infants, respectively. The model fit well, the area under the receiver operating characteristic curve was 0.911, and the Hosmer-Lemeshow test did not reject the model ($P = .19$). The results for the control variables for the other models are similar, as are the goodness-of-fit test results.

Table 3 displays the level of care ORs from the logistic regressions estimating the effect of the risk adjustment and the level of care at the hospital of birth on neonatal mortality by BW using regional NICU as the reference. The ORs for mortality are large and statistically significant for the BW ranges <2000 g, <1500 g, and <1250 g for births at hospitals with no NICU, at hospitals with intermediate NICUs regardless of average daily census, and at hospitals with community NICU with an average daily census of <15 patients. The ORs for mortality for infants who were <2000 g and born at a hospital with no NICU, an intermediate NICU of any census, or a

TABLE 2. Risk-Adjusted Mortality Model for Singleton Infants With a BW <2000 Grams Born in California in 1992 and 1993

| Variable | Risk Model | |
|---|------------|---------------|
| | OR | 95% CI |
| Female BW 500–749 g | 83.34 | 63.06–110.15 |
| Female BW 750–999 g | 12.22 | 8.94–16.71 |
| Female BW 1000–1249 g | 6.22 | 4.50–8.57 |
| Female BW 1250–1499 g | 2.27 | 1.61–3.19 |
| Male BW 500–749 g | 150.72 | 115.16–197.26 |
| Male BW 750–999 g | 22.01 | 16.61–29.17 |
| Male BW 1000–1249 g | 7.35 | 5.24–10.30 |
| Male BW 1250–1499 g | 2.69 | 1.89–3.82 |
| Hispanic | 0.98 | 0.85–1.15 |
| Black | 0.77 | 0.64–0.92 |
| Maternal education <8 y | 0.98 | 0.80–1.19 |
| Maternal education 8–11 y | 1.00 | 0.87–1.16 |
| Small for gestational age | 0.56 | 0.42–0.75 |
| Oligohydramnios | 2.20 | 1.41–3.44 |
| Hydrops nonimmune | 67.17 | 28.35–159.19 |
| Maternal complications affecting infant | 0.56 | 0.43–0.73 |
| Placental hemorrhage | 1.52 | 1.08–2.14 |
| Highest risk anomalies | 73.19 | 51.93–103.16 |
| Moderately high-risk anomalies | 1.64 | 1.36–1.98 |
| Respiratory distress syndrome | 0.42 | 0.36–0.50 |
| Medicaid insurance | 1.32 | 1.09–1.60 |
| HMO insurance | 1.11 | 0.92–1.34 |
| No insurance | 1.76 | 1.31–2.37 |
| Major teaching hospital | 1.39 | 1.04–1.86 |
| For-profit hospital | 0.82 | 0.65–1.03 |
| County hospital | 1.20 | 1.00–1.45 |

Area under the ROC curve = 0.91. Hosmer-Lemeshow test, $P = .19$.

BW 1500–1999 g was the reference for the OR calculations; the OR for males in this BW interval was not different from 1.0 (1.03).

community NICU with average census of <15 patient were 2.38 (95% CI: 1.81–3.13; $P < .001$), 1.92 (95% CI: 1.44–2.54; $P < .001$), and 1.42 (95% CI: 1.14–1.76; $P < .001$), respectively, compared with infants who were born at a hospital with a regional NICU. As the upper BW limit for the sample decreases to 1500 g and 1250 g, these ORs for risk-adjusted mortality increase (Table 3). In hospitals with a large (average daily census ≥ 15 patients) community NICU, risk-adjusted mortality was not significantly different compared with hospitals with a regional NICU (OR: 1.11; 95% CI: 0.87–1.43; $P = .41$) and the results were very similar for the <1500 g and <1250 g models.

Given that patient risk varies greatly across the BW range that we examined, we ran the same models on infants with BW between 1250 g and 1999 g and for 1500 g to 1999 g. Table 3 shows that the

TABLE 3. Risk-Adjusted Mortality OR by Level of Care and NICU Size at Hospital of Birth for Different BW Ranges

| NICU Level and Size at Hospital of Birth | BW <2000 Grams (OR [95% CI]) | BW <1500 Grams (OR [95% CI]) | BW <1250 Grams (OR [95% CI]) | BW 1250–1999 Grams (OR [95% CI]) | BW 1500–1999 Grams (OR [95% CI]) |
|--|------------------------------|------------------------------|------------------------------|----------------------------------|----------------------------------|
| No NICU | 2.38 (1.81–3.13) | 2.98 (2.10–4.24) | 3.20 (2.17–4.72) | 1.39 (0.83–2.33) | 1.35 (0.80–2.28) |
| Intermediate NICU, any census | 1.92 (1.44–2.54) | 2.37 (1.65–3.40) | 2.36 (1.56–3.58) | 1.29 (0.74–2.25) | 1.04 (0.56–1.95) |
| Community NICU, census <15 | 1.42 (1.14–1.76) | 1.51 (1.14–2.00) | 1.48 (1.07–2.05) | 1.38 (0.93–2.05) | 1.22 (0.84–1.76) |
| Community NICU, census ≥15 | 1.11 (0.87–1.43) | 1.05 (0.77–1.44) | 1.08 (0.76–1.54) | 1.26 (0.81–1.94) | 1.56 (1.04–2.34) |

Risk-adjusted mortality rate at hospitals with a regional NICU was the reference. The regression also controlled for the risk factors listed in Table 2.

elevated risks for births at lower level hospitals persisted for both of these BW ranges. With the smaller number of deaths in these BW ranges, most of the level-of-care variables were not statistically significant and the point estimates decreased for all levels of care except for large community NICUs. Conversely, the OR for births in hospitals with large community NICUs increased to 1.26 (95% CI: 0.81–1.94) for the 1250 g to 1999 g model and to 1.56 (95% CI: 1.04–2.34) for the 1500 g to 1999 g model.

The effect of including a variable for transfer to a higher level of care varied by BW interval, and most of the transfer variables were not statistically significant; however, the estimates are informative and confirm previous expectations. Transfer reduced the odds of mortality for the <1250 g model (OR: 0.70; 95% CI: 0.50–0.97) and for the <1500 g model (OR: 0.76; 95% CI: 0.55–1.04). When larger infants were considered, there was no effect for the <2000 g model (OR: 0.99; 95% CI: 0.77–1.27), and the effect switched for the 1250 g to 1999 g model (OR: 1.57; 95% CI: 0.96–2.59) and for the 1500 g to 1999 g model (OR: 1.61; 95% CI: 0.89–2.89). The addition of the variable for transfer to a higher level of care had only marginal effects on the estimated level-of-care parameters for the birth hospitals. However, when the same model is applied to infants with BW of 1250 g to 1999 and 1500 g to 1999, the results become mostly nonsignificant.

DISCUSSION

The results of our analyses show that there is empirical support for the 1976 Committee on Perinatal Health recommendation and that survival improves for infants who have a BW of <2000 g and are delivered in hospitals with regional level III NICUs. Although new technologies, such as better mechanical ventilators and surfactant replacement therapy, and the diffusion of trained neonatologists into lower level NICUs have certainly enhanced the ability of these hospitals to care for high-risk neonates, risk-adjusted mortality remains significantly lower when high-risk infants are born at hospitals with large regional NICUs. We also show that the level of care that is available at the hospital of birth is much more important for survival than is the level of care that ultimately is received. This strongly supports the concept that whenever possible, women with early preterm labor should be moved to the regional hospital rather than be transferred there later with her infant. It may be appropriate to change the committee's recommendations to indicate maternal instead of neonatal transport whenever it is feasible.

After correcting for risk factors, infants who have a

BW of <2000 g and are born at a hospital with a regional NICU have significantly lower mortality rates than those who are born at hospitals that provide lower levels of neonatal care, except for those few community NICUs that have large patient volumes. Although most of the estimates for births at hospitals with large community NICUs are not statistically significant, the differences represented by the ORs for large community NICUs represent clinically meaningful reductions in mortality. The issue of the safety of these deliveries in hospitals with large community NICUs needs additional investigation. As we explain below, our study did not have sufficient statistical power to address this issue.

These results are based on the average effect that each level of care/patient volume group has on neonatal mortality. There is significant variation in the relative performance at each level of care. Furthermore, although our classifications of levels of NICUs do effectively sort the different levels of NICUs, there is considerable variance in the levels of services provided across the units in each level of care. Given this variability and the small number of high-volume community NICUs, our analysis did not have sufficient power to detect significance for most of the differences in mortality between regional NICUs and large community NICUs that we report above. However, with the relatively high mortality rates for very low birth weight (VLBW) infants, even small reductions in mortality are clinically meaningful. Although we do not statistically demonstrate that mortality is lower for births that occur in hospitals with regional NICUs than those with large community NICUs, we consider it likely that the differences that we observe represent real differences. One telling indication is the results looking at different parts of the BW interval. Among the smallest infants, many of the deaths are probably unavoidable, regardless of where they are born, whereas, among the larger infants, many more of the deaths are probably preventable with proper care. That the mortality differential between regional and large community NICUs is significantly larger for the upper ranges of the BW interval that we studied is an indication of real differences in quality of care. This issue clearly needs additional study.

The mortality threshold of an average NICU census of 15 patients is not an exact number. Rather, it is our best estimate of the mortality threshold based on data from 139 hospitals that provide some level of neonatal intensive care. The results that we report are based on averages, and there is substantial variation in the performance of individual hospitals.

What our results suggest is that at a census of approximately 15 patients, we notice a marked reduction in average mortality risk. Although there are additional mortality reductions at higher patient volumes, the estimates become much more imprecise because of the small number of observations.

Although the ORs for transfers may, at first, seem counterintuitive, they actually are consistent with previous expectations. For VLBW infants, a great many of those infants who die do so in the first day of life. As a result, many of the sickest infants, who might potentially benefit from care at a higher level NICU, die before they can be transported. Thus, the VLBW infants who are transported to a higher level NICU are a selected population. Although they are very sick, many of the infants with the highest risks of mortality have been excluded from the transfer group because of their early death. Conversely, for larger infants, the risk of very rapid death is much lower, even among the highest risk cases. Thus, there is a greater chance that the highest risk larger infants will be transferred, and this higher mortality risk is reflected in the parameter estimates. In results not shown, the addition of the transfer variable has the opposite effects on the level-of-care variables. For the VLBW infants, selection process results in moderately larger ORs for all levels of NICU. Because some of these deaths were potentially preventable, this provides strong support for the concept of maternal transfer to hospitals with regional NICUs for all VLBW deliveries. Because the transfer variable is capturing much of the risk for the larger infants, there are moderate reductions in the ORs for each level of care in the 1250 g to 1999 g and 1500 g to 1999 g models, but the combined effect of the estimated parameters still results in significantly higher mortality risks for the highest risk cases when they are not delivered at a hospital with a regional NICU.

Although we show that moving all <2000 g deliveries to hospitals with large regional NICUs would reduce mortality, we readily acknowledge that it will never be feasible to move all such deliveries. However, it is feasible to concentrate the vast majority of these deliveries in hospitals with regional NICUs. The most obvious problem is mothers who live in rural areas as the increased transport times reduce the number of mothers who can be moved safely. Given the geographic access problems, patient volume standards will need to be lowered for rural areas as there is clear benefit to having some NICU care over having none. From a policy perspective, it must be remembered that although the rural exception will apply to a fairly large number of hospitals, it will apply only to a small percentage of the <2000 g births; most of the population lives in urbanized areas. We have previously reported that approximately 80% of the births in California occurred within 25 miles of a hospital with a regional NICU.⁹ The big policy problem in California is the proliferation of intermediate and community NICUs, most with very low patient censuses, in the big urban areas of the state. The impact on providers of a concerted effort to concentrate the <2000 g deliveries is smaller than one might think, as the number of

cases would remain unchanged. Furthermore, the existing regional centers do not have sufficient capacity to absorb all of these cases. Thus, there would have to be an expansion of the number of regional facilities, most likely through consolidating units among proximate hospitals and providing higher levels of service in single facilities.

This study has several limitations. First, the sources of the data (birth certificates, death certificates, and discharge abstracts) may not have recorded all of the diagnoses that each patient had during the hospitalization.^{14,15} However, the risk models were based on the linkage of birth certificates and discharge abstracts, and data validations have found the discharge abstracts to be accurate.¹¹ This linkage improves the predictive accuracy of the model, reaching values similar to those reported in other studies using clinical data prospectively recorded.¹⁶ Several disease severity scores for infants who receive neonatal intensive care that include epidemiologic and physiologic data have been developed and tested. These severity scores have been found to have good predictive performance.¹⁷⁻¹⁹ A possible problem of our study is that ICD-9-CM codes do not include information about severity of the diseases, which is likely to be associated with mortality.¹⁶ However, the overall predictive power of our patient risk model (>90% of the cases were correctly classified) and of other models that use epidemiologic data and patient characteristics at admission¹⁹ is not that different from the predictive power of the models that consider severity scores.¹⁶⁻¹⁸ Another limitation of this study is that we used BW in the analyses instead of gestational age. Gestational age would be more useful for clinical decision making about maternal transfer because it is the information available at the onset of labor. However, gestational age is not as reliably coded as BW, limiting its use in the analyses. Nevertheless, BW and gestational age were highly correlated.

Other potential limitations are the age of the data and that they are from only 1 state. Although these data are almost 10 years old, they are from after the introduction of the most important recent new technology: surfactant replacement therapy. Furthermore, because neonatal mortality rates have not declined markedly in the intervening years, the results are almost certainly applicable today. The reason for the long time lag was the effort required to create the linked data sets. Although the data are from only 1 state, California is the largest and most diverse state in the United States. The proportion of infants born outside a regional NICU in this study (69%) reflects the current status of deregionalization of neonatal care in California and is similar or higher than what has been reported more recently in other states.²⁰⁻²³ In some sense, California can be regarded as a leading indicator of where regionalization is headed as the trend toward less regionalization has been reported in almost every state in the country. Although there may be some differences in how neonatal care is provided across states, it is very unlikely that differences in care in California are what is driving the results.

A meta-analysis of population-based or center-based studies comparing inborn versus outborn mortality showed that infants who have a BW between 1000 g and 2000 g and are born at a hospital with a regional NICU have lower mortality than outborn infants.²⁴ The studies included in this meta-analysis were performed in the 1970s and 1980s, so they may not reflect the changes in neonatal care that occurred in the late 1980s and 1990s, including the introduction of surfactant replacement therapy, the proliferation of intermediate NICUs, the expanded capacity to treat sick neonates of many intermediate NICUs (ie, the emergence of community NICUs), and decreased referral rates to hospitals with a regional NICU. Even with these changes, most recent studies consistently find strong relationships between patient volume and/or level of NICU and mortality.^{5,7-8,22} In a study not included in this meta-analysis, mortality rate of VLBW infants according to level of care at birth in a population-based study in 4 states was compared.⁴ The analysis showed that after controlling for race and gender, mortality of infants who had BW between 750 g and 1500 g and were born at a hospital with a regional NICU was lower than for infants who were born at hospitals with lower levels of neonatal care. Another study conducted in the Netherlands²⁵ in 1983 showed that adjusted mortality of preterm infants of 32 weeks or less was lower in level III hospitals compared with level I and level II hospitals. Menard et al,²² in a population-based study in South Carolina, showed that controlling for gestational age and race, infants who have a BW of <1500 g and are born in level III hospitals have a lower mortality compared with those who are born in level I and level II hospitals. An important difference between our study and that of Menard et al is the lower proportion (31% vs 79%) of infants who were born in level III hospitals in our study. This difference with our and other published studies^{7,8,20,21,23} reflects current differences in maternal referral patterns between states. A report⁵ of 1989 to 1991 data from the state of Washington concluded that infants who have a BW <2000 g and are born in level III hospitals have a lower mortality than those who are born in level I or level II hospitals. However, this study did not control for risk factors or for bias of antenatal referral patterns.

Tommiska et al²⁶ in a national study of outcome in extremely LBW infants in Finland showed that the area with the lowest mortality rate was the area with the lower proportion of infants born outside the university level III hospital (8% vs 23%; $P = .001$) and the area with the highest morbidity was the area with the lowest proportion of infants born at the level III hospital (15% vs 33%; $P = .002$).

Some studies have not found a relation between place of birth and mortality, but the evidence is limited and does not fully apply to our study. Field and Draper²⁷ studied 1 health region in the United Kingdom and found that increased investment in the low-volume hospitals eliminated the mortality differential. The other studies that we know of were either of very restricted groups of patients (eg, infants of 25 or fewer weeks of gestation) or included

only NICUs that were on 1 side of our volume threshold and thus are not inconsistent with our findings. The most prominent of these studies is that of Horbar et al²⁸ from the Vermont-Oxford Clinical Trials Network. Horbar et al reported no effect of NICU patient volume on mortality outcomes of VLBW infants. As the authors acknowledge in their discussion, their data are different from those we used. Most important, the vast majority of the NICUs in Vermont-Oxford are regional NICUs, and the few community NICUs are large units. We calculated from the Vermont-Oxford data that most, if not all, of the NICUs in their analysis had an average total census of 15 or more. Because almost the entire sample is equivalent to the best outcome group in our study, this finding is actually consistent with our results.

CONCLUSION

The current study shows that infants with BW of <2000 g have a lower risk-adjusted mortality rate when born in a hospital with a regional NICU. Risk-adjusted mortality of infants who have BW between 1250 g and 2000 g and are born in a hospital with a regional NICU tended to be lower compared with infants who were born in hospitals with lower levels of neonatal care, but these differences were not statistically significant. These findings emphasize the importance of maternal referral of patients who are at risk for preterm delivery to appropriate settings. The significantly lower risk-adjusted mortality rates for infants who are born in hospitals with a regional NICU has important policy implications because of the large proportion of preterm deliveries that occur outside these hospitals.

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Eisenberg L. Themes in Twentieth Century American Psychiatry; Macy Conference; October 25, 2001; Toronto, Canada

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Mortality in Low Birth Weight Infants According to Level of Neonatal Care at Hospital of Birth

Javier Cifuentes, Janet Bronstein, Ciaran S. Phibbs, Roderic H. Phibbs, Susan K. Schmitt and Waldemar A. Carlo

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