International Journal of Epidemiology 2002;**31**:1061–1068

HEALTH SERVICES RESEARCH

Are we regionalized enough? Early-neonatal deaths in low-risk births by the size of delivery units in Hesse, Germany 1990–1999

Günther Heller,[a] Douglas K Richardson,[b] Rainer Schnell,[c] Björn Misselwitz,[d] Wolfgang Künzel[e] and Stephan Schmidt[f]

Background While agreement exists about the benefits of regionalization for high-risk births, little evidence exists regarding regionalization of low-risk births. The objective of this study was to investigate the impact of regionalization on neonatal survival focussed on low-risk births.

Methods Data from the perinatal birth register of Hesse, 1990–1999 were used comprising detailed information about 582 655 births covering more than 95% of all births in Hesse. Outcome events were death during labour or within the first 7 days of life (early-neonatal death). Mortality rates and corresponding 95% CI were calculated according to hospital volume measured by births per year and birthweight categories.

Results Birthweight-specific mortality rates were lowest in large delivery units and highest in smaller delivery units. This gradient was especially pronounced within low-risk births and was also confirmed in several logistic regression models adjusting for additional risk factors. A more than threefold mortality risk was observed in hospitals with <500 births/year compared with hospitals with >1500 births/year (odds ratio = 3.48; 95% CI: 2.64–4.58). Further trend analyses indicated that prenatal prevention programmes and the increasing usage of modern prenatal diagnostic procedures have not reduced this gradient in recent years.

Conclusions This analysis presents an urgent public policy issue of whether such elevated risk in smaller delivery units is acceptable or if further consolidation of birthing units should be considered to reduce early-neonatal mortality.

Keywords Perinatology, neonatology, neonatal mortality, perinatal mortality, regionalization, birthweight, low-risk birth, volume-outcome relationships, health facility size/*statistics & numerical data, hospitals, maternity/*standards/*utilization

Accepted 3 May 2002

[a] Institute of Medical Sociology & Social Medicine, Medical Centre of Methodology and Health Research, University of Marburg, Germany.

[b] Department of Neonatology, Beth Israel Deaconess Medical Centre, Harvard Medical School, Boston, MA, USA.

[c] Faculty of Politics and Management, University of Konstanz, Germany.

[d] Institute of Quality Assurance, Hesse, Germany.

[e] Medical Centre of Gynaecology and Obstetrics, University of Giessen, Germany.

[f] Department of Obstetrics, Medical Centre of Gynaecology and Obstetrics, University of Marburg, Germany.

Correspondence: Dr. med. Günther Heller, Institute of Medical Sociology & Social Medicine, Medical Centre of Methodology and Health Research, University of Marburg, Bunsenstrasse 2D 37033 Marburg, Germany. E-mail: hellerg@mailer.uni-marburg.de

The issue of centralization or regionalization of births has been discussed for decades in the scientific community. While general agreement exists about the benefits of regionalization for high-risk births or low birthweight infants, little evidence exists regarding regionalization of low-risk births.[1–16] There are reasons why there is still ongoing discussion about the necessary degree of centralization or regionalization for optimal perinatal and neonatal care. It is possible that substantial improvements in obstetric practices and antenatal ultrasound may have led to satisfactory early identification and subsequent referral of high-risk births into larger birth units making further centralization of births unnecessary. On the other hand, inadequate regionalization may simply represent historical patterns of low-risk care that have not been evaluated, or are sustained by conflicting political or financial incentives. As a consequence the degree of regionalization still varies considerably among regions and among several developed countries.[17]

The objective of this study was to assess how the type and size of the delivery unit affect early-neonatal mortality in low-risk births, based on descriptive analyses of regionalization trends over the last 10 years in Hesse, Germany.

Methods

Data from the perinatal birth register of Hesse, 1990–1999 were used. The register, originally introduced as a quality assurance tool, provides detailed information about 582 655 infants born in delivery units, about the mother, and about the current pregnancy and delivery, as documented by the obstetrician in charge of the birth using an evaluated standardized questionnaire with 67 different items.[18,19] The database includes more than 95% of all births in Hesse (<2% of births were home births in this time period). Mainly due to the fact that some delivery units joined the quality assurance programme after 1990, data for some years for some delivery units are not available. The remaining undocumented births (approx. 3%) were attributable to those delivery units in the years mentioned.

Outcome events were death during labour or within the first 7 days of life (defined here as 'early-neonatal death') as these outcomes are the ones most plausibly attributable to differences in quality of medical care in the delivery units.

To validate our results we used neonatal quality assurance data from the years 1989–1997. This comparison data set is comprised of infants transferred to a neonatal intensive care unit (NICU) in Hesse within the first 10 days of their lives.[19] We used neonatal mortality (death within 28 days of life) as outcome event and the size of the delivery unit as the predictive variable. All 17 NICU in Hesse provided detailed documentation for all admitted infants in the years they participated in the quality assurance programme. Similarly to the perinatal database, not all NICU participated in the documentation in all of the years mainly because some NICU joined the quality assurance programme after 1989. Through this mechanism approx. 15% of NICU stays were not documented.

According to legal regulation, every low-risk birth in Germany is to be managed by a midwife whereas high-risk births are managed by an obstetrician in collaboration with a midwife. The delivery units we describe in this article are hospitals, so in all cases an obstetrician was responsible for the deliveries. A paediatrician or neonatologist would only be present at a birth when the obstetric team anticipates a high-risk birth and when paediatric or neonatological service is available. This is less likely for smaller units and during the night.

Delivery units are categorized according to their organizational structure into attending hospitals, government hospitals and perinatal centres:

- within attending hospitals (Belegkliniken) the obstetricians are not employees of the hospital. They work as specialized obstetric practitioners providing ambulatory prenatal care in their own offices, usually located outside the hospital, and where they recruit their patients. Usually the attending hospital provides the rooms, medical equipment, midwives and nurses as well as anaesthesiology services. While midwives and nurses will be present in the hospital 24 hours a day, the obstetrician, as well as the anaesthesiologist, may be called to be present at the birth. However, usually several specialized obstetric practitioners work as a group in one hospital in a way that one obstetrician is present in the hospital all of the time.
- government hospitals (Chefarztkliniken): These are usually larger hospitals where all medical staff are employed by the hospital and work exclusively for the hospital's department of obstetrics and gynaecology. An obstetrician as well as midwives will be in house 24 hours a day. The same may be true for the anaesthesiologist, however anaesthesiology services may also be provided on call as in attending hospitals.
- among the group of government hospitals, specialized obstetric units are referred to as perinatal centres (Perinatalzentren) if a NICU exists within the same hospital. This would provide a higher level of availability of neonatal specialists to attend deliveries at the request of the obstetrician.
- although NICU are located close to perinatal centres, they are independently organized, subordinated to paediatric departments, and are run by different medical staff.

Routine prenatal care in Germany is mainly provided by midwives and specialized obstetric practitioners, whereas perinatal centres and government hospitals usually only provide prenatal care for high-risk pregnancies.

Similar to other countries, efforts have been made to identify and transport high-risk pregnancies to perinatal centres before birth. The proportion of very low birthweight infants (<1500 g) born outside perinatal centres is less than 10%, indicating a very high level of identification and referral. In every region a specialized neonatal transport service is maintained to provide transfer of high-risk babies who are 'outborn' (not born in a perinatal centre) to the nearest NICU.

Hospital volume was categorized according to the number of births per year into very small (⩽500 births/year), small (501–1000 births/year), intermediate (1001–1500 births/year) and large (>1500 births/year).

Low-risk births were assumed for normal weight babies (using the traditional cut-off of ⩾2500 g birthweight[20]), excluding those infants with a documented congenital anomaly as a cause of death. All other births were classified as non-low risk.

Early-neonatal mortality rates together with corresponding 95% CI were calculated for delivery unit size. Subgroup and logistic regression analyses were used to assess the effect of unit size adjusting for other risk factors like birthweight or gestational age.

Statistical analyses were performed using STATA Version 6.0. To account for possible clustering of both patient characteristics as well as differences in the quality of documentation between the involved delivery units, the cluster option within the STATA logistic command was used.[21] Graphics were plotted using SYSTAT Version 10.[22]

Results

In Table 1 delivery unit size is cross-tabulated by their organizational structure. It is evident that unit structure is strongly associated with the size of units. On average, delivery units closed during the study period were the smallest while perinatal centres were the largest units.

Table 1 Categorized delivery unit size[a] by type of delivery unit

	Type of birth clinic				
Size of birth clinic (births/year)	Closed n = 9	Attending hospitals n = 39	Government hospitals n = 31	Perinatal centres n = 12	Total n = 91
Very small (⩽500 births/year) n = 39	2939	59 260	26 448	–	88 647
Small (501–1000 births/year) n = 33	2766	85 383	119 360	25 583	233 092
Intermediate (1001–1500 births/year) n = 14	–	22 002	92 549	50 351	164 902
Large (>1500 births/year) n = 5	–	–	–	96 014	96 014
Total births	5705	166 645	238 357	171 948	582 655

[a] Measured by births per year

n = No. of clinics.

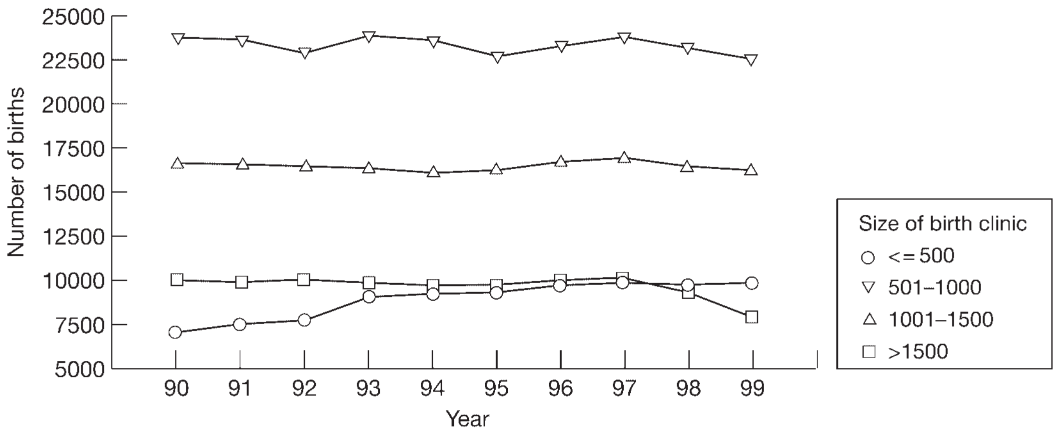

Figure 1 Number of births by size of birth clinic (all births)

A decrease in the annual volume of births in larger birth hospitals (>1500 births/year) occurred during the study period (Figure 1), while the number of births in the very small hospitals (⩽500 births/year) increased. These developments are mainly a function of the trends in low-risk births (Figure 2).

Table 2 illustrates that the different case mix by the size of delivery unit is reflected in a gradient of perinatal risk factors.

Among 582 655 births, 1319 early-neonatal deaths were documented. Among all births the crude mortality rates (per 1000 births) were highest in large birthing centres (early-neonatal death rate = 3.33; 95% CI: 2.98–3.72) (Table 3). Risk stratification of births according to birthweight (excluding deaths because of congenital anomalies) resulted in the highest mortality rates for very small units and lowest rates in large centres. This gradient was especially pronounced for normal weight babies where a monotonic downward trend inversely related with the size of the delivery unit was observed. Very small units showed the highest death-rate (0.60; 95% CI: 0.44–0.78), whereas in large delivery units the lowest early-neonatal death rate (0.19; 95% CI: 0.11–0.30) was seen (Table 3).

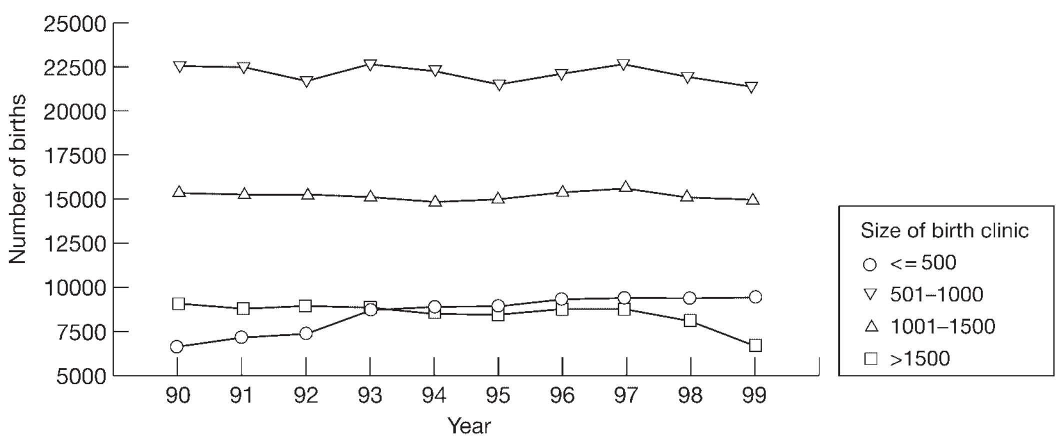

Figure 2 Number of births by size of birth clinic (low-risk births)

Table 2 Risk factors by type and size of birth clinic[a]

	Death from congenital anomaly (95% CI)	Congenital anomaly (95% CI)	Low birthweight (<2500 g) (95% CI)	Preterm (<37 completed weeks) (95% CI)	Caesarean section (95% CI)
Size of birth clinic (births/year)					
Very small (⩽500)	0.07 (0.05–0.09)	1.10 (1.04–1.18)	3.51 (3.39–3.63)	5.03 (4.88–5.17)	17.91 (17.66–18.17)
Small (501–1000)	0.09 (0.07–0.10)	1.86 (1.81–1.92)	4.74 (4.66–4.83)	6.42 (6.32–6.52)	19.88 (19.72–20.05)
Intermediate (1001–1500)	0.12 (0.10–0.14)	1.92 (1.86–1.99)	7.24 (7.11–7.36)	9.20 (9.06–9.34)	20.94 (20.74–21.13)
Large (>1500)	0.14 (0.12–0.17)	2.36 (2.26–2.46)	10.89 (10.70–11.09)	12.48 (12.27–12.69)	21.85 (21.59–22.11)

[a] Per 100 births.

Table 3 Numbers of births, early-neonatal deaths according to the size of birth clinics in all births, and birth risk defined subgroups

	No. of births	No. of early-neonatal deaths	Early-neonatal death rate (95% CI)[a]
All births			
Size of birth clinic (births/year)			
Very small (⩽500)	88 647	121	1.37 (1.13–1.63)
Small (501–1000)	233 092	381	1.63 (1.47–1.81)
Intermediate (1001–1500)	164 902	497	3.01 (2.76–3.29)
Large (>1500)	96 014	320	3.33 (2.98–3.72)
Total	582 655	1319	2.26 (2.14–2.39)
Birthweight-specific subgroups			
Birthweight <1000 g[b]			
Very small (⩽500 births/year)	57	15	263.16 (155.38–396.64)
Small (501–1000 births/year)	511	116	227.00 (191.38–265.83)
Intermediate (1001–1500 births/year)	864	221	255.79 (226.99–286.26)
Large (>1500 births/year)	938	157	167.38 (144.03–192.84)
Birthweight 1000–1499 g[b]			
Very small (⩽500 births/year)	111	4	36.04 (0.82–71.25)
Small (501–1000 births/year)	805	25	31.06 (19.05–43.06)
Intermediate (1001–1500 births/year)	1295	39	30.14 (20.81–39.47)
Large (>1500 births/year)	1404	26	18.52 (11.46–25.58)
Birthweight 1500–1999 g[b]			
Very small (⩽500 births/year)	370	4	10.81 (2.95–27.45)
Small (501–1000 births/year)	1846	17	9.21 (5.38–14.70)
Intermediate (1001–1500 births/year)	2620	24	9.16 (5.88–13.60)
Large (>1500 births/year)	2457	12	4.88 (2.53–8.53)
Birthweight 2000–2499 g[b]			
Very small (⩽500 births/year)	2536	8	3.15 (1.36–6.21)
Small (501–1000 births/year)	7776	13	1.67 (0.89–2.86)
Intermediate (1001–1500 births/year)	6989	19	2.72 (1.64–4.24)
Large (>1500 births/year)	5552	8	1.44 (0.62–2.84)
Normal birthweight (⩾2500 g)[b]			
Very small (⩽500 births/year)	85 465	51	0.60 (0.44–0.78)
Small (501–1000 births/year)	221 751	74	0.33 (0.26–0.42)
Intermediate (1001–1500 births/year)	152 586	42	0.28 (0.20–0.37)
Large (>1500 births/year)	85 490	16	0.19 (0.11–0.30)
Normal birthweight born at term[c]			
Very small (⩽500 births/year)	81 452	42	0.52 (0.37–0.70)
Small (501–1000 births/year)	210 154	63	0.30 (0.23–0.39)
Intermediate (1001–1500 births/year)	142 903	34	0.24 (0.16–0.33)
Large (>1500 births/year)	79 350	13	0.16 (0.09–0.28)

[a] Rate per 1000 births, exact binomial 95% CI.

[b] Without congenital anomalies as reasons of death, births with missing birthweights were excluded.

[c] >36 completed gestational weeks, >2499 g birthweight, without congenital anomalies as reasons of death, births with missing birthweight or gestational age were excluded.

Table 4 Number of births, early-neonatal deaths and relative risk of early-neonatal death in low-risk births[a] according to the size of birth clinics in three time intervals

	Time interval								
	1990–1993			1994–1996			1997–1999		
	No. of births	No. of early-neonatal deaths	Relative risk (95% CI)	No. of births	No. of early-neonatal deaths	Relative risk (95% CI)	No. of births	No. of early-neonatal deaths	Relative risk (95% CI)
Size of birth clinic (births/year)									
Very small (⩽500)	30 140	26	3.86 (1.75–8.52)	27 038	14	2.68 (0.97–7.45)	28 287	11	3.08 (0.86–11.05)
Small (501–1000)	89 577	40	2.00 (0.93–4.27)	66 055	16	1.26 (0.46–3.43)	66 119	18	2.16 (0.64–7.33)
Intermediate (1001–1500)	61 201	23	1.68 (0.75–3.76)	45 520	6	0.68 (0.21–2.24)	45 865	13	2.25 (0.64–7.88)
Large (>1500)	35 791	8	Ref.	25 915	5	Ref.	23 784	3	Ref.

[a] ⩾2500 g birthweight, without congenital anomalies as reasons of death.

Rate per 1000 births.

Table 4 provides relative risks for early-neonatal mortality by delivery size in low-risk births according to three time intervals within the study period (1990–1993, 1994–1996, and 1997–1999).

There is substantial variation in the described mortality gradient in each time interval (corresponding to the small numbers of deaths), but no clear downward trend towards the later 1990s was observed.

Additionally a logistic regression was performed, restricted to normal weight babies without congenital malformations as reasons of death. Deaths were excluded if they represented antepartum deaths before onset of labour, deaths before arrival at the delivery unit or other documented deaths where the time of death was unknown. In all, 545 127 births remained in the analyses. The analysis was performed controlling for numerous other risk factors such as gestational age, non-lethal congenital malformations (morbidity), mode of delivery (vaginal versus c-section) or timing of birth (Table 5).

A monotonically decreasing inverse relationship of the delivery unit size with the risk of early-neonatal death was observed in bivariate as well as in multivariate analyses. Low-risk babies

Table 5 Logistic regression for early-neonatal and neonatal death in low-risk births by size and type of birth hospital

Study population	**Babies born in Hesse (1990–1999)**		**Babies admitted to a NICU[a] in Hesse within the first 10 days of life (1989–1997)**
Dependent variable	Early-neonatal death		Neonatal death
	Normal birthweight[b] Odds ratio (95% CI)	Normal birthweight born at term[c] Odds ratio (95% CI)	Normal birthweight, admitted to NICU[d] Odds ratio (95% CI)
Size of birth clinic (births/year)			
Very small (⩽500)	3.48 (2.62–4.62)	3.48 (2.50–4.84)	2.90 (1.61–4.91)
Small (501–1000)	1.84 (1.45–2.35)	1.87 (1.38–2.55)	2.63 (1.56–4.20)
Intermediate (1001–1500)	1.43 (1.00–2.03)	1.41 (1.01–1.97)	1.88 (1.08–3.11)
Large (>1500)	Ref.	Ref.	Ref.
Log likelihood	–1605	–1360	–717
Degrees of freedom	24	20	15
No. of births	545 127	523 765	23 389
Observed deaths	201	162	143

[a] Neonatal intensive care unit.

[b] Including normal birthweight infants (⩾2500 g), without congenital anomalies as reasons of death, excluding antepartum deaths, infants born before the 26th week of gestation, deaths before arrival at the birth clinic, as well as deaths where the time of death was unknown. Adjusting for the following variables using dummy coding: gestational age (<30, 31–33, 34–36, 37–41, >41 gestational weeks, gestation age missing), birthweight (<3000, 3000–3499, 3500–3999, >3999 g, birthweight missing), mode of delivery (c-section versus vaginal delivery), time of birth (day versus night), congenital anomaly or malformation (morbidity), born before arrival at the birth clinic (yes, no, missing), maternal age (<20, 20–29, 30–39, ⩾40 years), parity (0, 1, ⩾2), born outside the birth clinic (yes, no, missing), birth planned in the birth clinic documenting the birth (yes, no, missing). No early-neonatal deaths occurred in the groups where the information on parity, or on the age of mother were missing. These variables were therefore not used in the analyses.

[c] Including normal weight infants (⩾2500 g) born at term (⩾37 gestational weeks), without congenital anomalies as reasons of death, excluding antepartum deaths, deaths before arrival at the birth clinic, as well as deaths where the time of death was unknown. Adjusting for the following variables using dummy coding: (37–41, >41 gestational weeks; gestational age missing), birthweight (<3000, 3000–3499, 3500–3999, >3999 g, birthweight missing), mode of delivery (c-section versus vaginal delivery), time of birth (day versus night), congenital anomaly or malformation (morbidity), born before arrival at the birth clinic (yes, no, missing), maternal age (<20, 20–29, 30–39, ⩾40 years), parity (0, 1, ⩾2), born outside the birth clinic (yes, no, missing), birth planned in the birth clinic documenting the birth (yes, no). No early neonatal deaths occurred in the groups where the information on parity, on the age of mother were missing, or on the fact whether the birth had been planned in the current birth clinic were missing. These variables were therefore not used in the analyses.

[d] Including normal birthweight infants (⩾2500 g), excluding infants born before the 26th week of gestation or where the birth clinic was not documented. Adjusting for the following variables using dummy coding: gestational age (<30, 31–33, 34–36, 37–41, >41 gestational weeks, gestational age missing), birthweight (<3000, 3000–3499, 3500–3999, >3999 g), maternal age (<20, 20–29, 30–39, ⩾40 years). No neonatal deaths occurred in the group where the information on birthweight was missing. This variable was therefore not used in the analyses.

born in very small delivery units (⩽500 births/year) had a more than threefold risk of early-neonatal death compared with low-risk births in large delivery units (>1500 births/year) (odds ratio[OR] = 3.48; 95% CI: 2.64–4.58). The risk for early-neonatal death was also increased in low-risk births delivered in small (501–1000 births/year) (OR = 1.86; 95% CI: 1.45–2.35), and intermediate delivery units (1001–1500 births/year) (OR = 1.43; 95% CI: 1.00–2.03) (Table 5).

A logistic regression analysis restricted to normal weight babies born at term yielded almost identical results (Table 5). Similar results were obtained using neonatal mortality (death by 28 days) as endpoint by relying on the neonatal database comprising those infants admitted to a NICU in Hesse, 1989–1997 (Table 5).

Discussion

It is common sense and current practice that anticipated high-risk births are transferred to larger obstetric units before birth to provide optimal medical care for the endangered mother and child. Consequently low-risk births constitute a larger percentage in smaller obstetric units. In Hesse, the large proportion of births that occur in these smaller obstetric units reflects a historical pattern of birthing near home. Patients seem to prefer the smaller delivery units because of the more personal and private atmosphere within these units.

Our results raise serious concern with regard to early-neonatal death and to neonatal death, not only in high-risk births inadvertently delivered in these smaller centres, but even among low-risk births deliberately planned for delivery in small birthing units. As a matter of health policy, there should be serious consideration of whether such a preference is justified in the face of the observed mortality gradient.

To validate the completeness of reported deaths, death rates have been compared with corresponding death rates as reported by the Statistical Office of Hesse.[23] This comparison revealed an approximately 13% lower mortality rate in the perinatal database used for the current analyses. It is important to note that almost identical death rates were observed when comparing death rates for normal weight births only. As we have based our definition of low-risk births mainly on normal birthweight it is very unlikely that differential misclassification of deaths biased the reported results.

A partial explanation for the higher mortality rates is that the Statistical Office of Hesse uses a slightly different definition of the target population than the perinatal birth register of Hesse. All babies born in delivery units in Hesse is the target population's definition in the perinatal database whereas all babies born to mothers residing in Hesse is the target population the Statistical Office of Hesse uses; a definition which also includes home births. However, there is no reason to assume that a mortality rate difference of this magnitude may be explained by referral of high-risk births out of Hesse.

The lack of information about deaths after discharge from the delivery unit may be more important in explaining the lower death rates in the perinatal database.

If the newborn has been transferred to a NICU, the obstetrician documenting the birth will not be informed automatically whether the transferred infant has survived its first week of life. This may lead to substantial under-documentation of deaths. We have therefore validated our analyses by using the corresponding neonatal database comprising only infants transferred to a NICU. The fact that similar results were obtained may serve as an additional indicator that the reported results have not emerged due to reporting bias. This additional database also provided us with the possibility of using neonatal mortality (death within the first 28 days of life) as an alternative endpoint of our analyses. This is important as it may be speculated that superior survival in larger perinatal centres may disappear after a few days; it may only be the consequence of more frequent resuscitation and advanced life support technology for moribund infants in these larger units. Although the coverage in the neonatal database is not as good as the perinatal database, each unit provided information on all admitted infants in the years it participated in the quality assurance programme. In other words entire years and not individual admissions are missing. Together with the fact that NICU are independent, in organization terms, of the delivery units, this indicates that there is no reason to suspect the reported results are influenced by reporting bias.

Within the group of newborns discharged home, virtually no subsequent deaths occur in the first week of life. This is because only apparently stable babies are discharged home within the first week of life, and can be expected to survive. Sudden infant deaths among those babies is not an issue because mortality from this condition is extremely rare in this age range, and is considerably lower than early-neonatal death resulting from perinatal events, especially in normal birthweight infants and in the first week of life.[24] Therefore we do not think that the lower mortality rate in the perinatal database has emerged from newborns discharged home.

The effects of delivery unit size were almost identical when low-risk birth was defined mainly based on gestational age.[25] An analysis restricted to preterm babies with normal birthweight, as described by Paneth *et al.*,[4] also yielded higher mortality risks in smaller birth units.[25] In the logistic regression models, we included infants where the birthweight or the gestational age was missing, and adjusted for the possible influence of this missing information using dummy variables. Additionally we adjusted for timing of birth, as higher early-neonatal death rates in low-risk babies born at night have been previously reported.[26,27] Almost identical results were obtained when not controlling for timing of birth, or when excluding births where birthweight or gestational age was unknown. This indicates that our results are robust in the face of differential missing data of birthweight or missing data of gestational age.

We adjusted for known perinatal risk factors, and excluded deaths due to anomalies in order to ensure that differential classification of risk factors between the different types of delivery units did not influence our results.

Another important aspect of the design of our study is that we excluded infants not actually born in the delivery unit. This was to ensure that asphyxiated home births later transferred to delivery units documenting those births did not influence our results.

Although several additional perinatal risk factors are documented in the database, we did not use them for further risk adjustment. It may be speculated that several of these risk factors are more likely to be documented in larger delivery units, including those risk factors might have biased our results away from the null hypotheses. In the current approach, however, misclassification into low-risk status should be more prevalent among women delivering in the larger centres, and therefore cannot explain the poor performance of the small centres. In other words not controlling for these additional risk factors is the more conservative analytical approach.

Another possible bias is from referral during pregnancy. Women anticipating non-low-risk births will have an increased probability of being transferred to larger delivery units with a higher degree of procedural capacity. This referral of high-risk cases helps explain the fact that an increased crude risk for early-neonatal death can be observed within larger delivery units or perinatal centres when analysing all births.

We can assume that, even within the group of low-risk births, more babies with higher risks have been transferred to larger units. In our regression, we controlled for caesarean delivery. This is a conservative analysis, because smaller delivery units may, in fact, be less capable of performing emergency caesarean sections in the face of fetal distress—one event that may lead to early-neonatal death. Therefore the observed relationship may even be underestimated.

The perinatal database differentiates antepartum deaths from death during labour. We used the latter together with mortality in the first 7 days of life as outcome event because these events may be (at least partly) attributed to the delivery unit. Using only deaths within the first 7 days of life as endpoint yielded almost identical results.[25] We do not report the results of the relationship of delivery unit size with the frequency of stillbirths for the reasons explained above: The unit documenting a stillbirth is not necessarily the same obstetric institution that is also responsible for the prenatal care of this pregnancy, which makes the causal attribution of stillbirth rates to hospital characteristics difficult.

We also classified whether the birth was planned for the current delivery unit or if the baby was born outside the unit that documented the birth. We then included this in the logistic regression model to ensure that transfer of high-risk babies during or immediately after birth did not influence our results.

As the mortality gradient with the size of the delivery unit showed no clear downward trend towards the late 1990s it is not justified to assume that improvements in prenatal diagnosis and subsequent referral of endangered pregnancies into larger obstetric units before birth have made further centralization of births unnecessary.

Numerous previous studies have shown a substantial impact of regionalization on neonatal survival in high-risk births but only few have specifically analysed the effect in low-risk births, with conflicting results.[5,6,15,16] In the current analyses we could demonstrate that a strong and independent early-neonatal death gradient with the size of the delivery unit is also present within low-risk births. Recent analyses from Norway have proposed delivery units with >2000 births/year in order to reduce neonatal death in low-risk births.[16] Their reported outcomes for delivery units with >2000 births per year were similar to ours for >1500 births. However, we were unable to assess any further effect of increasing size as obstetric care in Hesse is so dispersed that only two delivery units with >2000 births/year exist. This may, in fact, be the reason why we have been able to demonstrate such a powerful gradient in birth outcomes.

As a similar lack of regionalization also exits in several other developed countries[17] it is reasonable to expect similar mortality gradients in these countries. This underlines the importance of our findings.

Previously, we have also analysed early-neonatal mortality according to the type of delivery unit (attending hospital, government hospital, and perinatal centre),[25] but as delivery unit size and type were strongly collinear it was not possible to adequately separate the effects of these variables. However, it is common sense that neither the size nor type of the delivery units themselves are the direct causal reason for the observed mortality gradient. In our analyses we could not address the question of which specific problems within the delivery units may be responsible for the observed mortality gradient. We have previously speculated[27] that the mortality gradient may relate to the lower staffing and readiness inherent in low volume birthing hospitals. It is discouraging that the trend of birth location in Hesse reveals an overall deregionalization—that is, a relative increase in births in very small delivery units during the recent decade; apparently a migration of low-risk births out of larger institutions. This implies that an increasing proportion of women with low-risk births are putting themselves at greater risk for early-neonatal death.

Future analyses should aim to characterize more specifically the causal factors attributable to delivery unit size. This requires additional information (e.g. about staffing, skill, teamwork or medical equipment), which was not available for the present study. Once the causal factors for the observed mortality gradient can be better defined, it will also be easier to derive mechanisms (e.g. transfer guidelines, training programmes or staffing standards) to improve the situation. In these analyses it would also be useful to explore the role of the NICU size, or better, its procedural capacity, as well as the distance from the birthing unit to the next NICU in detail. Preliminary analyses show that the size of the NICU does not have a comparable impact on neonatal survival.[25] However, even if all additional neonatal deaths in smaller delivery units could be attributed to the fact that no adequate NICU is located nearby, it is unlikely that founding (numerous) additional NICU near these smaller birthing units would solve the problem because this would be the most expensive solution.

These results were observed despite adherence to a widely accepted and intensive prenatal care programme in Germany comprising 10 antenatal physician visits and 3 ultrasound scans; with corresponding low perinatal and neonatal mortality rates.[28]

Altogether our results give reason to believe that early-neonatal death may be substantially reduced by greater centralization of births. This will require changing public awareness, as well as persuading the obstetric community to consolidate delivery units. The difficulty of this process has been described by Donahue *et al.*[29]

Conclusion

Our results indicate that early-neonatal death in low-risk births in very small delivery units (⩽500 births) is substantially increased when compared with low-risk births in large delivery units (>1500 births). Even small (501–1000 births) and intermediate delivery units (1001–1500 births) showed a significantly increased early-neonatal death rate compared to large delivery units (>1500 births).

This presents an urgent public policy issue of whether this elevated risk in smaller delivery units is acceptable or if further consolidation of birthing units should be considered in an attempt to reduce early-neonatal death rates.

Acknowledgements

We would like to thank Christiane Gasse and Thomas Kratz for revising previous drafts of the paper as well as for their helpful comments.

KEY MESSAGES

- Numerous studies have demonstrated the benefits of regionalization for high-risk births.
- Improvements in obstetric practices and antenatal care may have led to satisfactory early identification and subsequent referral of high-risk births into larger delivery units and only few studies have addressed the impact of hospital volume in low-risk births.
- There is still ongoing discussion about the necessary degree of centralization for optimal perinatal and neonatal care.
- A persisting pronounced mortality gradient with the size of the delivery unit in low-risk births, despite a well-accepted intensive antenatal screening programme, was observed in Hesse, Germany.
- Reorganization of obstetric care should be discussed to reduce early-neonatal death rates.

References

1 Ryan GM, Pettigrew A, Fogerty S, Donahue CL. Regionalizing perinatal health services in Massachusetts. *N Engl J Med* 1977;**296:**228–30.

2 Gortmaker S, Sobol A, Clark C, Walker DK, Geronimus A. The survival of very low-birth weight infants by level of hospital of birth: a population study of perinatal systems in four states. *Am J Obstet Gynecol* 1985;**152:**517–24.

3 Rosenblatt RA, Reinken J, Shoemack P. Is obstetrics safe in small hospitals? Evidence from New Zealand's regionalised perinatal system. *Lancet* 1985;**ii:**429–32.

4 Paneth N, Wallenstein S, Kiely JL, Snook CP, Susser M. Medical care and preterm infants of normal birth weight. *Pediatrics* 1986;**77:**158–66.

5 Paneth N, Kiely JL, Wallenstein S, Susser M. The choice of place of delivery. Effect of hospital level on mortality in all singleton births in New York City. *Am J Dis Child* 1987;**141:**60–64.

6 Berg CJ, Druschel CM, McCarthy BJ, LaVoie M, Floyd RL. Neonatal mortality in normal weight babies: Does the level of hospital care make a difference? *Am J Obstet Gynecol* 1989;**161:**86–91.

7 Albers LL, Savitz DA. Hospital setting and fetal death during labor among women at low risk. *Am J Obstet Gynecol* 1991;**164:**868–73.

8 Cole SK, Macfarlane A. Safety and place of birth in Scotland. *J Public Health Med* 1995;**17:**17–24.

9 McCormick MC, Richardson DK. Access to NICU care. Low birth weight. *The Future Of Children* 1995;**5:**162–75. Packard Foundation, Los Altos, CA.

10 Powell SL, Holt VL, Hickok DE, Easterling T, Connell FA. Recent changes in delivery site of low-birth-weight infants in Washington: impact on birth weight-specific mortality. *Am J Obstet Gynecol* 1995; **173:**1585–92.

11 Richardson DK, Reed K, Cutler JC *et al.* Perinatal regionalization versus hospital competition: the Hartford example. *Pediatrics* 1995;**96:** 417–23.

12 Phibbs CS, Bronstein JM, Buxton E, Phibbs RH. The effects of patient volume and level of care at the hospital of birth on neonatal mortality. *JAMA* 1996;**276:**1054–59.

13 Rosenblatt RA, Macfarlane A, Dawson AJ, Cartlidge PH, Larson EH, Hart LG. The regionalization of perinatal care in Wales and Washington State. *Am J Public Health* 1996;**86:**1011–15.

14 Menard MK, Liu Q, Holgren EA, Sappenfield WM. Neonatal mortality for very low birth weight deliveries in South Carolina by level of hospital perinatal service. *Am J Obstet Gynecol* 1998;**179:**374–81.

15 Yeast JD, Poskin M, Stockbauer JW, Shaffer S. Changing patterns in regionalization of perinatal care and the impact on neonatal mortality. *Am J Obstet Gynecol* 1998;**178:**131–35.

16 Moster D, Lie RT, Markestad T. Relation between size of delivery unit and neonatal death in low risk deliveries: population based study. *Arch Dis Child Fetal Neonatal Ed* 1999;**80:**221–25.

17 Papiernik E, Zeitlin J, Milligan WA *et al.* Variations in the organisation of obstetric and neonatal intensive care in Europe. *Prenat Neonat Med* 1999;**4(Suppl.1):**73–87.

18 Künzel W. The birth survey in Germany—education and quality control in perinatology. *Eur J Obstet Gynecol Reprod Biol* 1994;**54:**13–20.

19 Quality assurance in perinatology [Qualitätssicherung in der Gebutshilfe] 9 November 2001. http://www.gqhnet.de/peri/txt.html (8 April 2002).

20 Lubchenco LO, Hansmann C, Dressler M, Boyd E. Intrauterine growth as estimated from liveborn birth weight data at 24–42 weeks of gestational age. *Pediatrics* 1963;**32:**793–801.

21 StataCorp. *Stata Statistical Software: Release 6.0*. College Station, TX: StataCorp, 1999.

22 SPSS. *SYSTAT 10.* Chicago, IL: SPSS, 2000.

23 Hofacker G. Säuglingssterblichkeit 1998 [Infant mortality 1998]. *Staat und Wirtschaft in Hessen* 1999;**11:**326–29.

24 Leach CE, Blair PS, Fleming PJ *et al.* Epidemiology of SIDS and explained sudden infant deaths. CESDI SUDI Research Group. *Pediatrics* 1999;**104:**953–58.

25 Heller G. Regionalization of births and risk of early neonatal death in Hesse 1990–1999. Additional analyses. December 2001. http://staff-www.uni-marburg.de/~heller/regio.html (December 2001).

26 Stewart JH, Andrews J, Cartlidge PHT. Numbers of deaths related to intrapartum asphyxia and timing of birth in all Wales perinatal survey, 1993–1995. *BMJ* 1998;**316:**657–60.

27 Heller G, Misselwitz B, Schmidt S. Early neonatal mortality, asphyxia related deaths, and timing of low risk births in Hesse, Germany, 1990–8: observational study. *BMJ* 2000;**321:**274–75.

28 Bundesministerium für Gesundheit. *Daten des Gesundheitswesens* [Federal Ministry of Health. Health care statistics]. Band 122. Ausgabe 1999. Schriftenreihe des Bundesministeriums für Gesundheit. Baden-Baden: Nomos Verlagsgesellschaft, 1999, pp. 207–13.

29 Donahue CL, Pettigrew AH, Young K, Ryan GM. The closure of maternity services in Massachusetts. The causes, process, and hospital impact. *Obstet Gynecol* 1977;**50:**280–84.