OBSTETRICS

Increased risk of peripartum perinatal mortality in unplanned births outside an institution: a retrospective population-based study

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BACKGROUND: Births in midwife-led institutions may reduce the frequency of medical interventions and provide cost-effective care, while larger institutions offer medically and technically advanced obstetric care. Unplanned births outside an institution and intrapartum stillbirths have frequently been excluded in previous studies on adverse outcomes by place of birth.

OBJECTIVE: The objective of the study was to assess peripartum mortality by place of birth and travel time to obstetric institutions, with the hypothesis that centralization reduces institution availability but improves mortality.

STUDY DESIGN: This was a national population-based retrospective cohort study of all births in Norway from 1999 to 2009 (n = 648,555) using data from the Medical Birth Registry of Norway and Statistics Norway and including births from 22 gestational weeks or birthweight ≥500 g. Main exposures were travel time to the nearest obstetric institution and place of birth. The main clinical outcome was peripartum mortality, defined as death during birth or within 24 hours. Intrauterine fetal deaths prior to start of labor were excluded from the primary outcome.

RESULTS: A total of 1586 peripartum deaths were identified (2.5 per 1000 births). Unplanned birth outside an institution had a 3 times higher mortality (8.4 per 1000) than institutional births (2.4 per 1000), relative risk, 3.5 (95% confidence interval, 2.5–4.9) and contributed 2% (95% confidence interval, 1.2–3.0%) of the peripartum mortality at the population level. The risk of unplanned birth outside an institution increased from 0.5% to 3.3% and 4.5% with travel time <1 hour, 1–2 hours, and >2 hours, respectively. In obstetric institutions the mortality rate at term ranged from 0.7 per 1000 to 0.9 per 1000. Comparable mortality rates in different obstetric institutions indicated well-functioning routines for referral.

CONCLUSION: Unplanned birth outside an institution was associated with increased peripartum mortality and with long travel time to obstetric institutions. Structural determinants have an important impact on perinatal health in high-income countries and also for low-risk births. The results show the importance of skilled birth attendance and warrant attention from clinicians and policy makers to negative consequences of reduced access to institutions.

Key words: access, availability, emergency obstetric and newborn care, health systems, perinatal mortality

Birth-related complications may arise quickly and threaten the life and future health of both the mother and child. Prevention of death and adverse outcomes requires urgent, skilled interventions. Whether delivery care in smaller obstetric institutions and midwife-led institutions is safe and cost effective compared with centralized care in larger obstetric institutions has been heavily debated.[1-6] Typically, previous studies comparing the planned place of birth have excluded unplanned births outside an institution.[3,4,7,8] Additionally, key studies have included only neonatal deaths and thus failed to address how a lack of adequate monitoring and interventions during labor may result in intrapartum death.[4,6,7,9,10]

Several authors have raised concerns about adverse consequences of reduced accessibility to obstetric and neonatal care as well as a risk of unnecessary interventions in the larger institutions.[1,5,11-15] However, conclusive studies linking structural factors and perinatal mortality are lacking. In Norway, the number of obstetric institutions was reduced from 95 to 51 during 1979–2009. The rate of unplanned births outside an institution increased in both rural and urban areas during this period.[16]

The aim of the present study was to assess peripartum mortality associated with the place of birth and availability of obstetric institutions, with the hypothesis that centralization reduces institution availability but improves the peripartum mortality.

Material and Methods

Study design, setting, and data sources

We designed a retrospective population-based cohort study of all births in Norway from Jan. 1, 1999, to Dec. 31, 2009 (n = 648,555 births). Data sources were the Medical Birth Registry of Norway (MBRN) and Statistics Norway. Inclusion criteria were births with a gestational age ≥22 completed weeks or birthweight ≥500 g.

The MBRN has received mandatory standardized notifications of all live births and stillbirths (≥16 weeks' gestation) since 1967. The registry is routinely linked with the National Registry through the mother's national identification number, given to all individuals residing in the country. This linkage provides identification numbers to all live births, ensures complete notification

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to the MBRN, and provides data on all dates of death.

The MBRN notification form was extended in 1999 to include more information about the mother, the neonate, and the birthplace. The notification of stillbirths specifies time of death in relation to labor (antepartum, intrapartum, or unknown) and to arrival in the institution (prior to or after). Stillbirth registration in the MBRN has been validated,[17] and the MBRN receives the autopsy report or, if autopsy is not performed, a written conclusion on likely cause of death for all stillbirths from 22 weeks' gestation.

In the present study, linkage with the National Registry provided data on each mother's registered address. Since 2000, Statistics Norway has assigned geographic coordinates to the National Registry addresses and updated addresses and coordinates on Jan. 1 each year. Coverage of individual coordinates was 98% of all addresses in 2000 and 99% in 2010.

Primary perinatal outcome

Peripartum mortality was defined as intrapartum death or neonatal death within 24 hours and will in the following text be referred to as mortality. Fetal death prior to labor (antepartum stillbirths) were excluded from the primary perinatal outcome.

Place of birth

Place of birth was categorized as unplanned outside an obstetric institution, in basic obstetric care institution (BOC), and in emergency obstetric and newborn care institution (EmONC). Unplanned birth outside an institution was defined as a birth at home, during transportation, or in a nonobstetric institution (eg, health center) for a woman who planned an institutional birth.

The World Health Organization Handbook for Monitoring Emergency Obstetric and Newborn Care was used to categorize institutions by the available treatment options.[18] BOC institutions provided midwife-led care for normal deliveries and intravenous administration of drugs and basic newborn resuscitation if needed before transfer.

EmONC institutions provided intravenous administration of uterotonic drugs, antibiotics, and magnesium sulphate, removal of the placenta or retained products of conception, newborn resuscitation, assisted vaginal delivery, cesarean delivery, and blood transfusion. All EmONC institutions had a specialist in obstetrics and gynecology on call.

We further classified EmONC institutions according to the annual number of deliveries (<500, 500−1499, and >1500). Institution closure or change in the level of care was corrected at the start of each calendar year, included institutions reported ≥10 births annually. Planned home births were rare (1253, 0.2%); 96% of these mothers lived within the 1 hour travel zone to all obstetric institutions. There were no peripartum deaths. These births have been described previously[19] and were excluded (Figure 1).

Travel zone

A travel zone was defined as the geographic area in which all women were estimated to reach the nearest obstetric institution within the given time. Institutions were registered by geographic coordinates, and surrounding travel zones were calculated based on the Norwegian electronic road database.[20] Estimates were based on registered speed limits and the standard duration of ferry/boat journeys and represented the minimum time for nonemergency transport. A merged area (polygon) was created for the travel zones (<1 hour, 1−2 hours, and >2 hours).

The mother's national identification number, or a substitute identification number for resident noncitizens, was used to link births in the MBRN to her registered address in the National Registry and then to the address coordinates (n = 638,155 births, 98.4%). For each birth the registered address was placed in a travel zone. Births to women lacking address coordinates were assigned to the travel zone of the majority of mothers in their municipality in the corresponding year (n = 9996 births, 1.5%). Few births lacked both address coordinates and municipality (n = 404, 0.06%), and these were excluded from the travel zone analyses. The annual relocation rate was 14% in 2000, 8.6% within the municipality, and 4.8% to another municipality.

Analyses

The infant/birth was the observation unit in all analyses. Cross-tables and generalized linear models were used to compute rates and relative risks (RRs) with 95% confidence intervals (CIs), while taking into account clustering by births to the same mother or in the same institution.

Multilevel models were used to assess both cluster levels. Attributable risk was calculated from the adjusted relative risk model.[21,22] Analyses were stratified on socioeconomic risk factors and maternal and fetal medical risk factors for perinatal mortality.

We also stratified analyses by season (summer, April to September; and winter, October to March) and by 5 year period (1999−2004 and 2005−2009). We used standardized sex-specific birthweight by gestational age (z-scores) to identify misclassified gestational age (z-score above 4, n = 330 births, 0.05%).[23] If gestational age was misclassified or only birthweight was recorded (n = 4810, 0.7%), we categorized births as preterm if birthweight was more than 2 SD below the average weight at 37 weeks (<2285 g for males and <2200 g for females, n = 677, 0.1%).

Statistical analyses were performed with SPSS (IBM SPSS Statistics for Mac, version 23.0; IBM Corp, Armonk, NY) and STATA 14 IC (StataCorp LP, College Station, TX). Travel zone analyses were performed with the GIS software Arc Info with Network Analyst (Environmental Systems Research Institute Inc, Redlands, CA).

Ethical approval

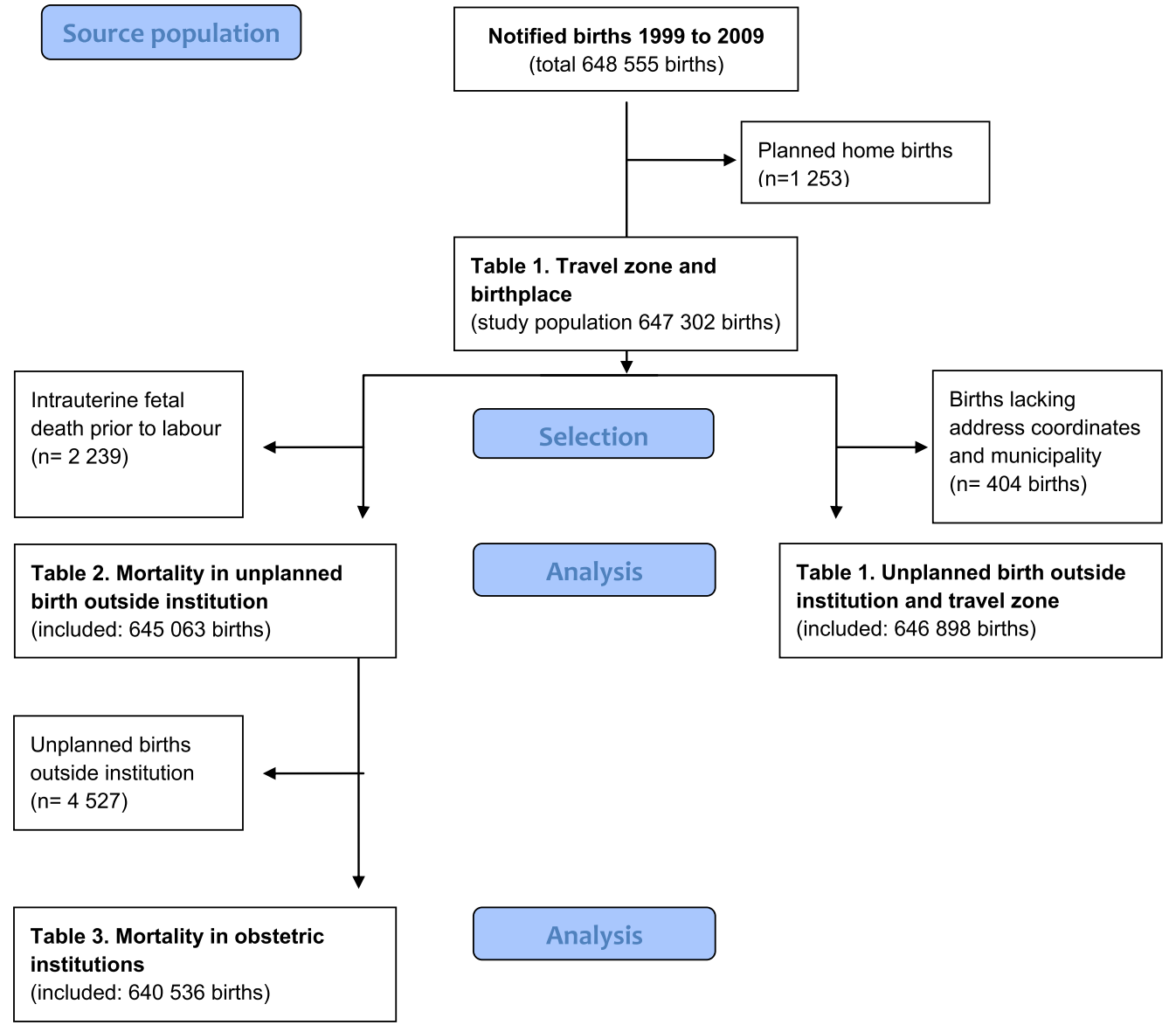
The Regional Medical Ethical Committee for Western Norway approved the study (REK-VEST 2010/3243).

Results

Travel zone and place of birth

Travel zone information was available for 646,898 births and the distribution

FIGURE 1
Study population flow diagram



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of travel zones and place of birth in the population is described in Table 1. Births were more likely to occur unplanned outside an institution, in BOC institutions, or in the lowest-volume EmONC institutions when mothers lived in rural areas with long travel time to institutions. A total of 9490 births occurred in BOC institutions. Few nulliparous women delivered in BOC institutions (n = 1680); among these, 87% would need to travel more than 1 hour to reach an EmONC institution.

A total of 4538 children with available travel zone information were born unplanned outside an institution: 1759 at home, 2148 during transport, 121 in former obstetric institutions, and 510 in other locations. Risk of unplanned birth outside an institution was 5 times higher in the 1−2 hour travel zone to all institutions compared with the <1 hour zone (adjusted RR, 5.3; 95% CI, 4.9−5.7) and 7 times higher when travel time exceeded 2 hours (adjusted RR, 7.1; I, 6.3−8.1).

The majority of unplanned births outside institutions occurred to low-risk women (online Appendix 1). There were no differences in frequency from the first to the last 5 year period (data not shown, $P = .48$). Stratified on the risk factors outlined in Table 2, analyses yielded similar relative risks as the crude relative risk, but women with medical risk

TABLE 1
Place of birth and the mother's travel zone to all obstetric institutions and to EmONC institutions

Institution	Travel zone	Total, n	Basic obstetric care, n	Emergency obstetric care <1500/y, n	Emergency obstetric care >1500/y, n	Unplanned birth outside institution		
						n	Relative risk (95% CI)[a]	Adjusted relative risk[b]
	Total births[c]	647,302	9490 (1.5)	204,612 (31.6)	428,654 (66.2)	4546 (0.7)		
	Travel zone available, n, %	646,898	9487 (1.5)	204,508 (31.6)	428,365 (66.2)	4538 (0.7)		
All institutions	Travel zone 1 h, n, %	615,896	8638 (1.4)	182,202 (29.6)	421,608 (68.5)	3488 (0.6)	Reference	Reference
	Travel zone 1–2 h, n, %	25,494	787 (3.1)	17,600 (69.0)	6263 (24.6)	844 (3.3)	5.9 (5.5–6.4)	5.3 (5.0–5.8)
	Travel zone >2 h, n, %	5508	62 (1.2)	4706 (85.4)	494 (9.0)	246 (4.5)	8.0 (7.0–9.1)	7.2 (6.3–8.2)
EmONC institutions	Travel zone <1 h, n, %	591,836	1187 (0.2)	170,512 (28.8)	417,067 (70.5)	3070 (0.5)		
	Travel zone 1–2 h, n, %	40,189	5148 (12.8)	25,031 (62.3)	8947 (22.3)	1063 (2.7)		
	Travel zone >2 h, n, %	14,873	3152 (21.2)	8965 (60.3)	2351 (15.8)	405 (2.7)		

Data from Statistics Norway and the Medical Birth Registry of Norway, 1999–2009.

EmONC, Emergency Obstetric Care.

[a] Relative risks adjusted for births to the same mother; [b] Relative risk adjusted for all risk factors outlined in Table 2; [c] Births at gestational age ≥22 weeks or birthweight ≥500 g; planned home births were excluded.

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factors were less likely to deliver unplanned outside an institution (online Appendix 1). Most resident noncitizen women lived within the 1 hour travel zone (n = 2315, 94%). Their rate of unplanned births outside an institution was 1.2% (n = 30), with no deaths.

Peripartum mortality in unplanned birth outside an institution

Antepartum fetal deaths occurred at a similar rate in the travel zones (overall number, 2239, 3.4 per 1000). Nearly all were delivered in EmONC institutions (n = 2208), 19 were born unplanned outside an institution, and 12 in BOC institutions. These births were excluded from further analyses (Figure 1).

Among the remaining 645,063 births, we identified 1586 deaths (Table 2), of which 773 (48.7%) were stillborn. Unplanned birth outside an institution was strongly associated with mortality risk (crude RR, 3.5; 95% CI, 2.5–4.9). Although the absolute mortality rate was higher for preterm births than term births (25.4 per 1000 versus 0.7 per 1000), the relative mortality risk associated with unplanned birth outside an institution was increased for both preterm and term births. There was no difference between the first and last 5 year period (data not shown, $P = .3$).

The stratified analyses shown in Table 2 illustrate higher absolute mortality rates in high-risk groups but similar RRs associated with unplanned birth outside an institution except for single, young, and nulliparous women.

The relative mortality risk was particularly high for births to nulliparous women (RR, 14.9; 95% CI, 8.8–25.1), but also births to parous women had a doubled risk of death if born unplanned outside an institution (RR, 2.2; 95% CI, 1.4–3.4). Few births with severe congenital malformations took place unplanned outside an institution (n = 170, 0.5%), and there were no peripartum deaths. We therefore excluded severe congenital malformations before adjusting for all tabulated risk factors (Table 2). The adjusted relative risk for peripartum mortality in an unplanned birth outside an institution was then 3.9 (95% CI, 2.8–5.3).

Attributable risk

Peripartum deaths were rare and occurred most frequently in institutional preterm births. However, among unplanned births outside an institution, the risk of death attributable to this exposure was high (attributable fraction, 0.7; range, 0.6–0.8) and accounted for 2.1% (95% confidence interval, 1.2–3.0%) of the peripartum mortality in the population.

Mortality in obstetric institutions

Figure 2 shows the relative risk of peripartum death in the different institution categories stratified on parity. After adjustment for socioeconomic factors and maternal and fetal risk factors and using the smallest EmONC institutions as reference, we did not find evidence of different mortality by annual number of births in EmONC institutions (Table 3).

In births with no major congenital malformations, the mortality rate in BOC institutions was lower for parous women

TABLE 2
Peripartum mortality comparing unplanned births outside an institution and births in obstetric institutions, overall and stratified by maternal and fetal risk factors

Variables	Category	Number of births, n = 645,063[a]	Unplanned outside institution, n = 4527, deaths (per 1000)	In obstetric institutions, n = 640,536, deaths (per 1000)	Relative risk (95% CI)
Overall mortality, n (per 1000)[b]			38 (8.4)	1548 (2.4)	3.5 (2.5–4.9)[c]
					3.9 (2.7–5.6)[d]
Gestational age, wks	≥37	600,129	7 (1.7)	429 (0.7)	2.3 (1.1–4.9)
	<37	44,934	31 (100.3)	1119 (25.4)	3.9 (2.8–5.6)
Maternal age, y	<20	15,251	6 (96.8)	56 (3.7)	19.3 (8.6–43.6)
	20–35	520,589	28 (7.8)	1163 (2.2)	3.4 (2.3–4.9)
	>35	109,183	4 (4.7)	329 (3.0)	1.5 (0.6–4.1)
Parity	1 or more	378,687	20 (4.9)	855 (2.3)	2.2 (1.4–3.4)
	0	266,376	18 (39.5)	693 (2.6)	14.4 (9.0–23.2)
Education, y	≥11	497,697	24 (7.3)	1038 (2.1)	3.5 (2.3–5.2)
	<11	148,431	14 (11.2)	510 (3.5)	3.1 (1.8–5.3)
Partner status	Partner	592,153	27 (6.5)	1358 (2.3)	2.7 (1.9–4.0)
	Single	43,598	11 (32.1)	158 (3.6)	8.8 (4.8–16.1)
Ethnicity	Western	585,324	35 (8.6)	1136 (2.3)	3.6 (2.6–5.1)
	Non-Western	59,739	3 (6.8)	212 (3.6)	1.9 (0.6–6.0)
Smoking	Nonsmoker	435,910	15 (5.1)	944 (2.2)	2.4 (1.4–3.9)
	No information[e]	106,533	11 (15.6)	335 (3.2)	4.5 (2.4–8.5)
	Any smoking	102,620	12 (13.4)	269 (2.6)	5.1 (2.9–9.0)
Chronic disease	No	583,274	35 (8.4)	1390 (2.4)	3.4 (2.4–4.8)
	Yes[f]	61,789	3 (7.9)	158 (2.6)	3.1 (0.99–9.7)
Plural	Singleton	621,789	33 (7.4)	1256 (2.0)	3.5 (2.5–5.0)
	Multiple	23,274	5 (87.7)	292 (12.6)	7.1 (3.0–16.5)
Major malformation[g]	No	623,064	38 (8.6)	1313 (2.1)	4.0 (2.9–5.5)
	Yes	21,999	0	235 (10.7)	n.a.
SGA[h]	≥10th percentile	590,418	31 (7.5)	1157 (2.0)	3.8 (2.7–5.4)
	<10th percentile	55,898	7 (19.0)	391 (7.0)	2.3 (1.0–5.2)
Severe maternal morbidity	No	630,105	37 (8.2)	1443 (2.3)	3.5 (2.5–4.9)
	Yes[i]	14,958	1 (20.4)	105 (7.0)	3.0 (0.4–20.7)
Previous CD	No	589,679	37 (8.5)	1380 (2.4)	3.5 (2.5–4.9)
	Yes	55,384	1 (5.9)	168 (3.0)	1.9 (0.3–13.8)
Previous stillbirth[j]	No	552,968	28 (7.6)	1239 (2.3)	3.3 (2.2–4.8)
	Yes	5437	1 (34.5)	41 (7.6)	4.8 (0.7–33.6)

Data are from the Medical Birth Registry of Norway and Statistics Norway, 1999–2009.

CD, cesarean delivery; *CI*, confidence interval; *n.a.*, not applicable; *SGA*, small for gestational age.

[a] Births from 22 weeks' gestational age or birthweight above 500 g. Antepartum fetal deaths and planned home births were excluded; [b] Intrapartum stillbirth and neonatal death, 0–24 hours; [c] Relative risks using institutional births as reference. Estimates were adjusted for clustering by births to the same mother; [d] Adjusted for all the maternal and fetal risk factors listed in Table 2 for births with no major malformations; [e] Women can decline to register information about smoking, and these births were analyzed separately; [f] Asthma, thyroid disease, epilepsy, rheumatoid arthritis, diabetes prior to and in pregnancy, chronic hypertension, epilepsy, chronic renal disease, and cardiac disease; [g] Eurocat definitions of severe malformations (http://www.eurocat-network.eu/content/EUROCAT-Guide-1.4-Section-3.3.pdf); [h] Small for gestational age, birthweight by gestational age classified according to Norwegian standards[16]; [i] Severe maternal morbidity: hemorrhage, >1.5 l, or hemorrhage and blood transfusion, eclampsia, hemolysis, elevated liver enzymes, and low platelet count (HELLP), sepsis, pulmonary embolism, organ failure, placental abruption with disseminated coagulation disorder, hysterectomy, or uterine rupture; [j] Previous stillbirth at gestation age ≥24 weeks; 86,658 births with missing information on this variable were excluded from the stratified analysis.

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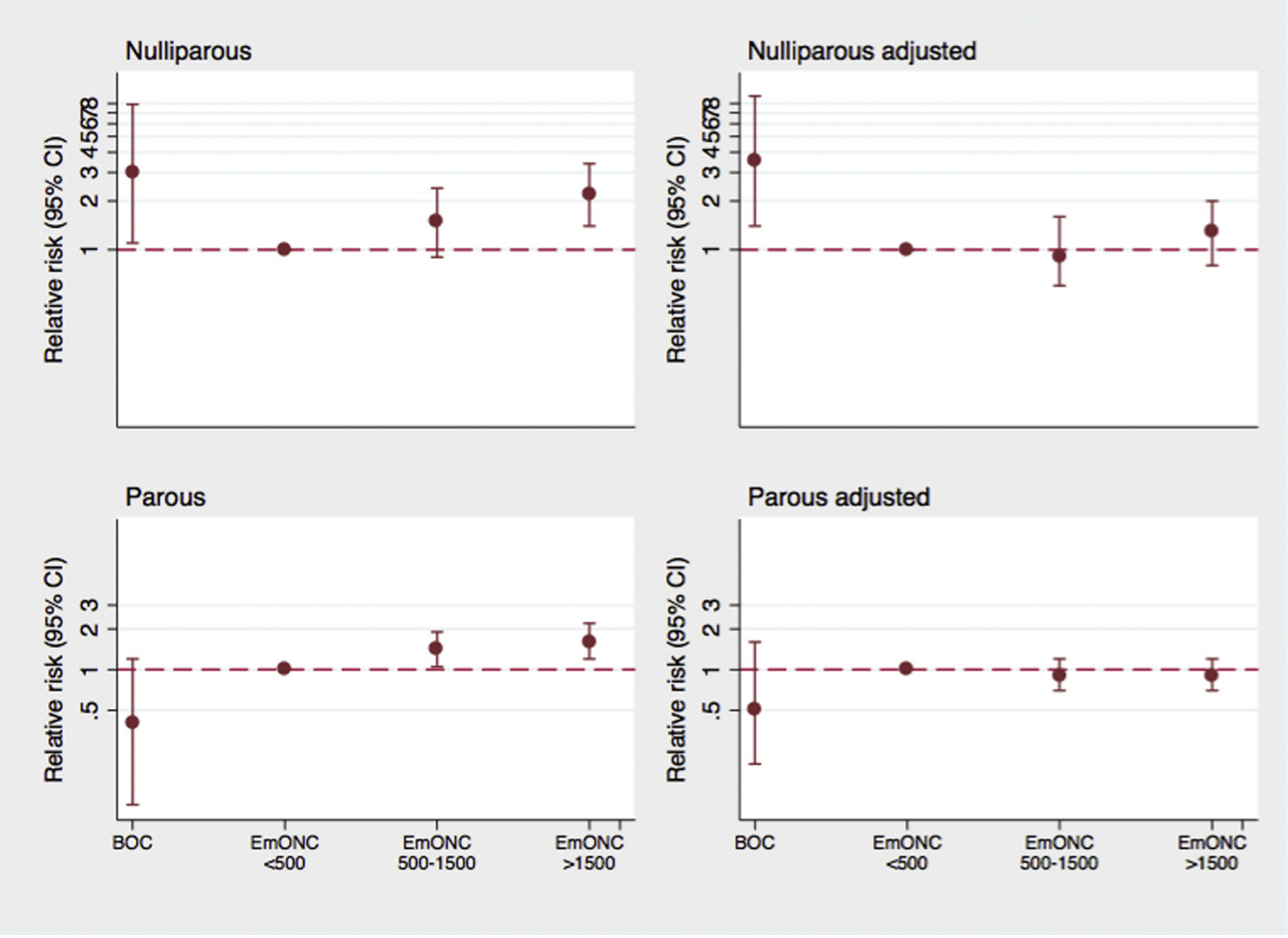
FIGURE 2
Relative risk of peripartum mortality by institution category, stratified on parity



Relative risks were calculated for births with no major malformations and adjusted for socioeconomic factors and medical maternal and fetal risk factors.
CI, confidence interval; *BOC*, basic obstetric care institution; *EmONC*, emergency obstetric and newborn care institution.
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(0.5 per 1000) than nulliparous women (3.6 per 1000), as shown in Figure 2 and Table 3. There was no difference between the first and last 5 year period in births with no major malformations (data not shown, $P > .6$ for nulliparous women and $P > .3$ for parous women).

In births with major malformations, the mortality was lower in the last 5 year period for both nulliparous and parous women (RR, 0.6; 95% CI, 0.5−0.8), these births took place in the EmONC institutions, and there were no difference between the different EmONC categories ($P > .4$). Results of stratified analyses are reported in online Appendix 2. Resident noncitizen women delivered in the largest EmONC institutions (n = 2021, 87%) with a mortality rate of 1.4% (n = 32).

Births at term to healthy women with a singleton pregnancy, no major congenital malformations, cephalic presentation, and normal vaginal delivery has been used to define a low-risk category in the literature.[1,24,25] In our study the mortality for this group ranged from 0.5 per 1000 to 0.6 per 1000 in the EmONC institutions ($P > .3$, data not shown).

Seasonal variations

During the winter season, from October to March, mortality was higher for births at term to parous women living outside the 2 hour zone to all institutions (2.5 per 1000) compared with births in which the mother lived within the 1 hour zone (0.6 per 1000, RR, 3.8; 95% CI, 1.4−10.5). For these births, residence outside the 2 hour travel zone to EmONC institutions was also associated with a seasonal increase in mortality risk (1.6 per 1000 vs 0.6 per 1000, RR, 2.5; 95% CI, 1.2−5.5).

Comment

Principal findings

Unplanned birth outside an institution was associated with the highest peripartum mortality rates both for births to women with risk factors and for births to women usually regarded as low risk.

TABLE 3
Peripartum mortality in obstetric institutions by institution function and volume category, total and stratified by parity

Category	n	Basic obstetric care, n (rate per 1000)	Emergency obstetric care, n (rate per 1000)		
			<500	500–1499	>1500
Total births[a]	640,532	9478	55,161	148,812	427,081
Peripartum deaths, n (per 1000)	1548 (2.4)	10 (1.1)	79 (1.4)	301 (2.0)	1158 (2.6)
Nulliparous births[b]	256,228	1650	20,224	56,137	178,830
Deaths, n (per 1000)	609 (2.4)	6 (3.6)	27 (1.3)	117 (2.0)	543 (2.9)
Relative risk[c]		3.0 (1.1–7.9)	Reference	1.5 (0.9–2.3)	2.2 (1.4–3.4)
Relative risk adjusted[d]		3.5 (1.4–8.9)	Reference	0.9 (0.6–1.6)	1.3 (0.8–2.0)
Parous total births[b]	362,421	7662	33,998	87,917	232,844
Deaths, n (per 1000)	704 (1.9)	4 (0.5)	44 (1.3)	161 (1.8)	495 (2.1)
Relative risk[c]		0.4 (0.1–1.2)	Reference	1.4 (1.0–1.9)	1.6 (1.2 –2.2)
Relative risk adjusted[d]		0.5 (0.2–1.6)	Reference	0.9 (0.7–1.2)	0.9 (0.7–1.2)

Data are from the Medical Birth Registry of Norway and Statistics Norway.

EmONC, emergency obstetric and newborn care.

[a] Births from 22 weeks' gestational age or birthweight >500 g. Planned home births, unplanned birth outside aninstitution, and antepartum fetal deaths were excluded. Institutions were classified according to the provided care: basic obstetric care for normal deliveries or EmONC in which emergency interventions were available. Births in EmONC institutions with volume <500 births was used as reference. Complete stratified analyses are presented in online Supplemental Table 2; [b] Births with no major congenital malformations (Eurocat definitions of major congenital malformations, http://www.eurocat-network.eu/content/EUROCAT-Guide-1.4-Section-3.3.pdf); [c] Relative risks in births with no major malformations; [d] Births with no major congenital malformations, adjusted for all risk factors in Table 2 except previous stillbirth and previous caesarean delivery in births to nulliparous women. All models included clustering by births in the same institution.

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Elimination of unplanned births outside an institution was estimated to reduce the peripartum perinatal mortality in the population by 2.1%. The risk of unplanned birth outside an institution was strongly associated with travel time to the nearest obstetric institution. Few high-risk births in the smallest institution categories and comparable mortality rates in obstetric institutions indicated well-functioning routines for selective referral.

Comparison with other studies

Previous studies have shown an association between reduced availability of institutions and higher neonatal morbidity, thus suggesting an increased risk of neonatal mortality.[26,27] Potential increases in neonatal mortality have also been modeled[28] and reported as a co-finding.[7] By combining traditional epidemiology with new geographic technologies, we were able to use population-based databases over a decade and obtain individual information about travel time and clinical outcomes, thus linking structural determinants and perinatal mortality. We found a clear association between unplanned birth outside an institution and mortality, and the increase in mortality was not confined to preterm birth or vulnerable groups as shown in previous studies.[13,15,29]

Improvement in monitoring and interventions during delivery has been proposed as an explanation for reduced intrapartum and 7 day neonatal mortality in term births during recent decades.[24] However, as much as 30% of the deaths in low-risk births at term occurred intrapartum in Scotland.[24] Our findings add to the evidence that including only neonatal deaths would lead to an underestimation of mortality.

Strengths and limitations

The cohort in this study covered the entire population and was large enough to study a rare outcome in relation to individual travel time. We had data for a range of potential covariates and risk factors and were able to take into account clustering of births to the same mother and in the same institution. Multilevel analyses yielded comparative odds ratios to the relative risks, except for higher odds ratios than the relative risks in smaller, high-risk groups. We thus chose to complete the analyses using generalized linear models and report the relative risks.

The MBRN lacked information on some covariates/risk factors that could be of importance, such as obesity. Although obesity is a significant risk factor for perinatal mortality, it is less likely to be strongly associated with the exposures under study. Similarly, alcohol consumption during pregnancy has been shown to be associated with smoking and older age, not with education or income, and it is not likely to explain the observed differences.[30]

Norway has a clear policy aim to reduce economic barriers to health care in pregnancy. Both primary and specialist health care related to pregnancy and childbirth is free for residents in Norway, and prenatal care is widely attended.[31]

The annual relocation outside the municipality was approximately 5% but

could lead to an underestimation of the relative risk. The travel time analyses did not take into account factors such as seasonal variations in driving conditions, but higher perinatal mortality during the winter season suggests potential consequences of reduced accessibility.

The registry linkages provide a larger data set than would have been achievable in a prospective study, but linkages had to be performed retrospectively, and the linkage process as well as the travel zone estimations were complicated and time consuming. Hence, the data collection had to be limited to births up to 2009, and the data set was completed by 2015. The individual travel zone calculations provided individual information using uniform methods. The institutional structure reported in this study is representative for the present annual statistics (http://statistikk.fhi.no/mfr/).

Theoretically, reduced access to specialist health care could influence antepartum stillbirths because of factors such as lower detection of risk pregnancies and less monitoring to assist timely delivery. However, we found no difference antepartum stillbirth rates in the different travel zones, and these births were referred to EmONC institutions. Other risk factors, such as fetal sex, are not associated with travel time and therefore no confounders in our analyses. Differences in available intrapartum care probably explain most of the differences in mortality by place of birth and are a likely mediator in our data.

Lack of acceptability resulting in deliberate avoidance of institutions has not been described as a major risk factor for unplanned birth outside an institution in Europe.[32,33] Few women with risk factors gave birth in BOC institutions and in the lowest volume category of EmONC institutions, indicating that the national guidelines for referral were well implemented. In accordance with recent publications, the mortality was higher in births to nulliparous than to parous women in BOC institutions.[1,7] However, the mortality rate was lower than for unplanned birth outside an institution for this group.

Some of the BOC institutions were based in rural hospitals. The lack of formalized obstetrician-led services disqualified them from classification as EmONC institutions. However, notifications included preterm births, instrumental vaginal births, breech births, and cesarean deliveries. These interventions highlight the importance of training, clinical guidelines, and preparedness to tackle emergency situations also in this setting.

Unanswered questions and future research

We identified and stratified on severe maternal morbidity that may increase the risk of fetal or neonatal death. A thorough assessment of maternal morbidity was beyond the scope of this study. A more comprehensive evaluation of the health system structure should take severe maternal and neonatal morbidity into account.[34] We found that structural determinants have an important impact on perinatal health in high-income countries and also for low-risk births. The results show the importance of skilled birth attendance and warrant attention to negative consequences of reduced access to institutions. ■

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APPENDIX 1
Risk of unplanned delivery outside an institution and travel time to the nearest institution

Variables	Category	Total births	Unplanned deliveries outside institution, n, %	Outside institution travel zone >1 h, n, %	Outside institution travel zone >2 h, n, %	Risk ratio (95% CI), 1–2 h vs <1 h	Risk ratio (95% CI), >2 h vs <1 h
Overall		646,898	4546 (0.7)	844/25,494 (3.3)	246/5508 (4.5)	5.9 (5.4–6.4)[a]	8.0 (7.0–9.1)[a]
Gestational age, wks	≥37	600,582	4218 (0.7)	805/23 820 (3.4)	229/5107 (4.5)	6.1 (5.6–6.6)	8.1 (7.1–9.3)
	<37	46,316	320 (0.7)	39/1717 (2.3)	17/407 (4.2)	3.8 (2.7–5.4)	7.0 (4.3–11.3)
Maternal age, y	<20	15,295	86 (0.6)	22/933 (2.4)	12/263 (4.6)	6.6 (4.0–10.9)	12.7 (6.9–23.7)
	20–35	521,941	3590 (0.7)	690/20,462 (3.4)	187/4318 (4.3)	6.2 (5.7–6.7)	8.0 (6.9–9.3)
	>35	109,625	861 (0.8)	132/4099 (3.2)	47/927 (5.1)	4.9 (4.1–6.0)	7.6 (5.7–10.2)
Parity	1 or more	379,749	4076 (1.1)	771/16,780 (4.6)	219/3576 (6.1)	5.4 (4.9–5.8)	7.1 (6.2–8.2)
	0	267,149	462 (0.2)	73/8714 (0.8)	27/1932 (1.4)	5.9 (4.6–7.6)	10.0 (6.8–14.8)
Education, y	≥11	498,143	3286 (0.7)	647/19,601 (3.3)	162/3875 (4.2)	6.3 (5.8–6.9)	8.0 (6.8–9.5)
	<11	148,755	1252 (0.8)	197/5893 (3.3)	84/1633 (5.1)	4.9 (4.1–5.7)	7.5 (6.0–9.4)
Partner status	Partner	593,783	4153 (0.7)	795/23,340 (3.4)	225/4941 (4.6)	6.2 (5.6–6.7)	9.0 (7.9–10.3)
	Single	43,762	344 (0.8)	41/1848 (2.2)	21/487 (4.3)	3.3 (2.3–4.6)	6.6 (4.3–10.3)
Ethnicity	Western	586,902	4099 (0.7)	801/24,372 (3.3)	223/5192 (4.3)	6.0 (5.5–6.5)	7.8 (6.8–9.0)
	Non-Western	59,996	439 (0.7)	43/1122 (3.8)	23/316 (7.3)	6.0 (4.3–8.3)	11.4 (7.5–17.4)
Smoking	Nonsmoker	436,983	2934 (0.7)	585/16,964 (3.5)	132/3246 (4.1)	6.5 (5.9–7.1)	7.6 (6.4–9.1)
	No information	106,928	707 (0.7)	92 (3.0)	40 (4.6)	5.3 (4.2–6.6)	8.2 (6.0–11.2)
	Any smoking	102,987	897 (0.9)	167/5411 (3.1)	74/1389 (5.3)	4.5 (3.8–5.4)	7.8 (6.2–9.9)
Chronic illness	No	584,909	4156 (0.7)	778/22,928 (3.4)	231/4963 (4.7)	6.0 (5.6–6.5)	8.3 (7.2–9.5)
	Yes[b]	61,987	382 (0.6)	66/2567 (2.6)	15/545 (2.8)	4.9 (3.8–6.5)	5.4 (3.1–9.3)
Plural	Singleton	623,408	4479 (0.7)	836/24,651 (3.4)	246/5323 (4.6)	5.9 (5.5–6.4)	8.1 (7.1–9.3)
	Multiple	23,490	59 (0.3)	8/843 (1.0)	0/185	4.2 (1.6–11.2)	NA
Major malformation	No	624,783	4421 (0.7)	822/24,611 (3.3)	243/5357 (4.9)	5.9 (5.5–6.4)	8.7 (7.7–9.9)
	Eurocat[c]	22,115	117 (0.5)	22/885 (2.5)	3/151 (2.7)	5.7 (3.6–9.0)	6.1 (2.3–16.3)
SGA	≥10th percentile	591,419	4162 (0.7)	797/23,573 (3.4)	222/5048 (4.4)	6.1 (5.6–6.6)	8.7 (7.6–9.9)
	<10th percentile	56,675	376 (0.7)	47/1961 (2.4)	24/465 (5.2)	4.1 (3.0–5.7)	9.2 (6.0–14.0)
Previous	No	592,524	4368 (0.7)	819/23,072 (3.6)	241/4962 (4.9)	6.1 (5.6–6.5)	8.3 (7.3–9.5)
CD	Yes	55,593	170 (0.3)	25/2422 (1.0)	5/546 (0.9)	3.9 (2.6–6.0)	3.4 (1.4–8.4)
Previous stillbirth	No	554,536	3687 (0.7)	670/20,860 (3.2)	178/4343 (4.1)	6.0 (5.5–6.5)	7.7 (6.6–8.9)
	Yes[d]	5488	29 (0.5)	5/241 (2.1)	2/21 (3.9)	4.9 (1.9–12.9)	9.2 (2.2–37.6)

Births were at gestational age ≥22 weeks or birthweight ≥500 g. Residence within the 1 hour travel zone to all institutions was used as reference. Data are from Statistics Norway and the Medical Birth Registry of Norway, 1999–2009.

CD, cesarean delivery; *CI*, confidence interval.

[a] Relative risks are adjusted for clustering in the mother; [b] Athma, thyroid disease, rheumatoid artritis, epilepsy, chronic hypertension, chronic cardiac or renal disease, diabetes before or in pregnancy; [c] Eurocat definitions of severe malformations (http://www.eurocat-network.eu/content/EUROCAT-Guide-1.4-Section-3.3.pdf); [d] Previous stillbirth at gestational age ≥24 weeks.

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APPENDIX 2
Peripartum mortality in obstetric institutions, stratified on maternal and fetal risk factors

Variable		Total mortality[a]	Basic obstetric care		Emergency obstetric care, annual volume					
					<500[b]		500–1499		>1500	
Risk factor	Category	n (per 1000)	n (per 1000)	Relative risk (95% CI)	n (per 1000)	Reference	n (per 1000)	Relative risk (95%CI)	n (per 1000)	Relative risk (95% CI)
Gestational age, wks	≥37	429 (0,7)	8 (0.9)	1.2 (0.6–2.4)	38 (0.7)	1	104 (0.7)	1.1 (0.7–1.5)	279 (0.7)	1.0 (0.7–1.3)
	<37	1119 (25.1)	2 (11.2)	0.5 (0.2–1.5)	41 (21.5)	1	197 (19.8)	0.9 (0.7–0.3)	879 (27.0)	1.3 (0.9–1.7)
Maternal age, y	<20	56 (3.7)	1 (4.4)	1.6 (0.2–15.7)	6 (2.8)	1	19 (4.1)	1.5 (0.5–4.2)	30 (3.6)	1.3 (0.4–3.5)
	20–35	1163 (2.2)	9 (1.2)	0.9 (0.5–1.5)	61 (1.4)	1	227 (1.9)	1.4 (0.98–1.9)	866 (2.5)	1.9 (1.3–2.6)
	>35	329 (3.0)	0		12 (1.4)	1	55 (2.4)	1.7 (0.8–3.7)	262 (3.6)	2.5 (1.1–5.5)
Parity	≥1	855 (2.3)	4 (0.5)	0.3 (0.1–0.99)[c]	52 (1.5)	1	184 (2.0)	1.4 (1.04–1.8)	615 (2.5)	1.6 (0.97–2.8)
	0	693 (2.6)	6 (3.6)	2.7 (0.99–7.2)[c]	27 (1.3)	1	117 (2.0)	1.5 (0.9–2.5)	543 (2.9)	2.3 (1.2–4.2)
Education, y	≥11	1038 (2.1)	8 (1.1)	0.8 (0.5–1.6)	55 (1.3)	1	198 (1.7)	1.3 (0.98–1.8)	777 (2.4)	1.9 (1.1–3.2)
	<11	510 (3.5)	2 (0.9)	0.5 (0.06–3.8)	24 (1.9)	1	103 (3.1)	1.7 (1.01–2.8)	381 (3.7)	2.0 (1.06–3.6)
Partner status	Partner	1358 (2.3)	8 (0.9)	0.7 (0.3–1.4)	67 (1.3)	1	260 (1.9)	1.4 (1.04–1.9)	1 023 (2.7)	2.0 (1.2–3.2)
	Single	158 (3.7)	2 (3.9)	1.5 (0.4–5.5)	11 (2.6)	1	36 (3.7)	1.4 (0.7–2.8)	109 (3.1)	1.2 (0.5–2.7)
Western		1336 (2.3)	9 (1.0)	0.7 (0.4–1.3)	70 (1.3)	1	285 (2.0)	1.5 (1.1–2.0)	972 (2.6)	2.0 (1.2–3.2)
Non-Western		212 (3.6)	1 (2.7)	0.9 (0.1–7.4)	9 (3.1)	1	16 (2.1)	0.7 (0.3–1.7)	186 (3.8)	1.1 (0.5–2.7)
Smoking	No	959 (2.2)	3 (0.5)	0.4 (0.1–1.1)	44 (1.2)	1	198 (1.9)	1.6 (1.1–2.2)	699 (2.4)	2.0 (1.3–2.9)
	No information	335 (3.2)	3 (2.4)	1.1 (0.3–3.6)	19 (2.1)	1	29 (2.0)	0.9 (0.5–1.6)	284 (3.5)	1.6 (1.1–2.4)
	Yes	269 (2.6)	4 (2.2)	1.4 (0.6–3.8)	16 (1.5)	1	74 (2.3)	1.6 (0.9–2.7)	175 (3.1)	2.1 (1.2–3.4)
Chronic disease[d]	No	1390 (2.4)	10 (1.1)	0.8 (0.4–1.5)	71 (1.4)	1	272 (2.0)	1.4 (1.03–1.9)	1 047 (2.7)	1.9 (1.4–2.6)
	Yes	158 (2.6)	0		8 (1.5)	1	39 (2.5)	1.6 (0.8–3.3)	111 (2.5)	1.8 (0.9–3.5)
Plural	Singleton	1256 (2.0)	10 (1.1)	0.8 (0.2–1.5)	70 (1.3)	1	255 (1.8)	1.4 (1.08–1.8)	921 (2.2)	1.7 (1.1–2.6)
	Multiple	292 (12.6)	0		9 (10.3)	1	46 (9.0)	0.9 (0.4–2.1)	237 (14.0)	1.4 (0.5–3.5)
Major malformation[e]	No	1313 (2.1)	10 (1.1)	0.8 (0.5–1.5)	68 (1.3)	1	261 (1.8)	1.4 (1.1–1.9)	974 (2.4)	1.9 (1.4–2.4)
	Yes	235 (10.7)	0		11 (7.1)	1	40 (8.4)	1.2 (0.6–2.2)	184 (11.9)	1.7 (0.9–3.2)
SGA	≥10	1157 (2.0)	9 (1.0)	0.9 (0.4–1.6)	60 (1.2)	1	235 (1.7)	1.5 (1.1–1.9)	853 (2.2)	1.9 (1.1–3.1)
	<10	391 (7.0)	1 (2.1)	0.4 (0.08–2.3)	19 (5.0)	1	66 (5.6)	1.1 (0.7–1.9)	305 (8.2)	1.6 (0.95–2.8)
Maternal morbidity[f]	No	1443 (2.3)	10 (1.1)	0.8 (0.4–1.5)	72 (1.3)	1	277 (1.9)	1.4 (1.06–1.9)	1084 (2.6)	1.9 (1.2–3.2)
	Yes	105 (7.0)	0		7 (5.6)	1	24 (6.8)	1.2 (0.6–2.7)	74 (7.1)	1.3 (0.6–2.6)

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(continued)

APPENDIX 2
Peripartum mortality in obstetric institutions, stratified on maternal and fetal risk factors *(continued)*

Variable		Total mortality[a]	Basic obstetric care		Emergency obstetric care, annual volume					
					<500[b]		500–1499		>1500	
Risk factor	Category	n (per 1000)	n (per 1000)	Relative risk (95% CI)	n (per 1000)	Reference	n (per 1000)	Relative risk (95%CI)	n (per 1000)	Relative risk (95% CI)
Previous CD	No	1380 (2.4)	8 (0.9)	0.7 (0.3–1.4)	64 (1.3)	1	275 (2.0)	1.6 (1.1–2.2)	1033 (2.6)	2.0 (1.4–2.9)
	Yes	168 (3.0)	2 (7.0)	2.5 (.3–19.7)	15 (2.7)	1	26 (1.9)	0.7 (0.4–1.3)	125 (3.5)	1.3 (0.7–2.4)
Previous stillbirth[g]	No	1239 (2.3)	8 (1.1)	0.9 (0.5–1.8)	54 (1.2)	1	231 (1.9)	1.6 (1.1–2.3)	946 (2.4)	2.1 (1.4–3.0)
	Yes	41 (7.6)	0		2 (4.7)	1	12 (9.1)	2.0 (0.5–8.4)	27 (7.5)	1.6 (0.4–6.4)

CD, cesarean delivery; *CI*, confidence interval; *EmONC*, emergency obstetric and newborn care; *SGA*, small for gestational age.

[a] Intrapartum death and neonatal death 0–24 hours. Births from 22 weeks' gestation or birthweight >500 g. Planned home births, unplanned births outside an institution and intrauterine fetal death prior to the start of labor were excluded. Data are from the Medical Birth Registry of Norway and Statistics Norway; [b] Births in EmONC institutions annual volume <500 are used as reference; [c] $P = .05$; [d] Asthma, thyroid disease, epilepsy, rheumatoid arthritis, diabetes prior to and in pregnancy, chronic hypertension, epilepsy, chronic renal disease, and cardiac disease; [e] Eurocat definitions of major congenital malformations (http://www.eurocat-network.eu/content/EUROCAT-Guide-1.4-Section-3.3.pdf); [f] Severe maternal morbidity included the following: hemorrhage >1.5 l or hemorrhage and coagulation disorder, blood transfusion or manual removal of placenta, placental abruption with disseminated intravascular coagulation, eclampsia, hemolysis, elevated liver enzymes, and low platelet count (HELLP), pulmonary embolism, sepsis, organ failure, or complications to anesthesia; [g] Previous stillbirth at gestational age ≥24 weeks.

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