Perinatal mortality in contaminated regions of Ukraine after the Chernobyl accident

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Perinatal mortality rates in the Ukrainian regions most affected by the Chernobyl fallout - Zhitomir oblast, Kiev oblast and the city of Kiev (study region) - show a rise and fall during the 1990's relative to the rest of Ukraine (control region). A biological model, which was previously applied to perinatal mortality data from Belarus, 1985-1998, and to perinatal mortality in Germany following the atmospheric nuclear weapon tests, interprets the observed increase as a late effect from incorporated strontium-90. The observed effect translates to 1048 excess perinatal deaths in the study region until 2004.

Introduction

In 1987 the year following the Chernobyl accident, a short-term increase of perinatal mortality rates was found in Germany. This increase was shown to correlate with incorporated radioactive caesium [1] which has a short biological half-life of only some months. After the atmospheric weapons tests in the 1960's, a deviation from the long-term trend of perinatal mortality was observed in West Germany with the maximum incidence in 1970, seven years after the peak fallout in 1963. This increase was interpreted as a late effect of incorporated strontium [2]. In the regions of Belarus and Ukraine near the Chernobyl site, strontium soil depositions exceeding 1 Ci/km² (37 kBq/m²) were detected outside the 30 km exclusion zone. A late effect of strontium on perinatal mortality rates could therefore be expected in the regions neighbouring the Chernobyl reactor. Actually, a rise of perinatal mortality rates in the Gomel region (*oblast*) relative to the rest of Belarus was found in the 1990's which could be associated with incorporated strontium [3]. In the present study, the perinatal mortality rates in the three most contaminated Ukrainian regions Zhitomir oblast, Kiev oblast and Kiev city are compared with the rest of Ukraine.

Data and Methods

All data in this study are from the State Committee of Statistics of Ukraine and the Ministry of Public Health of Ukraine. Ukrainian data on maternal age distribution (needed to calculate the average strontium burden of pregnant women) were not available, so Belarus data from the Statistics Department of the Ministry of Health of Belarus were used instead.

Using the approach adopted in [3], the perinatal mortality rates in the two most contaminated Ukrainian oblasts and Kiev city are compared with the corresponding rates in the rest of Ukraine to ascertain possible effects of strontium in the 1990's. This approach has the advantage that no assumptions have to be made for the secular trend of the data. If the study and control regions differ in radiation contamination but are similar in socio-economic structure, other factors that might have a global influence on infant mortality in Ukraine should not influence the ratio of the perinatal mortality rates in the study and the control region.

Instead of the rate ratios, the odds ratios (OR) are used which are defined by

$OR = p_1/(1-p_1) / (p_0/(1-p_0))$

where p_1 and p_0 are the rates in the study region (1) and the control region (0). For p_1, $p_0 << 1$ the odds ratios approach the rate ratios.

For the data analysis the logarithms of the odds ratios are used. A population weighted non-linear regression model of the form

(1) $\log(OR) = \beta_0 + \beta_1 \cdot t + \beta_2 \cdot Sr$

is applied where parameter β_0 is the intercept, β_1 allows for a temporal trend of the odds ratios, parameters β_2 and β_3 estimate the effect of strontium concentration (Sr) in pregnant women.

The data are weighted with weights var (ln(OR)) which are defined by

$var(\ln(OR)) = 1/(SB_1+NEO_1)+1/(LB_1-NEO_1)+1/(SB_0+NEO_0)+1/(LB_0-NEO_0)$,

where LB, SB and NEO are the numbers of live births, stillbirth and early neonatal deaths in the study (1) and the control (0) regions, respectively.

In addition to model (1), model (2) is applied which allows for a curvilinear shape of the dose response relationship.

(2) $\ln(OR) = \beta_0 + \beta_1 \cdot t + \beta_2 \cdot Sr\verb|^|\beta_3$

Here parameter β_3 is the power of dose.

The following calculation of the development of strontium concentration in pregnant women is based on two simple model assumptions; (a) strontium incorporation occurs in 1986, the year of the Chernobyl accident, and (b) strontium is incorporated at age 14, the age of maximum bone growth [4]. A possible adverse effect of strontium on the newborn will only manifest several years later, at the time of birth. Then the average strontium concentration in a given year following 1986 is proportional to the percentage of pregnant women born in 1972. This percentage follows from the maternal age distribution. Since Ukrainian data on the maternal age distribution could not obtained we used data from Belarus. The data are grouped in 5 year strata. The shaded area in Figure 1 is the average maternal age distribution in Belarus for 1992-1996. To determine annual values, the data were approximated by the superposition of two lognormal distributions (solid line in Figure 1).

Also the strontium excretion from the body must be taken into account. According to the model used in ICRP Publication 67 [5], strontium excretion contains both a fast and a slow component. The strontium term Sr(t), which is proportional to the strontium concentration, thus has the following form:

$Sr(t) = F(t-1972) \cdot (A_1 \cdot \exp(-\ln(2) \cdot (t-1986)/T_1)+A_2 \cdot \exp(-\ln(2) \cdot (t-1986)/T_2))$

where F(t-1972) is the fraction of pregnant women in year t who were born in 1972. T_1=2.4 years and T_2=13.7 years are effective half-lives of strontium in the female body. The constants A_1, A_2 and the half-lives T_1, T_2 are determined from a regression of tabulated values given in [5]. A more detailed description of the model is given in [3].

The function nls() of the statistical package R is used for the data evaluation [6].

Results

The trends of perinatal mortality rates, 1985-2004, in the three most contaminated Ukrainian regions combined, i.e. Zhitomir oblast, Kiev oblast, Kiev city (study region), together with the rates in the rest of Ukraine (control region), are displayed in Figure 2. Perinatal mortality data for Kiev city were not available before 1985, and the definition of stillbirth was changed after 2004, so the time span for the data evaluation is 1985-2004. The time variable t is calendar year minus 1980, i.e., t=0 in 1980.

The results of a regression of the odds ratios of perinatal mortality with a linear strontium term (β_3=1) are listed in Table 1. The residual sum of squares (SSE) is 31.4 with 17 degrees of freedom (df=17).

Table 1: Regression results with model (1)

parameter	meaning	estimate	SE	t-value	p-value
β_0	intercept	0.0732	0.0279	2.628	0.0176
β_1	temporal trend	-0.0078	0.0023	-3.456	0.0030
β_2	strontium effect	0.0564	0.0092	6.124	1.1E-05

The odds ratios show a significant time trend (p=0.003). The strontium term is highly significant ($p < 0.0001$).

A regression of the data using the full model (eq.1), which allows for a curvilinear dose response, leads to an appreciable reduction of the sum of squares (SSE=26.8, df=16); the F test yields p=0.119. The effect of the strontium term (parameters β_2 and β_3) on the goodness of fit is highly significant; the sums of squares are 100.6 (df=18) without and 26.8 (df=16) with the strontium term (F=22.0; p=3E-6; F test with 2 and 16 degrees of freedom). The parameter estimates are given in Table 2.

Table 2: Regression results with model (2)

parameter	meaning	estimate	SE	t-value	p-value
β_0	intercept	0.0767	0.0265	2.891	0.0106
β_1	temporal trend	-0.0063	0.0023	-2.746	0.0144
β_2	strontium effect	0.0196	0.0199	0.984	0.3396
β_3	power of dose	1.8031	0.7660	2.354	0.0317

The best estimate of the power of dose is 1.80 ± 0.77. Figure 3 shows the trend of the odds ratios and the regression line.

Discussion

The present study finds a highly significant association of perinatal mortality rates in the most contaminated regions of Ukraine (Zhitomir oblast, Kiev oblast and Kiev city) with the calculated strontium burden of pregnant women. The increase translates to 1048 excess perinatal deaths. The peak deviation from the long-term trend is observed in 1993, 7 years after the Chernobyl accident. There is no appreciable increase in 1987, the first year after the Chernobyl accident, when the main effect from caesium is expected.

In West Germany, a similar deviation from the secular trend of perinatal mortality was found after the atmospheric nuclear weapons tests which peaked in 1970, seven years after the maximum fallout intensity. The same model as in the present analysis was applied, i.e., the excess perinatal mortality was interpreted as a late effect of incorporated strontium. The best estimate of the power of dose in the strontium term was 1.9 [2].

Our results contradict the negative findings reported in the WHO report published in 2005 [7]. *Inter alia*, the WHO report evaluated data of pregnancy outcome from Ukraine and the other countries of the former Soviet Union and stated that they were mostly of a descriptive nature and provided only percentage changes without specification of the time period and the actual numbers involved. So the WHO Expert Group concluded that it was not able to evaluate the evidence and draw conclusions.

The WHO report does not deal with perinatal mortality but it contains data on infant mortality. The time trends of infant mortality in the contaminated Ukrainian oblasts of Zhitomir and Kiev and their most highly contaminated districts (5 each) are compared with the corresponding rates in Poltava oblast, a so-called “clean” area. In Poltava oblast, the rates exhibit a monotonously falling trend during 1981-2000, but in the highly contaminated Zhitomir and Kiev oblasts the rates in 1991-1995 were higher than in 1986-1990 and in 1996-2000. The authors of the report state that no clear trend of infant mortality was found.

Our results challenge the concept of a dose threshold of around 100 mGy fetal dose of low-LET radiation for teratogenic effects [8] since the estimated individual foetal doses were only in the range of some mSv in the years following the Chernobyl accident.

The results of this study should be interpreted with due caution since they are based on highly aggregated data. But as long as there is no other feasible way to study small radiation effects in large human populations the findings must not be dismissed on grounds of the inherent limitations of the ecological study design.

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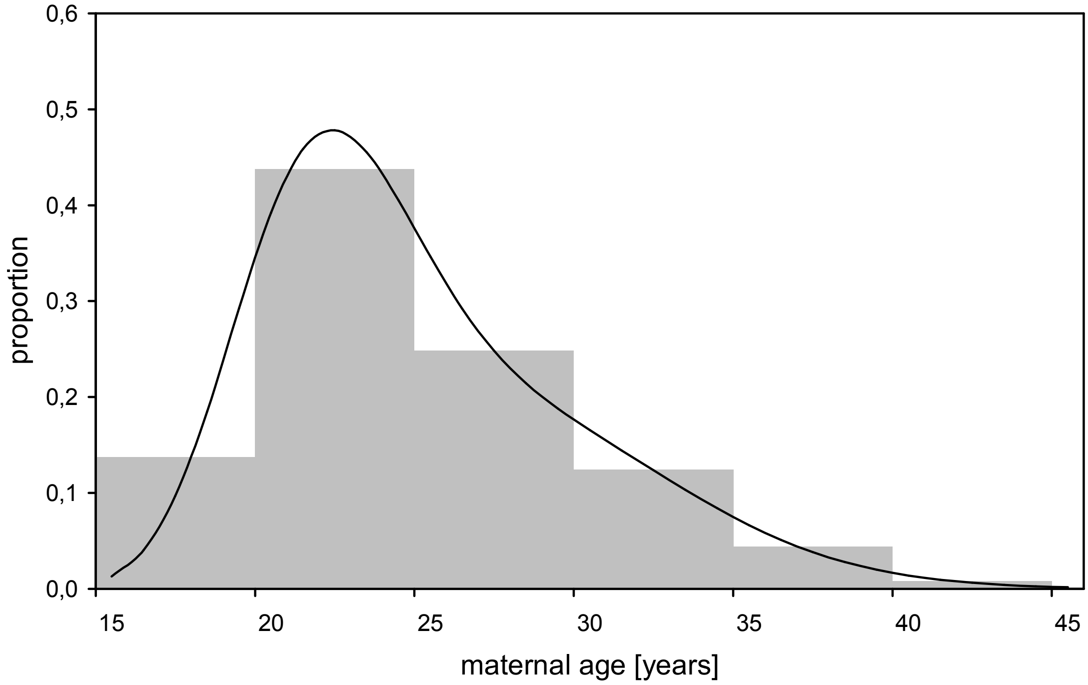

Fig. 1: Maternal age distribution in Belarus, averaged over 1992-1996, and interpolation curve using two superimposed lognormal distributions

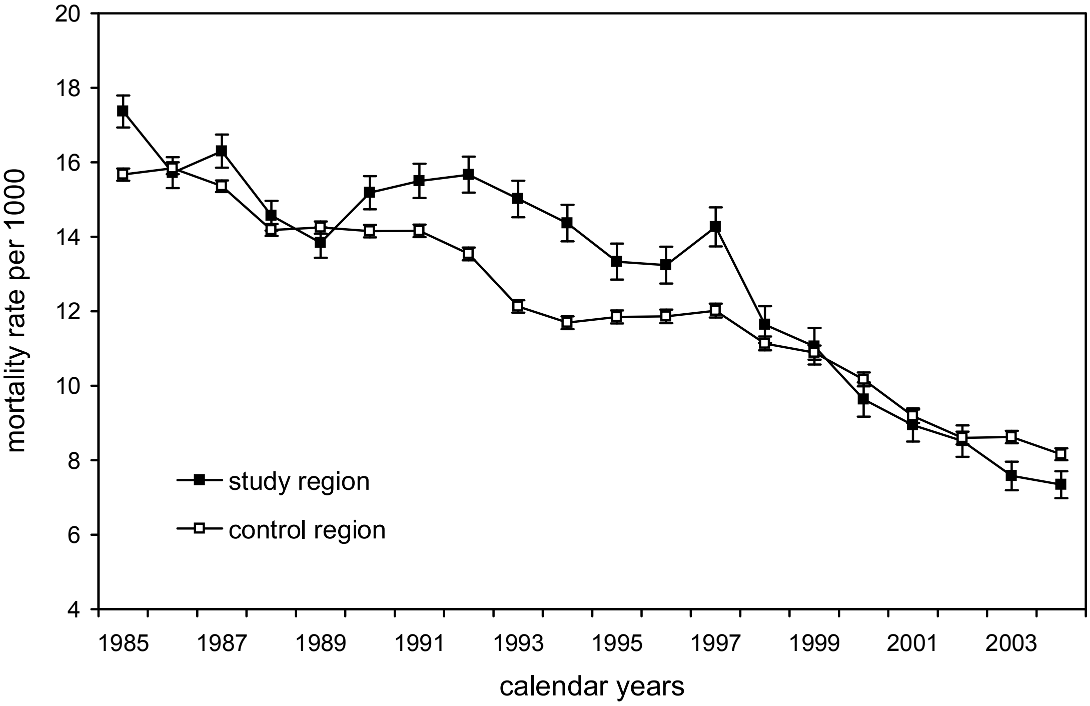

Fig. 2: Trends of perinatal mortality rates in Zhitomir oblast, Kiev oblast and Kiev City combined (study region) and in the rest of Ukraine (control region).

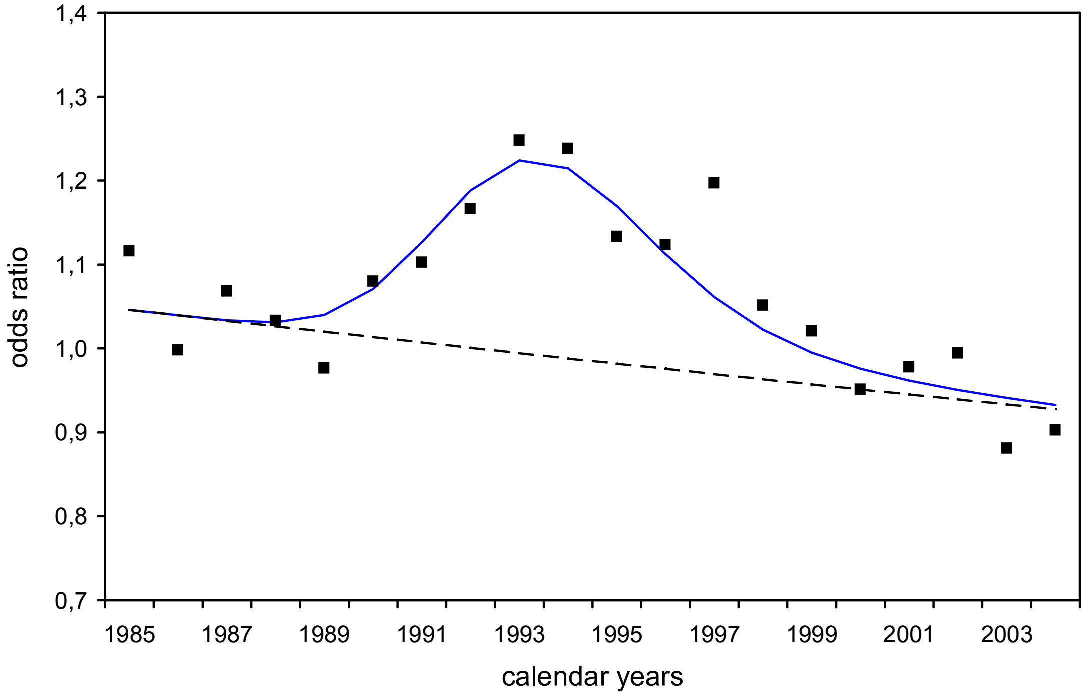

Fig. 3: Odds ratios of perinatal mortality rates in Zhitomir oblast, Kiev oblast and Kiev city combined (study region) and in the rest of Ukraine (control region). The solid line is the regression result, the broken line is the expected undisturbed trend of the odds ratios.

Appendix: Perinatal mortality data in the study and control regions

	study region			control region		
year	live births	stillbirths	early neona-tal deaths	live births	stillbirths	early neona-tal deaths
1985	91285	906	695	580205	6029	3158
1986	90169	792	638	612236	6289	3508
1987	79919	762	553	601013	5980	3342
1988	89380	824	490	565296	5062	3027
1989	82572	718	435	525837	4707	2853
1990	75203	668	484	506796	4388	2847
1991	71079	593	518	488655	4152	2825
1992	66395	555	494	463995	3708	2625
1993	61915	488	449	433637	3014	2283
1994	58293	451	393	404959	2805	1963
1995	55738	432	317	381385	2545	2003
1996	53526	400	314	360159	2418	1883
1997	50968	404	329	340645	2158	1961
1998	47272	308	246	324694	1981	1657
1999	44664	273	224	299880	1807	1479
2000	45030	235	201	295066	1606	1411
2001	44381	229	170	287716	1372	1283
2002	47442	238	168	295804	1361	1194
2003	50961	234	154	306667	1501	1157
2004	55165	260	147	316929	1466	1131