European stillbirth proportions before and after the Chernobyl accident

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Background Numerous investigations have been carried out concerning the possible impact of the Chernobyl accident, in April 1986, on the prevalence of anomalies at birth and on perinatal mortality. The accident has contaminated Eastern Europe more heavily than Western Europe. If there was an effect of the radioactive contamination on perinatal mortality or stillbirth proportions one would expect to find it more pronounced in Eastern Europe as compared to Western Europe. We therefore studied long-term time trends in European stillbirth proportions.

Methods Linear logistic regression was applied to model the time trends in stillbirth proportions. Dummy variables were used to account for effects that can be associated with certain years or locations. A synoptic logistic regression model is suggested for the western, central, and eastern parts of Europe.

Results There is a marked differential effect in the long-term stillbirth time trends between Western Europe (Belgium, France, Great Britain, Iceland, Ireland, Luxembourg, Portugal, Spain), Central Europe (Austria, Denmark, Germany, Italy, Norway, Switzerland), and Eastern Europe represented by four countries (Greece, Hungary, Poland, Sweden). In contrast to the western and central European trends, the eastern European trend exhibits an absolute increase of the stillbirth proportion in 1986 as compared with 1985 and an apparent upward shift of the whole trend line from 1986 on.

Conclusion Our results are in contrast to those of many analyses of the health consequences of the Chernobyl accident and contradict the present radiobiological knowledge. As we are dealing with highly aggregated data, other causes or artefacts may explain the observed effects. Hence, the findings should be interpreted with caution and further independent evidence should be sought.

Keywords Chernobyl accident, perinatal mortality, stillbirth, time trend, regression analysis

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To date, the explosion of the nuclear reactor in Chernobyl, Ukraine, about 160 km north-west of Kiev, on 26 April 1986, is the most serious accident in a nuclear power station. The event led to a release of large quantities of radioactive material in the range of 100–200 MegaCurie[1] over a 10-day period. Depending on atmospheric conditions at the time, the extent of contamination in Europe was very variable. Whereas Ukraine, Belarus, as well as parts of Russia and Scandinavia were highly contaminated by radioactive fallout, markedly less contamination occurred, e.g. in Great Britain, Ireland, France, Portugal and Spain.[2,3]

Doses received by the human population involved a number of different pathways: inhalation of activity, direct gamma radiation from the atmosphere, exposure to external radiation from ground-deposited activity, and ingestion of contaminated food. The Gray (Gy) is the energy by ionizing radiation absorbed per unit mass. 1 Gy equals 1 J/kg. The equivalent dose takes into account the biological potency of different types of radiation. The effective equivalent dose unit is the Sievert (Sv).[1] Data on estimated effective dose equivalents in the first year after the accident were reviewed and compiled by the United Nations Scientific Committee on the Effects of Atomic Radiation.[3] Outside the USSR, the highest country-wide mean doses within the first post-Chernobyl year were roughly between 0.5 and 1.0 mSv in Bulgaria, Austria, Greece and Romania. In Germany, estimated effective dose equivalents in the first year after the accident range from below 0.1 mSv to 0.2 mSv. However, on a more local or even individual scale, much higher doses than reflected by national mean values are to be expected.[4,5]

Numerous investigations have been carried out concerning the possible impact of the Chernobyl accident on the prevalence

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of anomalies at birth and on perinatal mortality. Pertinent reviews of the material were compiled by Bard *et al.*[1] and by Little.[6] In most studies aimed at the detection of differences of pregnancy outcome measurements between regions or time periods, the authors concluded that there is no evidence of a detrimental physical effect on congenital anomalies or other outcomes of pregnancy following the accident.[1,6]

More recently however, Petridou *et al.*[7] reported that infants in Greece exposed *in utero* to ionizing radiation from the Chernobyl accident had 2.6 times the incidence of leukaemia compared to unexposed children, i.e. children born prior to and 1.5 years after the accident. Similarly, Michaelis *et al.*[8] found an increase in the incidence of infant leukaemia of 48% for children born in West Germany between 1 July 1986 and 31 December 1987 as compared with children born prior to the accident or after 1988. However, Michaelis *et al.* did not attribute this finding to the ionizing radiation from Chernobyl, mainly because a correlation with exposure levels was missing. In their reply, contained in the letter to *Nature* by Michaelis *et al.*, Petridou *et al.* stated: 'The lack of response to exposure in several subgroup analyses in Germany is hardly surprising, given the unavoidable non-differential exposure misclassification, the questionable correspondence between environmental measurements and personal exposures, and the sparse data'. Körblein and Küchenhoff[9] studied another possible health effect of the Chernobyl accident. They reported a significant increase of about 5% in German perinatal mortality in 1987 relative to an exponential plus constant trend model based on annual data from 1980 to 1993, but their results have been debated.[10,11]

We investigated perinatal mortality and stillbirth proportions in the Federal Republic of Germany (FRG) in greater detail.[12–14] Using logistic regression, we found a relative increase in perinatal mortality in 1987 of 4.8% ($P = 0.0045$). For the supposedly more highly exposed populations of Bavaria and the former German Democratic Republic (GDR), we found relative increases of 8.5% ($P = 0.0702$) and 7.2% ($P = 0.0913$), respectively. Since Bavaria and the former GDR show similar excess perinatal death proportions in 1987, we pursued a joint analysis of these two regions to gain greater statistical power. The regression coefficients in this model are allowed to vary by region but a common variable is fit for 1987. The result of this combined analysis is a significant relative increase in 1987 of 7.6% ($P = 0.0383$). In addition, we employed a spatial/temporal analysis of stillbirth and perinatal death proportions with the caesium deposition after the Chernobyl accident in Bavaria on a district level and we found a significant exposure-response relationship.[14] However, we concluded that these results have to be considered with caution because of the several limitations of studies using aggregated data and that evidence from independent information should be sought. So, the question arises whether similar effects on stillbirths or on perinatal mortality as in Germany can be observed in other European countries.

Data and Statistical Methods

We were able to compile complete data on official national stillbirth statistics together with the corresponding stillbirth definitions for 1980–1992 for the following 23 European countries: Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany (former FRG + former GDR), Great Britain, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Netherlands, Norway, Poland, Portugal, Spain, Sweden, and Switzerland. For the remaining European countries not mentioned, it was not possible to obtain any data at all (e.g. Turkey) or complete data (e.g. Ukraine) or the exact definition of stillbirth (e.g. Belarus) for 1980–1992. Due to the larger numbers, we would have liked to also investigate perinatal deaths as has been done for Germany. However, we were not able to compile European neonatal death data apart from a minor subset of the above list. We therefore concentrated on the available stillbirth statistics. Since in Finland, Czech Republic, Latvia, Lithuania, and in the Netherlands the definitions of stillbirth were changed in 1987, 1988, 1991, 1990, and in 1991, respectively, these five countries were excluded from the synoptic analysis. Evaluation of stillbirth data from Belarus and Ukraine would have been very interesting. Although we obtained complete data for Belarus and only the 1981 data point is missing for the Ukraine, we had to exclude these countries from the synoptic analysis for formal reasons. For both countries we could not get the exact stillbirth definition, and it is not clear whether there were any changes in the definitions during 1980–1992. In a number of European countries, stillbirth definitions changed in the 1990s, as for example in Great Britain and in Poland by the end of 1992 and in 1994, respectively. In Germany, the weight limit in the stillbirth definition was reduced from 1000 g to 500 g by 1 January 1994. All in all, there remain 18 countries with complete stillbirth data and no changes of stillbirth definition for 1980–1992.

The data on European live births, stillbirths, and neonatal deaths was obtained from national and international publications (National Statistical Yearbooks, EUROSTAT, and WHO). In addition, we asked the individual National Statistical Offices to send their most recent figures or confirm the published figures. During this process, several minor corrections of the published material were made.

As can be learned from the investigation of German perinatal mortality, population size and effect size are critical determinants of the statistical analysis. We therefore considered the statistical power connected with regression analyses more closely.[14] Comparison of the power functions of the t-test for polynomial regression and the Wald χ^2-test for logistic regression reveals that logistic regression is considerably more powerful than polynomial regression and should therefore be preferred. Additionally, it became apparent that for Germany as a whole a hypothetical 5% increase in perinatal mortality can be detected with a probability of somewhat above 80% using a two-sided 5% level test. The typical minimum value of the desired power in epidemiological studies is 80%. Taking Bavaria alone, power decreases and hypothetical excesses in perinatal mortality have to be greater than 13.5% to be detectable with a power of at least 80%. For stillbirth proportion alone, which constitutes roughly one-half of the perinatal death proportion, there is insufficient probability to detect such a small relative increase in Germany in 1987. Hence, to investigate possible statistical effects in the range of a few per cent on European stillbirth data, an aggregation of national stillbirth statistics into larger data sets is called for to achieve a sufficient statistical power.

Consequently, we partitioned the 18 countries with appropriate data into three groups according to their geographical

Table 1 Definitions of stillbirth;[a] limits for distinction of spontaneous abortion from stillbirth (late fetal death). The definitions did not change in the time window 1980–1992

West	Definition	Central	Definition	East	Definition
Belgium	180 days	Austria	35 cm	Greece	28 weeks
France	180 days	Denmark	28 weeks	Hungary	28 weeks
Great Britain	28 weeks	Germany	1000 g	Poland	28 weeks
Iceland	28 weeks	Italy	180 days	Sweden	28 weeks; 35 cm
Ireland	28 weeks	Norway	28 weeks		
Luxembourg	28 weeks	Switzerland	30 cm		
Portugal	28 weeks				
Spain	28 weeks				

[a] For Belarus and Ukraine no definitions are available; definitions changed in 1987–1991 for Czech Republic, Finland, Latvia, Lithuania, and Netherlands.

location. The western group comprises Belgium, France, Great Britain, Iceland, Ireland, Luxembourg, Portugal, and Spain. The central group consists of Austria, Denmark, Germany, Italy, Norway, and Switzerland. The eastern group comprises Greece, Hungary, Poland, and Sweden. Definitions that distinguish stillbirth (late fetal death) from spontaneous abortions are presented in Table 1. They did not change over 1980–1992. Definitions, although not identical, are similar enough to study the mean trends in these three groups. Our hypothesis was that, if exposure to the radioactive fallout from Chernobyl had an effect on stillbirth proportions, this effect should be most pronounced in countries from Eastern Europe. As we obtained perinatal death data for the countries in the eastern group, we also analysed the time trend of this data.

Figure 1 is a map of Europe including published exposure estimates. National or regional mean values may not reflect the actual contamination appropriately. In Bavaria, e.g. where the mean deposition was 14.9 kBq/m^2, the Cs-137 measurements ranged from the detection limit to 120.7 kBq/m^2.

There is evidence that radioactive exposure of parents may have an influence on the sex ratio of the offspring, namely that the sex ratio of live births is shifted in favour of the female gender.[15,16] For Denmark, Germany, Hungary, Norway, and Sweden we obtained gender-specific stillbirth data. For Poland we obtained a gender-specific stillbirth statistic employing a weight limit of 600 g only. For each year from 1980 to 1992 we computed the stillbirth odds ratio for gender and analysed the time trends of the odds ratios using a straightforward change point method. We used dummy coding of time intervals before and after the possible change points in 1980–1992 and we estimated the change points and the corresponding magnitude of the changes.

Table 2 shows the observed absolute numbers of live births and stillbirths, as well as the stillbirth proportions from 1980 to 1992 for the three parts west, central, and east of Europe, as defined above and additionally for Belarus and Ukraine together. Table 3 (live births and stillbirths for each country for the combined years 1986 and 1987) shows the relative contribution of each country. As can be seen from this Table, study results for the western, central, and eastern groups are not driven by the stillbirth rate of a single country, but are rather due to the combined effects of all countries in a group.

As the fetus is most sensitive to radiation during the period of organogenesis in the first trimester of conception, the impact of external radioactivity from the accident on stillbirths, if any, could be expected 6–9 months after the exposure, i.e. November 1986 to January 1987.[9] Taking into account the somewhat delayed internal exposure from contaminated food as well, the major impact of the total internal and external radioactive exposure from the accident should be expected in 1987.[17,18] To assess the underlying time trends and possible deviations from the trends in the European stillbirth proportions, we developed a synoptic statistical model based on linear logistic regression.[19,20] The basic variables in this model are an intercept, time t, time squared t^2, and the cube of time t^3. Time is coded as 1 to 13. The purpose of t^2 and t^3 is to allow for a smooth modelling of the possibly changing rates of the overall secular reduction of stillbirth proportions. We used dummy coding of the two points in time 1986 and 1987 and additionally of 1988–1992 to allow for an effect and a possible residual effect of the accident. The basic temporal dummy variables used in this study are defined as follows: $d_{86} = 1$ for 1986 and 0 else; $d_{87} = 1$ for 1987 and 0 else; $d_{88-92} = 1$ for 1988 to 1992 and 0 else. A corresponding null hypothesis states, for example, that the stillbirth proportion in 1986 does not deviate from the trend as computed from the remaining years. In technical terms this means that the coefficient of the dummy variable d_{86} equals zero. For the synoptic European model we also used dummy coding of the three regions West, Central, and East. The spatial dummy variables are defined as: $d_{west} = 1$ for Western Europe and 0 else; $d_{central} = 1$ for Central Europe and 0 else; $d_{east} = 1$ for Eastern Europe and 0 else. A location-specific time-dependent variable is then derived by multiplying the temporal (dummy) variable by the corresponding spatial dummy variable. Table 4 contains the maximum set of variables in the synoptic European model. In this formulation the global intercept is identical with the intercept of the partial western model. Starting with this maximum model, we eliminated non-significant variables ($P > 0.05$) by backward stepping[20,21] using the procedure LOGISTIC in SAS 6.12.[22]

Results

Table 5 shows, step by step, the intermediate results of the backward elimination of variables starting with the full variable set of Table 4. The eliminated effects for Central Europe are the cube of time and the special effects for 1986, 1987, and 1988–1992. Hence, the remaining partial model for Central Europe is

West		Central		East		Excluded	
Belgium	0.8	Austria	22.0	Greece	2.4-8.0	Belarus	39.0
France	0.2-3.2	Denmark	1.3	Hungary	1.5-4.8	Czech	2.5-5.3
Great Britain	0.1-3.0	Germany	2.0-16.0	Poland	5.2	Finland	15.0
Iceland	–	Italy	4.0-6.0	Sweden	0.8-31.0	Latvia	2.8
Ireland	3.4	Norway	5.3			Lithuania	2.8
Luxembourg	2.7	Switzerland	1.3-15.0			The Netherlands	1.8
Portugal	0.0					Ukraine	15.0
Spain	0.1						

Figure 1 Map of Europe with the countries included in the synoptic model and population-weighted deposition of Cs–137. West – light, Central – medium, East – dark, White – countries excluded for none or incomplete data or unknown or changed stillbirth definition in 1980 to 1992

simple and contains only an intercept, time and time squared. The partial Western and Eastern European models are more complicated since only the effect variable for 1986 (West) and the cube of time (East) have been excluded. The final synoptic model has 15 variables that are the complement of the excluded six variables in Table 5 relative to Table 4. Since we have 39 observations (3 $*$ 13) the error term of the model has 24 degrees of freedom (d.f.). The deviance is 16.03 and yields an upper tail χ^2 probability of 0.8868, i.e. the data are not unlikely under the hypothesis of the model that we derived by the backward elimination procedure.

Table 6 displays the pertinent information for the synoptic European model. The Table contains the parameter estimates, the *P*-values, and the confidence limits for the parameters. As seen above, there is a certain underdispersion of the data relative to the derived model. But this underdispersion can be attributed to chance variation. However, to be conservative, we did not correct the *P*-values and confidence limits for the

Table 2 Live births (LB), stillbirths (SB), and stillbirth proportions (SBp = SB/[LB + SB]) in parts of Europe 1980–1992

	West			Central			East			Belarus + Ukraine[a]		
Year	LB	SB	SBp	LB	SB	SBp	LB	SB	SBp	LB	SB	SBp
1980	2 490 613	20 858	0.00831	1 779 055	11 966	0.00668	1 086 669	7430	0.00679	896 921	8615	0.00951
1981	2 426 150	19 149	0.00783	1 756 689	11 047	0.00625	1 056 604	7184	0.00675	157 899	1192	0.00749
1982	2 382 824	17 730	0.00739	1 754 031	10 594	0.00600	1 065 933	7038	0.00656	904 955	8638	0.00945
1983	2 292 489	16 338	0.00708	1 694 397	9913	0.00582	1 072 402	6813	0.00631	980 621	8926	0.00902
1984	2 293 660	15 949	0.00691	1 666 181	9230	0.00551	1 044 013	6511	0.00620	960 784	9079	0.00936
1985	2 290 389	15 525	0.00673	1 658 155	8743	0.00525	1 022 720	6043	0.00587	927 809	9108	0.00972
1986	2 285 872	14 908	0.00648	1 674 787	8360	0.00497	977 712	5880	0.00598	964 185	9144	0.00939
1987	2 277 663	13 838	0.00604	1 692 764	8236	0.00484	942 423	5622	0.00593	923 788	8751	0.00938
1988	2 283 519	13 001	0.00566	1 747 458	8125	0.00463	931 622	5170	0.00552	907 249	7866	0.00860
1989	2 251 899	12 409	0.00548	1 731 740	7660	0.00440	903 514	4918	0.00541	844 430	7154	0.00840
1990	2 265 351	11 973	0.00526	1 773 695	7597	0.00426	897 663	4674	0.00518	799 369	6678	0.00828
1991	2 252 140	11 631	0.00514	1 698 801	7089	0.00416	899 518	4499	0.00498	762 858	6214	0.00808
1992	2 222 061	10 888	0.00488	1 687 002	6695	0.00395	862 269	4045	0.00467	724 756	5571	0.00763

[a] Data for 1981 missing for Ukraine.

Table 3 Live births (LB) and stillbirths (SB) for each country in the synoptic model and in addition for Belarus and the Ukraine for the combined years 1986 and 1987

West	LB	SB	Central	LB	SB	East	LB	SB
Belgium	234 468	1452	Austria	173 467	674	Greece	219 202	1779
France	1 546 296	10 919	Denmark	111 533	530	Hungary	254 044	1710
Great Britain	1 530 599	7992	Germany	1 716 201	7149	Poland	1 240 240	7178
Iceland	8074	33	Italy	1 106 984	7067	Sweden	206 649	835
Ireland	120 053	895	Norway	106 541	505			
Luxembourg	8547	43	Switzerland	152 825	671			
Portugal	249 966	2620				Belarus	334 548	2518
Spain	865 532	4792				Ukraine	1 553 425	15 377

Table 4 Initial variable set of the synoptic European model

West	Central	East
intercept	intercept * $d_{central}$	intercept * d_{east}
t * d_{west}	t * $d_{central}$	t * d_{east}
t^2 * d_{west}	t^2 * $d_{central}$	t^2 * d_{east}
t^3 * d_{west}	t^3 * $d_{central}$	t^3 * d_{east}
d_{86} * d_{west}	d_{86} * $d_{central}$	d_{86} * d_{east}
d_{87} * d_{west}	d_{87} * $d_{central}$	d_{87} * d_{east}
$d_{88–92}$ * d_{west}	$d_{88–92}$ * $d_{central}$	$d_{88–92}$ * d_{east}

underdispersion. This yields somewhat larger *P*-values and wider confidence intervals.

Figure 2 shows the observed European stillbirth proportions of Table 2 and the corresponding synoptic model of Table 6 graphically. The striking decline in all three regions is probably due to an overall reduction of risk factors and an improved antenatal care. Obviously, the trend of the stillbirth proportions is relatively smooth and void of any abrupt changes in Central Europe. By way of contrast, in Western Europe there are discontinuities in 1987 and in 1988 as well. A continuously reduced progress from approximately 6% to 3% per year in 1980 to 1986 is followed by an abrupt improvement of the stillbirth proportion of about 7% in 1987. Also, a relatively large improvement of 6% is visible from 1987 to 1988. In the remaining years, the progress is reduced to about 4% per year. In the Eastern European data there is a peculiar absolute increase of the stillbirth proportions in 1986 as compared with 1985 and an apparent upward shift of the whole trend line from 1986 on. There is no parallel to this deterioration in any of the other years or in the other two European regions. An alternative approach is to keep also the non-significant effects for 1986, 1987, and 1988–1992 for all three parts of Europe in the synoptic model to obtain and compare the corresponding excesses and their confidence intervals. The result is shown in Figure 3.

As for Belarus where we do not know the exact definitions, if we take the WHO definition of stillbirth as a basis and include the Belarus in the eastern part of Europe, the parameter estimates of d_{86} * d_{east}, d_{87} * d_{east}, and $d_{88–92}$ * d_{east} as well as the corresponding *P*-values get more pronounced. The (estimates, *P*-values) for 1986, 1987, and 1988–1992 are, respectively: (0.0454, 0.0028), (0.0794, 0.0001), (0.0515, 0.0096) (Table 6 for comparison). If we interpolate the missing data point and also include the Ukraine in the eastern part of Europe, the synoptic model gets 48% overdispersion due to the very strong variability of the Ukrainian stillbirth data and only the effect for 1986 remains significant: (d_{86} * d_{east}, *P*-value) = (0.0308,

Table 5 Results of the backward elimination process starting with the initial variable set of Table 4. The variable is the variable with the minimum Wald χ^2 or the maximum *P*-value that is eliminated in the corresponding step

Step	Variable	*P*-value for variable	d.f.	Deviance	Deviance/d.f.	Probability>Deviance
1	$d_{87} * d_{central}$	0.8089	18	13.13	0.7294	0.7838
2	$t^3 * d_{central}$	0.7737	19	13.17	0.6933	0.8296
3	$t^3 * d_{east}$	0.4811	20	13.23	0.6615	0.8673
4	$d_{88–92} * d_{central}$	0.4735	21	13.56	0.6456	0.8878
5	$d_{86} * d_{west}$	0.2327	22	13.89	0.6314	0.9053
6	$d_{86} * d_{central}$	0.1646	23	14.79	0.6430	0.9020
Final model			24	16.03	0.6681	0.8868

Table 6 Model information of the synoptic logistic regression for European stillbirth proportions 1980–1992 according to Table 2; the two-sided *P*-values for H_0: parameter = 0 correspond to the Wald χ^2 distribution. The *P*-values and CI are conservative, i.e. not corrected for underdispersion; d.f. = 24, deviance = 16.03

Partial model	Variable	Parameter estimate	*P*-value	95% CI
West				
	intercept	–4.7076	0.0001	(–4.7328, –4.6823)
	$t * d_{west}$	–0.0825	0.0001	(–0.1006, –0.0645)
	$t^2 * d_{west}$	0.0075	0.0001	(0.0042, 0.0108)
	$t^3 * d_{west}$	–0.0003	0.0001	(–0.0005, –0.0002)
	$d_{87} * d_{west}$	–0.0510	0.0001	(–0.0758, –0.0262)
	$d_{88–92} * d_{west}$	–0.0951	0.0001	(–0.1261, –0.0640)
Central				
	intercept $* d_{central}$	–0.2484	0.0001	(–0.2798, –0.2170)
	$t * d_{central}$	–0.0519	0.0001	(–0.0585, –0.0454)
	$t^2 * d_{central}$	0.0006	0.0091	(0.0002, 0.0011)
East				
	intercept $* d_{east}$	–0.2454	0.0001	(–0.2811, –0.2097)
	$t * d_{east}$	–0.0218	0.0001	(–0.0310, –0.0126)
	$t^2 * d_{east}$	–0.0010	0.0072	(–0.0017, –0.0003)
	$d_{86} * d_{east}$	0.0392	0.0190	(0.0065, 0.0719)
	$d_{87} * d_{east}$	0.0674	0.0002	(0.0316, 0.1032)
	$d_{88–92} * d_{east}$	0.0463	0.0338	(0.0035, 0.0891)

0.0176). Moreover, the Ukrainian stillbirth proportions are much higher and do not follow a smooth trend as opposed to all the other national data in our model. Therefore, it seems not reasonable to use these data in the synoptic European model even if there were no problems with the stillbirth definition. We recommend that the Belarus and Ukraine data be assessed and analysed by national statisticians who have better access to the pertinent information.

The dashed line in Figure 2 represents the expected stillbirth proportions under the partial Eastern European model with the coefficients for the dummy variables for 1986, 1987 and 1988–1992 set to zero (reduced model). The relative increases and conservative 95% CI in per cent of the expected stillbirth proportions under the reduced model for 1986, for 1987, and for the offset in 1988–1992 are, respectively: 3.97 (95% CI : 0.64–7.41), 6.93 (95% CI : 3.19–10.80), and 4.72 (95% CI : 0.35–9.27). This translates to the following estimated absolute excess numbers and 95% CI : 225 (95% CI : 36–419) in 1986, 364 (95% CI : 168–568) in 1987, and 210 (95% CI : 16–413) on average per year for 1988–1992. Hence, there is a theoretical total excess of 1639 stillbirths in Greece, Hungary, Poland, and Sweden in 1986–1992. Extrapolating this result to the presumably higher contaminated countries as for example Belarus, Bulgaria, Romania, Russia, Ukraine, and so on, one can imagine that perhaps several thousand additional stillbirths have occurred in the affected parts of Central and Eastern Europe in the years following the Chernobyl accident.

Analysis of the combined perinatal death data from Hungary, Greece, Poland, and Sweden shows that only an excess in 1987 of 3.1% is significant ($P = 0.0297$). The variability of the neonatal death data is much higher than the variability of the stillbirth data, because neonatal mortality, the other part in the perinatal mortality, is more subject to quality and progress of medical care than stillbirths are. Moreover, neonatal deaths amount to about 60% of the perinatal deaths in these countries, whereas in Germany, for example, this portion decreased from 53% in 1980 to 43% in 1992. So, the clear structural change of stillbirth proportions in the year 1986 in the eastern group gets hidden to a considerable extent in the perinatal death proportions.

For Denmark, Germany, Hungary, Norway, and Sweden combined, we evaluated the available gender-specific stillbirth data. In 1987 there is a significant ($P = 0.0095$) change point in regression for the stillbirth odds ratios for gender. The odds ratio

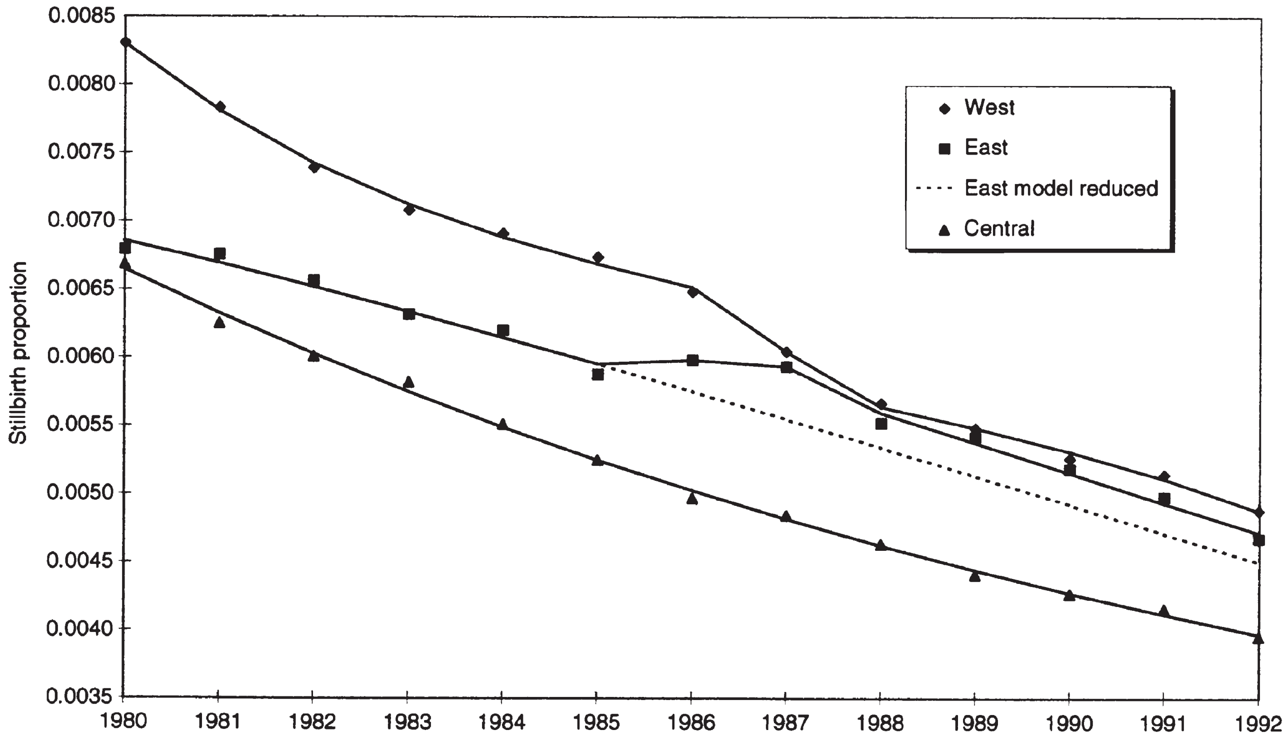

Figure 2 European stillbirth proportions 1980–1992 and synoptic linear logistic regression model according to data in Table 2 and model information in Table 6

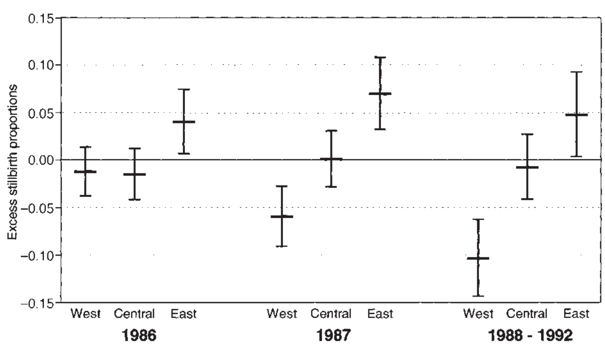

Figure 3 Excesses and corresponding 95% confidence interval for the stillbirth proportions in Europe. The excesses refer to the reduced partial models with the effects for 1986, 1987, and 1988–1992 set to zero

increases from 1.059 to 1.101. In the separate Polish gender-specific stillbirth data, based on a 600 g weight limit of the fetus, there is a peculiar structural change in the trend of male stillbirths in 1986. No corresponding effect is seen for female stillbirths. Although the Polish numbers are smaller and more variable than the numbers of the five countries above, there is a significant change point in regression in 1986 ($P = 0.0371$). The stillbirth odds ratio for gender increases from 0.993 to 1.055 in Poland.

Discussion

Annual stillbirth proportions in Europe for 1980–1992 were investigated with emphasis on the possible impact of the Chernobyl disaster on data for 1986, 1987, and eventually for 1988–1992. We compared the stillbirth proportions of the part of Eastern Europe from which we could get valid and complete data (Greece, Hungary, Poland, Sweden) to essentially the complete Western and Central Europe. In contrast to the Western and Central European trends, the Eastern European trend shows a marked structural deterioration in 1986.

Studies of the survivors of the atomic bombing of Hiroshima and Nagasaki who were exposed to ionizing radiation *in utero* have demonstrated a significant increase in perinatal loss.[23] The epidemiological data are, however, too sparse to settle unequivocally the nature of the dose-response function and, in particular, whether there is or is not a threshold to damage.

In Belarus, geographical differences in reproductive health and immune status were apparent that may be related to radiation exposure after the Chernobyl accident.[24] A retrospective analysis was conducted on pregnancies occurring between 1982 and 1990, and a comparison of results was made between pregnancy outcomes prior to and after the meltdown for individuals residing in heavily exposed and lightly exposed areas. Neonates born in heavily contaminated areas (Mogilev and Gomel) of the Republic of Belarus were at risk for development of congenital malformation and perinatal death. No such effect was seen in a retrospective analysis of spontaneous miscarriages, congenital anomalies, and perinatal mortality in the two largest obstetric hospitals of Kiev between 1969 and 1990.[25]

Several epidemiological studies following the Chernobyl accident come from Scandinavian countries. In Finland, there was a significant rise in preterm births among children who were exposed to radiation during the first trimester, but no increase in the incidence of malformations or perinatal deaths was observed.[26] These findings are consistent with a higher incidence of spontaneous abortions in Norway found for pregnancies conceived during the first 3 months after the accident. The increase in the spontaneous abortion rate the first year after the accident was followed by a slight decrease during the second and third years, but figures were still higher than in the period prior to the accident. The long-term persistence is not supposed to be the result of external radiation, but internal radiation from food polluted by radioactive fallout is a possible explanation.[27] Apart from single positive studies concerning highly contaminated areas, the majority of investigations focusing on possible health effects of the Chernobyl disaster ended in negative results.[1] In a comprehensive review, Little[6] concludes that there is no consistent evidence of a detrimental physical effect of the accident on congenital anomalies or other measured outcomes of pregnancy.

One of the first investigations of the possible impact of the Chernobyl disaster on gestation in Germany was a trend extrapolation of monthly neonatal mortality from the years 1975 to 1985 to 1986 and 1987.[28] This work has been criticized because the results were dependent on the statistical model chosen, a common criticism aimed at extrapolation.[29] Most of the published subsequent work on German perinatal mortality or infant death data did not show any peculiar effects.[10,17,18,26–28] However, as we pointed out,[13] the negative results of these studies may be due to insufficient methodology resulting in low statistical power.

The apparent offset in the Eastern European stillbirth proportions from 1988 on (Figure 2) is not without a certain parallelism in the time trend of German infant leukaemia observed by Michaelis *et al.*[8] As mentioned above, Michaelis *et al.* found a rate ratio for infant leukaemia of 1.48 for children born in Germany between 1 July 1986 and 31 December 1987 (cohort B) as compared with children born between 1980 and 1985 (cohort A) combined with children born between 1988 and 1990 (cohort C). However, a direct comparison of cohorts B and C with cohort A yields rate ratios of 1.64 and 1.28 respectively. The authors attributed the increase in cohort C to a possible underreporting of leukaemia cases in the initial phase of the German childhood cancer registry. Nevertheless, it cannot be ruled out that the increase in cohort C may also partly be due to some residual effect of the Chernobyl accident from 1988 on. Probably, Michaelis *et al.* could have increased the statistical power of their study by enlarging the time interval for cohort B, since there may be additional children exposed *in utero* in 1987 born after 1 January 1988.

As an obvious limitation of our ecological type of study it has to be emphasized that in principle no causal inference[30] is possible based on such highly aggregated data. Alternative causes of the observed excess annual stillbirth proportions other than radioactive exposure cannot be ruled out. The most simple explanation of the relatively increased stillbirth proportions refers to a discontinuity of the steady improvement in medical care. Table 7 summarizes results and interpretations concerning the European stillbirth data.

In conclusion, our investigation shows a peculiar structural change of the stillbirth proportions in 1986, the year of the Chernobyl accident, in the combined data from Greece, Hungary, Poland, and Sweden. No such effect is seen in the western and central parts of Europe. As we have shown in a parallel investigation,[14] there is a significant exposure-response relationship between the caesium deposition after the Chernobyl accident and stillbirths on a district level in Bavaria. These findings are in contrast to those of many other studies in this field and contradict the generally accepted radiobiological theory. Therefore, and because an ecological study has many weaknesses with respect to causal interpretation, the results should be considered with caution and independent evidence should be sought.

Table 7 Pertinent results and corresponding interpretations

Result	Interpretation
Significant (relative) increases in eastern European SBps[a] from 1986–1992 are found.	If this effect is a consequence of the radioactivity by the Chernobyl accident it cannot be explained by conventional radiobiological theory. The assumption of a threshold dose of 50 mSv for the induction of stillbirths may not be appropriate, or the threshold may be <50 mSv.
The yearly SBps decrease in western European countries but increase (relatively) in eastern European countries from 1986 on.	A negative economic development in eastern European countries in the second half of the eighties with a negative impact on health care might explain or contribute to this effect.
There is a significant absolute increase in eastern European SBps in 1986. No corresponding excess is present in Germany, in other western or central European countries, and even in the more heavily contaminated Bavaria.	The acute exposure in 1986 was perhaps much higher in eastern European countries than in western and central European countries, but this is not reflected by official measurements; see the data in Figure 1.
Although more heavily contaminated, Belarus and Ukraine do not show effects as clearly as the countries in the eastern part of the synoptic European model.	Definitions changed, or data is more variable. Especially in Ukraine the population or the data recording mechanisms may not have been stable over the time period 1980–1992.
The effect is not seen so clearly with perinatal death proportions.	The variability of perinatal deaths is higher than of stillbirths. Neonatal deaths are more subject to differing quality and progress of social and medical care than stillbirths are. Radioactivity induces less neonatal deaths than stillbirths.
The effect is stronger for male than for female stillbirths.	There is evidence from the literature that the developing male embryo or fetus is more vulnerable against intrauterine irradiation than the developing female embryo or fetus.

[a] Stillbirth proportions.

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