Perinatal mortality after the Fukushima accident

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This study investigates trends in perinatal mortality rates in Fukushima Prefecture and four neighboring prefectures (Miyagi, Gunma, Tochigi, and Ibaraki) before and after the Fukushima nuclear disaster in March 2011. Beginning in 2012, perinatal mortality rates deviate upwards from the trend in preceding years; the monthly data show significant peaks in May 2012 and March 2013. It is unlikely that these peaks are associated with external radiation exposures received during March 2011. They might rather be associated with internal radiation exposure from the ingestion of radioactively contaminated food. These findings agree with similar observations in Germany after Chernobyl, but they conflict with statements by WHO and UNSCEAR that no adverse effects of the Fukushima accident on pregnancy outcomes are expected.

Background

After the accident at the Fukushima Daiichi nuclear power plant (FDNPP) in March 2011, little attention was paid to possible adverse effects on pregnancy outcomes in Fukushima and neighboring prefectures. The 2013 UNSCEAR report on Fukushima stated that prenatal exposures from the accident at FDNPP were not expected to increase the incidence of spontaneous abortions, miscarriages, perinatal mortality, congenital effects or cognitive impairment [1]. A recent survey of stillbirth rates, pre-term births, low birth weight, and congenital anomalies by the Radiation Medical Science Center for the Fukushima Health Management Survey found no statistically significant increases in adverse pregnancy outcomes [2].

After the Chernobyl nuclear disaster in April 1986, a statistically significant increase of perinatal mortality occurred in Germany in 1987. Monthly data showed peaks in the beginning and the end of that year [3]. The objective of the present study is to investigate whether a similar increase of perinatal mortality occurred in Fukushima and four neighboring prefectures following the Fukushima accident.

Data and Methods

Monthly data of live births, stillbirths and early neonatal deaths, 2002 through 2014, are available at http://www.e-stat.go.jp [4]. Stillbirths are defined as fetal deaths from the 22th weeks of pregnancy. A study region was defined consisting of Fukushima Prefecture
and four neighboring prefectures: Miyagi, Gunma, Tochigi, and Ibaraki (see Figure 1). Perinatal mortality rates in the study region were compared to the rates in the rest of Japan, defined as the control region. To this end, a combined logistic regression of the data from the study and control regions was carried out. The logistic regression applied a linear-quadratic time dependency to allow for possible curvature of the temporal trend. Dummy coding was used to estimate differences in intercepts and slopes between study and control region. Dummy variables d2011 through d2014 were added to estimate possible deviations of perinatal mortality in 2011 to 2014 from the extrapolated trend of the rates in 2002 to 2010.

Figure 1: District average effective dose (mSv) in the first year in the study region (prefectures Fukushima, Miyagi, Gunma, Tochigi, and Ibaraki). Source: UNSCEAR 2013 [1]

When analyzing monthly data, seasonal effects have to be taken into account. A simple way to do this is using dummy variables for the months February through December with January as the reference month.
The number of variables can be radically reduced when the ratios of perinatal mortality in the study region to the rates in the control region (Japan without the study region) are analyzed. Seasonal variations can be neglected since the comparison is on a monthly basis. Only an intercept and a trend parameter are needed which now estimate any difference in the level of perinatal mortality and in time trends, respectively, between study- and control region.

For ease of calculation, odds ratios (OR) were evaluated instead of rate ratios. The odds ratio is the ratio of the odds in the study region to the odds in the control region. Odds are defined as \( p / (1-p) \) where \( p \) is perinatal mortality, defined as the number of stillbirths (SB) plus early neonatal deaths (NEO) divided by the number of live births (LB) plus stillbirths, i.e. \( p = (SB + NEO) / (LB + SB) \). When the natural logarithm of the odds ratios is used as the dependent variable, the variances (var) take the following simple form:

\[
\text{var} = 1/(\text{SB}_1 + \text{NEO}_1) + 1/(\text{LB}_1 - \text{NEO}_1) + 1/(\text{SB}_0 + \text{NEO}_0) + 1/(\text{LB}_0 - \text{NEO}_0).
\]

Index 1 denotes the study region and 0 (zero) the control region.

Weighted linear regression of the logarithms of the odds ratios with weights=1/var was applied with time \( t \) as the independent variable. Dummy coding was used to estimate any deviation of the odds ratios in 2011-2014 from the extrapolated trend of the odds ratios in 2002-2010. Data analysis and plotting was done with the open software R (http://www.r-project.org) [5]. All statistical tests were two-sided, and a p-value smaller than 0.05 was considered statistically significant.

**Results**

**Annual data**

A combined logistic regression of the annual data in the study region before the Fukushima accident (2002-2010) and in the control region (2002-2014) was carried out with independent variables study, \( t \), \( t^2 \), and \( t_{\text{study}} \) as defined in the method section.

Increases of perinatal mortality rates in the study region relative to the rates expected from the trend in 2002-2010 were detected in 2012 (+13.9%, \( P=0.049 \)), 2013 (+17.8%, \( P=0.020 \)), and in 2014 (+11.6%, \( P=0.155 \)). No notable deviation from the trend was found in 2011 (-1.0%, \( P=0.88 \)). The trend of the data is shown in Figure 2.

An additional analysis was conducted to estimate the increase in 2012-2014 (dummy variable \( d_{1214} \)) in the study region relative to the extrapolated trend of the data in 2002-2011. A statistically significant 15% rise was determined (OR=1.15, 95% CI: 1.04-1.27, \( P=0.0048 \)) in 2012-2014 which translates to 143 excess perinatal deaths.
Figure 2: Annual data of perinatal mortality rates in the study region (●) and in the control region (○), and respective trend lines. The error bars are standard deviations.

Monthly data

First, a combined logistic regression of monthly perinatal mortality rates from the study region before March 2011 and the control region in 2002-2014 was carried out. To allow for seasonal variations, 11 dummy variables for February through December were introduced with January as the reference month. Altogether the regression model used 16 variables: 5 for the time trend (intercept, study, t, t2, tstudy) and 11 parameters for seasonality. The model fits the data well (deviance=240.0 with 250 degrees of freedom). The effect of seasonality is significant ($P=0.044$, chisquare test).

Next, an analysis of the odds ratios of perinatal mortality rates in the study region to the rates in the control region was carried out using linear regression. The increases in 2012 and 2013 are statistically significant; the odds ratios in 2012 through 2014 are OR=1.148 ($P=0.034$), OR=1.236 ($P=0.002$), and OR=1.142 ($P=0.071$), respectively.
Figure 3: Upper panel: Ratio of monthly perinatal mortality rates in the study region to the rates in the rest of Japan, and regression line. Lower panel: Standardized residuals and 3-month moving average (solid line). The vertical line indicates March 2011, the date of the accident.

Figure 3 shows the monthly odds ratios and the deviations of the odds ratios from the expected trend, in units of standard deviations (standardized residuals). The trend of the odds ratios exhibits peaks around May 2012 and March 2013; the rates in these two months are about 50% higher in the study region than in the control region.

**Discussion**

After the Chernobyl disaster in April 1986, peaks in perinatal mortality rates were found in Germany at the beginning and end of 1987 which were associated with cesium concentration in pregnant women from the consumption of contaminated cow milk [3]. The best estimate of the time-lag between the peaks in cesium burden and perinatal mortality was seven months. Figure 4 compares the residuals of the odds ratios, i.e. the
deviations from the expected trend, in the study region near Fukushima with the residuals of perinatal mortality rates in Germany after the Chernobyl accident.

Figure 4: Standardized residuals of the odds ratios of perinatal mortality rates in the study region near Fukushima (upper panel), and standardized residuals. The solid lines are the 3-month moving averages of the residuals. The vertical lines indicate the date of the nuclear accidents (March 2011 and end of April 1986, respectively).

Interestingly, two significant peaks are observed in each data set but the peaks are somewhat delayed in the Fukushima region compared to the peaks in the German data. In Germany, cow milk was considered the main path of cesium ingestion after Chernobyl. The first mortality peak in February 1987 was associated with the initial high cesium concentration in milk and, consequently, in pregnant women. The second mortality peak in November 1987 was attributed to elevated cesium concentration in cow milk during winter 1986/87, when cows were fed contaminated silage harvested in summer 1986. Due to lower milk consumption, the milk path might have played a minor role in Japan than in Germany.
Measurements of radiocesium activity in food samples were carried out and published by the Japanese Ministry of Health, Labour and Welfare (MHLW) after the Fukushima nuclear accident. The data comprise concentrations of Cs-134 \( (T_{1/2} = 2.1 \text{ a}) \) and Cs-137 \( (T_{1/2} = 30.1 \text{ a}) \) and, in the early stage after the accident, short-lived I-131 \( (T_{1/2} = 8.0 \text{ d}) \) in 877,635 samples (from 2011-03-11 until 2014-08-31).

The present study focuses on cesium contamination levels in 21,549 food samples from Fukushima prefecture for the first year (2011-03-11 until 2012-03-31). Of the 8110 samples of vegetables with defined sampling date, only 2214 samples had Cs-134 concentrations above the detection limit. Cs-134 rather than Cs-137 concentrations were chosen for the data analysis as a greater number of the former were available. To reduce statistical fluctuations, weekly averages were calculated. The 3-week moving average of cesium concentration shows no clear trend for meat/eggs or grain but exhibits a distinct pattern for vegetables (Figure 5).

![Weekly averages of cesium-134 concentration in vegetables from Fukushima prefecture (dots) and 3-week moving average (solid line).](image)

There is a steep decline of Cs-134 concentration in April 2011 followed by a rise with a maximum in September 2011 and a second peak in November 2011. These peaks were attributed to fresh and dried mushrooms, respectively [6].

With continued cesium ingestion, the cesium concentration in the human body builds up until cesium excretion equals cesium intake. Cesium excretion is determined by the
biological half-life of cesium of about 90 days. In women, the biological half-life is shorter than in men, and during pregnancy it is shorter than in non-pregnant women [7]. Due to the biological half-life of cesium there is a time-lag between the peak of cesium concentration in food and the peak of cesium burden in body.

To calculate the cesium concentration in pregnant women (cesium burden, Bq/kg) resulting from ingestion of vegetables, assumptions about average body weight (60 kg), daily consumption of vegetables (0.5 kg), and biological half-life of cesium (50 days, shorter than used in [3]) were made. The calculation yields a maximum cesium burden in September 2011, see green line in Figure 6.

![Figure 6: Weekly Cs-134 concentrations in vegetables (dots) and in pregnant women (green line). The red line shows the expected radiation effect when perinatal mortality is assumed to be associated with cesium concentration to the power of 3.5 (arbitrary units).](image)

While the perinatal mortality peaks in 2012 and 2013 in the Fukushima study region are rather narrow, the peak of cesium burden is not very high. In the German study [3], the association between cesium burden and perinatal mortality was found to be non-linear; the best fit to perinatal mortality data was obtained with a power of 3.5 of cesium burden. A non-linear, sigmoid shape of the dose response was also found after in-utero irradiation of experimental animals, usually mice or rats [8]. Applying the same dose-response relationship, i.e. a power of 3.5 of cesium burden, to the Fukushima data, the effect takes the shape of the red line in Figure 6 (arbitrary units).
Since the most vulnerable period of fetal development is during major organogenesis [8], a possible effect on perinatal mortality is expected some 7 to 8 months after September 2011. After Chernobyl, significant peaks of perinatal mortality were found by the present author in May 1987 in Bavaria, the most contaminated province of Germany, and in April 1987 in the Zhytomyr region of Ukraine. In Poland, infant mortality also peaked in April 1987. Thus, the peak in May 2012 in the Fukushima study region is paralleled by similar peaks in European countries after the Chernobyl accident.

Conclusion

After the accident in the Fukushima Daiichi nuclear power plant in March 2011, a statistically significant rise in perinatal mortality rates is observed in a study region that includes Fukushima Prefecture and four neighboring prefectures. The trend of monthly rates shows peaks around May 2012 and March 2013. These peaks cannot be attributed to the initial external radiation exposures as an increase in perinatal mortality would manifest by the end of 2011 at the latest. It seems more likely, therefore, that the peaks are caused by ingestion of contaminated food. Support for this hypothesis comes from a prominent peak of cesium concentration in vegetables, especially mushrooms, in September 2011, and from the fact that the most vulnerable period of fetal development is major organogenesis in the second month of pregnancy.

To conclude, the study is based on aggregated data; therefore the results need to be interpreted with caution as other possible causes for the increased perinatal mortality cannot be excluded. In addition, according to Publication 90 of the International Commission on Radiation Protection (ICRP) [8], teratogenic effects are not expected to occur below a threshold dose of 100 mSv, a position also held by WHO and UNSCEAR, while, after Fukushima, the average dose to the public from radiocesium in food was estimated less than 1 mSv in the first year [9]. However, the similarity of the results with findings after the Chernobyl accident is notable. Continued observation of the trend of perinatal mortality in the Fukushima region is recommended.
References


4. [Trends of population statistics].
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