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[Original article]

Final Report of Trends in Pregnancy and Birth Survey after the Great East Japan Earthquake and Fukushima Daiichi Nuclear Power Plant Accident: The Fukushima Health Management Survey

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Abstract

This study aimed to assess long-term changes in pregnancy and birth outcomes after the Great East Japan Earthquake and the accident at the Tokyo Electric Power Company's Fukushima Daiichi Nuclear Power Plant in Fukushima Prefecture. This is the final report on perinatal outcomes of the Prefectural Health Survey, which ended after a 10-year observation period. Questionnaires based on a pregnancy and birth survey conducted by the Radiation Medical Science Center for the Fukushima Health Management Survey were sent to women who had received maternal and child health handbooks from municipal officers in Fukushima Prefecture. Annual data from six geographic areas in Fukushima Prefecture were separately analyzed. The number of eligible respondents, which was approximately 16,000 in 2011 when the earthquake occurred, declined temporarily the following year, recovered temporarily one year later, and has gradually declined since then. However, the response rate remained at approximately 50% throughout the decade. The incidence of preterm deliveries, low-birthweight infants, and congenital anomalies did not vary over the decade and showed a similar trend in national surveys and general reports. Our analysis shows that the disaster had no significant adverse perinatal outcomes in Fukushima Prefecture and we recommend measures to ensure the safe delivery of babies in the region.

Keywords : earthquake, nuclear accident, pregnancy, congenital anomaly, survey

Introduction

The Great East Japan Earthquake that occurred on March 11, 2011, led to the combined disasters of a massive earthquake, massive tsunami, and a radiation disaster at the Tokyo Electric Power Company

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(TEPCO)'s Fukushima Daiichi Nuclear Power Plant (NPP). In addition, Fukushima Prefecture is still suffering reputational damage, and some say that full recovery is still a long way off. The biggest problem is the "fear" of low-dose radiation exposure.

After these disasters, the Fukushima Prefectural Government launched a prefecture-wide cohort survey (Fukushima Health Management Survey ; FHMS) to investigate the health effects of long-term low-dose radiation exposure and disaster-related stress[1,2]. The FHMS consisted of a basic survey (to estimate external radiation exposure) and four detailed surveys[1]. The pregnancy and birth survey, one of the four detailed surveys, aimed to accurately determine the mental health, physical condition, opinions, and requests of pregnant women seeking to have children and mothers raising children in Fukushima Prefecture, reduce their anxiety, and provide necessary care[1,2]. This survey has been conducted annually since 2011 and ended after 10-year observation period. In the first year (2011)[3] and the 8-year summary[4], we reported no significant adverse outcomes across the entirety of Fukushima prefecture following the disaster. Evacuation and concerns about radioactive contamination were significantly associated with depressive symptoms[5].

To date, surveys and support for pregnant and nursing mothers in Fukushima Prefecture have included the FHMS of Pregnant and Nursing Mothers, the Japan Environment and Children's Study (JECS)[6], a nationwide prospective birth cohort study funded by the Ministry of the Environment of Japan (conducted in Fukushima Prefecture since October 2012), congenital anomaly monitoring undertaken by the Japan Society of Obstetricians and Gynecologists throughout Fukushima Prefecture since the earthquake, and spontaneous and artificial abortion surveys conducted by the Department of Obstetrics and Gynecology at Fukushima Medical University[7].

This is the final report on pregnancy and delivery outcomes in the Prefectural Health Survey, which ended after a 10-year observation period.

Materials and Methods

For analysis, the present study used the results of the questionnaire of a maternal survey, a population-based study conducted as part of the FMHS launched by the Fukushima Prefecture government in 2011. The methods used for the FHMS and maternal surveys have been reported previously[1-4]. We divided Fukushima Prefecture into six districts : Kenpoku, Kenchu, Kennan, Soso, Iwaki, and Aizu, as shown in Figure 1[3] and included women who received Maternal and Child Health handbooks from August 1, 2010. This handbook describes the unique perinatal healthcare system in Japan and helps maintain a record of women's antenatal and postnatal checkups performed by physicians. A self-administered questionnaire was sent to the women by mail on January 18, 2012. Mothers were asked to refer to their handbooks when completing the questionnaire. Pregnant women who delivered between March 11, 2011, and December 31, 2020, and their newborns were included in this study. Women who delivered before March 11, 2011, and received a handbook outside Fukushima Prefecture were excluded from the present analysis. Moreover, from 2016 to 2020, we did not send questionnaires to women who had an abortion, who experienced stillbirth, or whose neonates could not be confirmed to be alive.

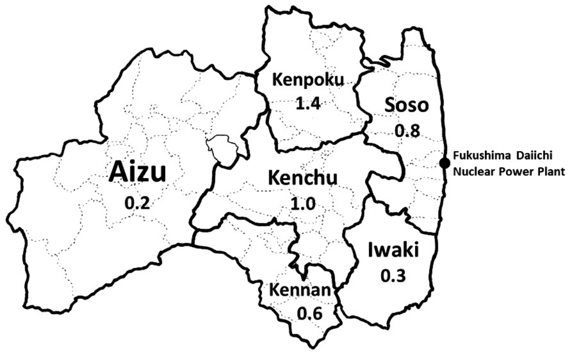

Fig. 1. Map of the Fukushima prefecture
The average estimated external dose by area (mSV) is shown

This survey was approved by the local ethics review committee of Fukushima Medical University and was guided by the local policy, national law, and the World Medical Association Declaration of Helsinki (approval #13047).

The self-administered questionnaire aimed to collect maternal information, such as the geographic district where the pregnant women received the Maternal and Child Health handbook, the year of delivery, maternal age at delivery, single or multiple gestational pregnancies, gestational weeks at delivery, method of pregnancy, mode of delivery, and neonatal information, such as neonatal birth weight, sex of the newborn, and anomalies in the newborn. Stillbirth was defined as fetal death after 22 weeks of gestation. Preterm birth (PTB) was defined as delivery before 37 weeks of gestation. The PTB rate was measured as the number of PTBs (singleton or multiple) divided by the total number of live births (based on the WHO definition)[8]. A birth weight less than 2,500 g was defined as low birth weight (LBW). The incidence of LBW is measured in a population as the percentage of LBW from total live births during the same period[9]. The method of pregnancy was categorized as natural pregnancy or pregnancy with the aid of fertility treatments, such as ovulation, artificial insemination, or in-vitro fertilization. The mode of delivery was categorized as vaginal delivery or cesarean section. Major anomalies in newborns were categorized as follows : cataract, cardiac malformation, kidney or urinary tract malformation, spina bifida, microcephaly, hydrocephalus, cleft lip or palate, intestinal atresia (esophagus, duodenum, ileum), imperforate anus, poly or syndactylism and others[3].

Maternal and neonatal characteristics were categorized into ten groups according to birth year. The demographic and perinatal outcome data of the participants were presented as mean ± standard deviation or as incidences, where appropriate. There were discrepancies in the total number of valid respondents owing to missing data in each category. The Mantel-Haenszel test for trend or the chi-square test was used to analyze annual or geographical trends, respectively. The Jonckheere-Terpstra trend test was used to compare continuous variables by year. SPSS version 24 (IBM Japan, Tokyo, Japan) was used for data analysis. Statistical significance set at $p < 0.05$ was considered significant.

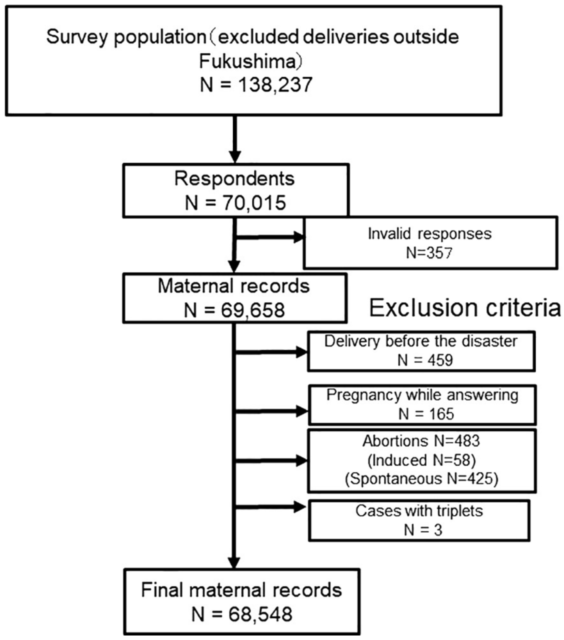

Fig. 2. Flowchart showing study enrollment

Results

Over the past ten years, a questionnaire was sent to 138,237 pregnant women in Fukushima Prefecture. The response rate was 50.6%, with 70,015 responses (Figure 2). A total of 357 invalid responses (63 without answers, 1 participant death, 83 multiple responses, 209 inconsistent answers, and 1 canceled registration after reply) were excluded, and 69,658 participants were included in the study. Of these, 68,548 individuals participated in this analysis after the exclusion of 459 participants whose deliveries had occurred before the disaster, 165 participants who were pregnant while answering, 58 participants who had induced abortions, and 425 participants who had spontaneous abortions and 3 participants who had triplets (Figure 2).

In the first year (2011), the number of participants was 15,972, which decreased to 14,420 in 2012 and then temporarily increased to 15,108 in 2013. Subsequently, the number gradually decreased every year, reaching 11,289 in 2020 (Table 1). The response rate was relatively high at 58.2% in the first year, but fluctuated around 50% in subsequent years and finally reached 55.5% in 2020. The rates differed significantly by region and year. Kenpoku had a higher response rate than other areas. Soso, located closest to the Fukushima Daiichi Nuclear Power Plant, had a higher response rate only in 2011, and has remained lower since then (Table 1).

Table 2 shows the participants' characteristics based on the years since delivery. Significant differences were observed in maternal age, gestational week at delivery, mode of pregnancy, and sex of neonates over the decade. Maternal age and cesarean section rate increased, while natural pregnancy rate decreased significantly over time (Table 2).

Table 3 shows that no significant differences were observed in the incidence of preterm deliveries based on the region and year. Regional differences were observed only in 2012, when the incidence was lower in Kenpoku and higher in Aizu.

Table 4 shows the incidence of LBW infants by region and year. No significant differences were observed in Fukushima Prefecture as a whole. Regional differences were only observed in 2011 and 2012. In 2011, the incidence was lower in Kenpoku and higher in Iwaki, whereas in 2012, the incidence was lower in Kenpoku and higher in Aizu.

Table 5 presents the incidence of congenital anomalies in newborns in each district over time. It ranged from 2.19% to 2.85% in Fukushima Prefecture, with no significant change over time. Different regions showed no significant changes over time.

Table 1. Changes in response rate over time

	2011-2020	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	p-value[a]
Response rate												
All of Fukushima, %	50.6	58.2	49.1	47.3	46.8	47.8	51.3	47.1	51.4	52.7	55.5	0.321
(Res/Send)	(70015/138237)	(9299/15972)	(7085/14420)	(7152/15108)	(7024/15017)	(6913/14454)	(7191/14019)	(6332/13435)	(6541/12730)	(6212/11793)	(6266/11289)	
Kenpoku, %	55.2†	62.8†	55.5†	53.2†	52.4†	52.3†	55.9†	50.9†	56.5†	54.0	58.9†	0.011
(Res/Send)	(18103/32780)	(2289/3647)	(1857/3347)	(1936/3637)	(1841/3515)	(1806/3453)	(1875/3352)	(1634/3212)	(1702/3015)	(1523/2818)	(1640/2784)	
Kenchu, %	49.6†	59.3	48.7	44.5†	44.8†	45.2†	49.8*	46.8	51.1	51.8	54.4	0.990
(Res/Send)	(20426/41180)	(2858/4819)	(2067/4243)	(1982/4453)	(1961/4376)	(1924/4261)	(2065/4150)	(1862/3980)	(2006/3923)	(1857/3588)	(1844/3387)	
Kennan, %	49.7*	50.2†	48.1	48.5	46.5	47.9	51.1	45.1	50.0	54.9	56.9	< 0.001
(Res/Send)	(5426/10927)	(631/1256)	(560/1164)	(588/1213)	(553/1188)	(560/1168)	(571/1118)	(473/1048)	(504/1008)	(502/914)	(484/850)	
Soso, %	46.5†	65.6†	43.7†	45.4	42.2†	44.2†	43.6†	40.5†	42.3†	45.4†	45.4†	< 0.001
(Res/Send)	(5169/11124)	(963/1468)	(500/1145)	(535/1178)	(512/1213)	(523/1183)	(511/1171)	(442/1091)	(424/1003)	(392/864)	(367/808)	
Iwaki, %	49.3†	55.9†	47.8	45.1*	45.8	46.6	50.1	45.5	49.1*	53.0	55.0	0.051
(Res/Send)	(11743/23836)	(1515/2711)	(1203/2516)	(1195/2649)	(1213/2648)	(1148/2461)	(1192/2377)	(1054/2317)	(1034/2105)	(1086/2048)	(1103/2004)	
Aizu, %	49.7†	50.4†	44.8†	46.3	45.5	49.4	52.8	48.5	52.0	54.6	56.9	< 0.001
(Res/Send)	(9148/18390)	(1043/2071)	(898/2005)	(916/1978)	(944/2077)	(952/1928)	(977/1851)	(867/1787)	(871/1676)	(852/1561)	(828/1456)	
p-value[b]	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	

[a] P-value was calculated using the Extended Mantel Haenszel Chi Square for linear trends.
[b] p-value was calculated using the chi-square test.
† indicates $p < 0.01$, * indicates $p < 0.05$

Table 2. Characteristics of respondents based on the year of delivery

	2011-2020	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	p-value
Maternal age, mean±SD	31.4±5.0	30.7±5.0	31.0±5.0	31.3±5.0	31.4±5.1	31.6±5.0	31.4±5.0	31.6±5.0	31.8±5.0	31.9±5.0	32.1±4.9	<0.001[b]
n	68548	8598	6940	7044	6940	6815	7091	6288	6463	6148	6221	
Single pregnancy, *n* (%)	67930 (99.1)	8517 (99.1)	6877 (99.1)	6967 (98.9)	6868 (99.0)	6757 (99.1)	7031 (99.2)	6240 (99.2)	6404 (99.1)	6098 (99.2)	6171 (99.2)	0.162[a]
Gestational week, mean±SD	38.8±1.7	38.9±1.7	38.9±1.7	38.9±1.7	38.9±1.8	38.8±1.8	38.9±1.7	38.8±1.7	38.8±1.8	38.8±1.7	38.9±1.5	<0.001[b]
n	68414	8566	6926	7015	6930	6801	7086	6286	6453	6136	6215	
Neonatal weight, mean±SD	3003±433	3013±418	2993±435	3004±434	2996±453	2994±445	2999±430	3007±432	3003±438	3000±433	3019±410	0.111[b]
n	68861	8603	6935	7087	6997	6859	7121	6319	6504	6178	6258	
Mode of pregnancy												
Natural pregnancy, *n* (%)	63468 (93.0)	8203 (95.7)	6541 (94.6)	6590 (94.0)	6462 (93.4)	6324 (93.1)	6499 (92.1)	5753 (92.0)	5899 (91.6)	5564 (91.1)	5633 (90.8)	<0.001[a]
Sex of newborn												
male, *n* (%)	34654 (50.8)	4423 (51.4)	3642 (52.5)	3574 (50.4)	3595 (51.3)	3435 (50.1)	3535 (50.3)	3163 (50.7)	3247 (50.8)	3000 (49.7)	3040 (50.4)	0.008[a]
Stillbirth, *n* (%)	161 (0.23)	22 (0.25)	20 (0.29)	24 (0.34)	15 (0.21)	17 (0.25)	15* (0.21)	14* (0.22)	12* (0.18)	13* (0.21)	9* (0.14)	0.032[a]
Mode of delivery												
cesarean delivery, *n* (%)	14692 (21.7)	1745 (20.7)	1446 (21.7)	1409 (20.3)	1440 (21.0)	1511 (22.3)	1489 (21.2)	1364 (21.8)	1452 (22.6)	1441 (23.6)	1395 (22.6)	<0.001[a]

* Not including confirmed abortions and stillbirths or neonates not confirmed to have survived before sending the questionnaires.
[a] *P*-value was calculated using the Extended Mantel Haenszel Chi Square for linear trends.
[b] *p*-value was calculated using the Jonckheere-Terpstra trend test.

Table 3. Incidence of preterm birth in different districts over time

	2011-2020	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	p-value[a]
All of Fukushima, *n* (%)	3573 (5.2)	395 (4.6)	393 (5.6)	373 (5.3)	375 (5.4)	386 (5.6)	380 (5.3)	335 (5.3)	341 (5.2)	319 (5.2)	276 (4.4)	0.466
Kenpoku, *n* (%)	861 (4.8)	91 (4.3)	82 (4.5)*	94 (4.9)	96 (5.2)	105 (5.9)	91 (4.9)	72 (4.4)	89 (5.3)	75 (5.0)	66 (4.0)	0.960
Kenchu, *n* (%)	1042 (5.2)	114 (4.3)	127 (6.2)	95 (4.8)	107 (5.5)	119 (6.2)	103 (5.0)	103 (5.6)	108 (5.4)	81(4.4)	85 (4.6)	0.566
Kennan, *n* (%)	278 (5.2)	28 (4.7)	23 (4.1)	33 (5.7)	25 (4.6)	34 (6.1)	30 (5.3)	27 (5.7)	29 (5.8)	27 (5.4)	22 (4.5)	0.539
Soso, *n* (%)	263 (5.2)	38 (4.3)	31 (6.5)	35 (6.6)	31 (6.1)	30 (5.8)	29 (5.7)	21 (4.8)	9 (2.2)	22 (5.7)	17 (4.6)	0.301
Iwaki, *n* (%)	607 (5.3)	71 (5.1)	65 (5.5)	69 (5.9)	72 (5.9)	46 (4.1)	63 (5.3)	62 (5.9)	56 (5.5)	62 (5.8)	41 (3.8)	0.384
Aizu, *n* (%)	522 (5.8)	53 (5.4)	65 (7.3)*	47 (5.2)	44 (4.7)	52 (5.5)	64 (6.6)	50 (5.8)	50 (5.7)	52 (6.1)	45 (5.4)	0.963
p-value[b]	0.050	0.633	0.020	0.501	0.718	0.215	0.498	0.481	0.111	0.413	0.561	

[a] *P*-value was calculated using the Extended Mantel Haenszel Chi Square for linear trends.
[b] *p*-value was calculated using the chi-square test.
* indicates $p < 0.05$

Table 4. Incidence of infants with low-birth-weight in different districts over time

	2011-2020	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	*p*-value[a]
All of Fukushima, *n* (%)	6295 (9.2)	736 (8.6)	640 (9.3)	680 (9.6)	681 (9.8)	650 (9.5)	658 (9.3)	584 (9.3)	589 (9.1)	567 (9.2)	510 (8.2)	0.277
Kenpoku, *n* (%)	1496 (8.4)†	160 (7.6)	138 (7.6) †	171 (8.9)	168 (9.2)	155 (8.7)	151 (8.1)	155 (9.5)	145 (8.6)	134 (8.9)	119 (7.3)	0.633
Kenchu, *n* (%)	1870 (9.3)	217 (8.3)	208 (10.3)	190 (9.7)	190 (9.7)	208 (10.9)	187 (9.2)	166 (9.0)	180 (9.0)	166 (9.0)	158 (8.6)	0.418
Kennan, *n* (%)	490 (9.2)	47 (8.0)	51 (9.2)	58 (9.9)	49 (9.1)	54 (9.8)	56 (9.9)	38 (8.1)	46 (9.3)	41 (8.2)	50 (10.3)	0.738
Soso, *n* (%)	464 (9.3)	70 (7.9)	43 (9.3)	47 (8.9)	57 (11.3)	56 (10.9)	46 (9.1)	50 (11.3)	34 (8.2)	31 (8.1)	30 (8.1)	0.956
Iwaki, *n* (%)	1090 (9.5)	143(10.3)*	101 (8.6)	120 (10.3)	119 (9.8)	99 (8.7)	117 (10.0)	98 (9.3)	99 (9.7)	106 (9.9)	88 (8.1)	0.344
Aizu, *n* (%)	885 (9.8)*	99 (10.2)	99 (11.3)*	94 (10.4)	98 (10.4)	78 (8.4)	101 (10.4)	77 (8.9)	85 (9.7)	89 (10.4)	65 (7.9)	0.085
p-value[b]	0.002	0.031	0.025	0.763	0.736	0.099	0.364	0.638	0.867	0.599	0.401	

[a] *P*-value was calculated using the Extended Mantel Haenszel Chi Square for linear trends.
[b] *p*-value was calculated using the chi-square test.
† indicates $p < 0.01$, *indicates $p < 0.05$

Table 5. Incidence of anomalies in newborns in different districts over time

	2011-2020	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	*p*-value[a]
All of Fukushima, *n* (%)	1655(2.43)	238 (2.85)	161 (2.35)	170 (2.44)	163 (2.36)	150 (2.21)	176 (2.49)	153 (2.44)	144 (2.23)	164 (2.67)	136 (2.19)	0.142
Kenpoku, *n* (%)	424 (2.41)	55 (2.66)	39 (2.17)	44 (2.32)	54 (2.99)	31 (1.75)	41 (2.22)	40 (2.47)	41 (2.45)	47 (3.12)	32 (1.97)	0.894
Kenchu, *n* (%)	492 (2.48)	78 (3.07)	49 (2.43)	50 (2.60)	49 (2.54)	48 (2.54)	57 (2.81)	34 (1.85)	36 (1.82)	45 (2.45)	46 (2.51)	0.065
Kennan, *n* (%)	133 (2.51)	24 (4.20)	13 (2.39)	9 (1.56)	11 (2.04)	18 (3.26)	12 (2.14)	9 (1.92)	10 (2.01)	14 (2.83)	13 (2.69)	0.392
Soso, *n* (%)	102 (2.06)	18 (2.09)	13 (2.86)	9 (1.75)	9 (1.79)	7 (1.36)	13 (2.60)	8 (1.82)	12 (2.88)	7 (1.82)	6 (1.63)	0.765
Iwaki, *n* (%)	281 (2.47)	38 (2.81)	26 (2.23)	35 (3.04)	22 (1.83)	27 (2.41)	26 (2.24)	33 (3.15)	22 (2.15)	31 (2.92)	21 (1.94)	0.613
Aizu, *n* (%)	223 (2.49)	25 (2.63)	21 (2.40)	23 (2.58)	18 (1.93)	19 (2.04)	27 (2.80)	29 (3.36)	23 (2.67)	20 (2.36)	18 (2.18)	0.898
p-value[b]	0.615	0.268	0.970	0.411	0.261	0.181	0.787	0.099	0.607	0.672	0.752	

[a] *P*-value was calculated using the Extended Mantel Haenszel Chi Square for linear trends.
[b] *p*-value was calculated using the chi-square test.

Table 6. Incidence of major anomalies in newborns over time

	2011-2020	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	p-value*
All anomalies	1655/68007	238/8345	161/6858	170/6954	163/6915	150/6790	176/7064	153/6278	144/6455	164/6133	136/6215	0.142
%	2.43%	2.85%	2.35%	2.44%	2.36%	2.21%	2.49%	2.44%	2.23%	2.67%	2.19%	
Cataract	11	1	2	1	0	0	1	1	2	1	2	0.447
%	0.02%	0.01%	0.03%	0.01%	0.00%	0.00%	0.01%	0.02%	0.03%	0.02%	0.03%	
Cardiac malformation	560	77	54	70	53	53	66	38	60	51	38	0.104
%	0.82%	0.92%	0.79%	1.01%	0.77%	0.78%	0.93%	0.61%	0.93%	0.83%	0.61%	
Kidney/urinary tract malformation	179	22	14	12	24	14	16	25	14	21	17	0.231
%	0.26%	0.26%	0.20%	0.17%	0.35%	0.21%	0.23%	0.40%	0.22%	0.34%	0.27%	
Spina bifida	34	5	5	3	5	4	3	4	3	0	2	0.117
%	0.05%	0.06%	0.07%	0.04%	0.07%	0.06%	0.04%	0.06%	0.05%	0.00%	0.03%	
Microcephaly	4	1	1	0	1	0	0	0	0	1	0	0.327
%	0.01%	0.01%	0.01%	0.00%	0.01%	0.00%	0.00%	0.00%	0.00%	0.02%	0.00%	
Hydrocephalus	19	1	3	4	2	1	2	1	1	3	1	0.689
%	0.03%	0.01%	0.04%	0.06%	0.03%	0.01%	0.03%	0.02%	0.02%	0.05%	0.02%	
Cleft lip/palate	134	17	14	14	14	14	11	8	7	15	20	0.622
%	0.20%	0.20%	0.20%	0.20%	0.20%	0.21%	0.16%	0.13%	0.11%	0.24%	0.32%	
Intestinal atresia	60	6	7	7	9	4	10	7	5	5	0	0.228
%	0.09%	0.07%	0.10%	0.10%	0.13%	0.06%	0.14%	0.11%	0.08%	0.08%	0.00%	
Imperforate anus	28	4	2	2	5	2	2	3	4	1	3	0.966
%	0.04%	0.05%	0.03%	0.03%	0.07%	0.03%	0.03%	0.05%	0.06%	0.02%	0.05%	
Poly/syndactylism	167	22	15	22	14	14	18	16	13	20	13	0.869
%	0.25%	0.26%	0.22%	0.32%	0.20%	0.21%	0.25%	0.25%	0.20%	0.33%	0.21%	
Others	634	104	61	55	63	58	64	59	54	62	54	0.189
%	0.93%	1.25%	0.89%	0.79%	0.91%	0.85%	0.91%	0.94%	0.84%	1.01%	0.87%	

[a] P-value was calculated using the Extended Mantel Haenszel Chi Square for linear trends.

Table 7. Incidence of microcephaly in newborns in different districts over time

	2011-2020	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
All of Fukushima, *n* (%)	4 (0.01)	1 (0.01)	1 (0.01)	0 (0.00)	1 (0.01)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	1 (0.02)	0 (0.00)
Kenpoku, *n* (%)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)
Kenchu, *n* (%)	4 (0.02)	1 (0.04)	1 (0.05)	0 (0.00)	1 (0.05)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	1 (0.05)	0 (0.00)
Kennan, *n* (%)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)
Soso, *n* (%)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)
Iwaki, *n* (%)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)
Aizu, *n* (%)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)

Table 8. Incidence of spina bifida in newborns in different districts over time

	2011-2020	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	*p*-value[a]
All of Fukushima, *n* (%)	34 (0.05)	5 (0.06)	5 (0.07)	3 (0.04)	5 (0.07)	4 (0.06)	3 (0.04)	4 (0.06)	3 (0.05)	0 (0.00)	2 (0.03)	0.189
Kenpoku, *n* (%)	9 (0.05)	2 (0.10)	1 (0.06)	0 (0.00)	3 (0.17)	1 (0.06)	0 (0.00)	1 (0.06)	1 (0.06)	0 (0.00)	0 (0.00)	0.117
Kenchu, *n* (%)	7 (0.04)	2 (0.08)	0 (0.00)	1 (0.05)	1 (0.05)	1 (0.05)	1 (0.05)	0 (0.00)	1 (0.05)	0 (0.00)	0 (0.00)	0.162
Kennan, *n* (%)	2 (0.04)	0 (0.00)	1 (0.18)	0 (0.00)	0 (0.00)	0 (0.00)	1 (0.18)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	0.433
Soso, *n* (%)	3 (0.06)	0 (0.00)	1 (0.22)	1 (0.19)	0 (0.00)	1 (0.19)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	0.293
Iwaki, *n* (%)	6 (0.05)	1 (0.07)	1 (0.09)	0 (0.00)	1 (0.08)	1 (0.09)	0 (0.00)	1 (0.10)	0 (0.00)	0 (0.00)	1 (0.09)	0.632
Aizu, *n* (%)	7 (0.08)	0 (0.00)	1 (0.11)	1 (0.11)	0 (0.00)	0 (0.00)	1 (0.10)	2 (0.23)	1 (0.12)	0 (0.00)	1 (0.12)	0.538
p-value[b]	0.765	0.836	0.543	0.378	0.586	0.752	0.439	0.332	0.867	-	0.462	

[a] *P*-value was calculated using the Extended Mantel Haenszel Chi Square for linear trends.
[b] *p*-value was calculated using the chi-square test.

Table 6 shows changes in the incidence of each anomaly over time. Cardiac malformation was the most common anomaly in Fukushima Prefecture, with an incidence rate of 0.61%-1.01%. No significant changes were observed in the incidence of all anomalies over time.

The onset of microcephaly and spina bifida is thought to be caused by radiation exposure. Tables 7 and 8 show the incidences of microcephaly and spina bifida, respectively, in each district over the study period. In 2011, 2012, 2014, and 2019, sporadic cases of microcephaly in newborns were reported in Kenchu. While 0-5 cases of spina bifida in newborns were observed every year in the Fukushima Prefecture, no chronological or regional fluctuations were observed.

Discussion

Immediately after the nuclear accident, we were concerned that radiation exposure might cause damage, especially to fetuses and newborns. The rates of air-radiation dose in Fukushima Prefecture have decreased significantly since April 2011 and are almost at the same level as those in major cities overseas[10]. However, the basic survey, which is a part of the FHMS, reported individual external gamma-ray doses for residents ; in the first four months after the disaster, the distribution was as follows : 62.0% < 1 mSv, 94.0% < 2 mSv, and 99.4% < 3 mSv[11]. In terms of the affected regions, the radioactive plume from the damaged NPP was carried north by wind and rain toward the prefecture's most populated Kenpoku area[12]. Therefore, external gamma ray doses in the first four months were reported to be highest in the specific Soso area (the evacuation area or deliberate evacuation area), followed by the Kenpoku and Kenchu areas. The average doses for the Soso, Kenpoku, Kenchu, and Iwaki areas were 0.8 mSv, 1.4 mSv, 1.0 mSv, and 0.3m Sv, respectively (Fig. 1) [10]. The average dose for all respondents was 0.8 mSv. The average dose for the Aizu area was the smallest (0.2 mSv) in Fukushima Prefecture owing to its greater distance from the Fukushima Daiichi NPP. Despite regional differences in radiation doses, no significant adverse outcomes or regional differences were observed in pregnancy and birth surveys. Moreover, no differences over the ten-year period were observed across Fukushima P refecture.

The gradual decline in the number of pregnant women (participants) and births observed in this survey is recognized as a recent social phenomenon in Japan. However, the response rate in the present study was approximately 50%. The response rates varied significantly over the years and between regions. While Kenpoku consistently had a relatively higher response rate than the other areas, Soso had a higher response rate only in 2011, perhaps because of the concern that radiation doses are relatively higher in Kenpoku and Soso areas.

Regarding changes in the participants over the study period, natural pregnancy rate decreased and cesarean section rate increased significantly (Table 2). The change in these rates may be related to a significant increase in maternal age, similar to the current situation in Japan.

In the entirety of Fukushima Prefecture, the post-disaster incidences of PTB (4.4-5.6%) (Table 3), LBW (8.2-9.8%) (Table 4), and congenital anomalies (2.19-2.85%) (Table 5) over the decade are similar to the recent averages in Japan. The incidence of stillbirths (over 22 completed gestational weeks) is not comparable to that of epidemiological statistics because, as noted in the Materials and Methods section, questionnaires have not been sent to pregnant women known to have miscarriages or stillbirths since 2016.

Despite the increasing incidence of high-risk pregnancies in Japan owing to advanced maternal age and complicated pregnancies, the incidence of PTB (5.6%, Mother's & Children's Health Organization, 2024)[13] and LBW (9.4%, Mother's & Children's Health Organization, 2024)[14] remained almost stable during the post-disaster period.

The incidence of congenital anomalies in Fukushima Prefecture ranged from 2.19% to 2.85% (mean value of the observation period ; 2.43%), indicating no regional differences over time. It is widely reported that 2-3% of newborns have major congenital abnormalities detectable at birth[15,16]. According to a report from the International Clearinghouse for Birth Defects Surveillance and Research (ICBDSR), Japan Center[17], from 2011 to 2020, the incidence of birth defects was 2.43-3.15% in Japan. The ICBDSR, Japan Center also reported that research findings have not yet shown the more frequent occurrence of a particular anomaly in a particular area. It has also been reported that the prevalence of major congenital anomalies per 10,000 pregnancies, including miscarriages, stillbirths, and live births, at delivery or in 1-month-old infants using data from the JECS was 298.6[18]. Moreover, the JECS found that Fukushima Prefecture was not at high risk for the occurrence of congenital anomalies in infants compared with other geographical regions in Japan from 2011 to 2014[19].

Disasters can potentially influence adverse perinatal outcomes, including maternal mental health[20,21]. Congenital anomalies are associated with several major environmental and technical disasters, including nuclear-reactor accidents at Chernobyl, Ukraine, in 1986 and at Three Mile Island, Pennsylvania, in 1979. Chernobyl involved a much larger radiation leak and affected many more people than Three Mile Island or Fukushima. Reviews of the effects of the Chernobyl disaster indicated increased microcephaly and neural tube defects[22-24]. However, birth defects have not increased in most European countries[25-27]. Although data for most exposed areas are limited, an increase in congenital anomalies in Chernobyl's immediate vicinity has been reported[28].

Based on these previous observations and our findings, we conclude that the Great East Japan Earthquake and the accident at TEPCO's Fukushima Daiichi NPP did not have any significant adverse perinatal outcomes. The participants of this study were pregnant women who received the Maternal and Child Health Handbook. Because pregnant women received their handbooks at approximately 10 weeks of gestation, spontaneous and artificial abortions before that time could not be evaluated. Therefore, we examined and reported on the non-evaluable part of this study to assess the changes in spontaneous and artificial abortions after the disaster in Fukushima Prefecture[7]. According to this report, the spontaneous abortion rate did not show any specific change after the disaster. In contrast, a monthly analysis using the cross-sectional method revealed specific increases in the induced abortion rate during the year after the disaster. In the longitudinal method, induced abortions increased among women who became pregnant within one year after the disaster. Spontaneous abortions showed no specific periodicity, whereas induced abortions showed the cycles of 6 and 12 months, with a particular increase in May of each year. Changes in the induced-abortion rate after the disaster may have overlapped with the timing of the increased periodicity and cannot be attributed solely to the disaster[7].

This survey analyzed each district and did not investigate the relationship between individual radiation-exposure doses. Recently, we reported the individual external-radiation doses that were obtained by a basic survey among residents because the accident at TEPCO's Fukushima Daiichi NPP was not associated with congenital anomalies, LBW, SGA, or preterm birth in 2011[29].

Our study had some major limitations. First, the response rate was approximately 50%, which limits the generalizability of our findings. Second, as this study used self-administered questionnaires, it was assumed that the mothers answered correctly, especially regarding fetal anomalies. Third, although the incidence may be underestimated when using a self-administered questionnaire with variable response rates, we found no significant adverse outcomes based on pregnancy-and-birth surveys over the entire Fukushima Prefecture after the disaster.

In conclusion, the Great East Japan Earthquake and the accident at TEPCO's Fukushima Daiichi NPP does not appear to have caused significant adverse outcomes in Fukushima Prefecture over the decade since the disaster. Our results suggest that women with routine pregnancies in Fukushima received appropriate prenatal care after the disaster. We hope that this report will be widely used as information on how to ensure the safe delivery of babies and raising of children in Fukushima Prefecture.

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Conflict of Interest Disclosure

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