SSM - Population Health 3 (2017) 740–748

Contents lists available at ScienceDirect

SSM - Population Health

journal homepage: www.elsevier.com/locate/ssmph

Article

Environmental radiation level, radiation anxiety, and psychological distress of non-evacuee residents in Fukushima five years after the Great East Japan Earthquake: Multilevel analyses☆

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ARTICLE INFO

Keywords:
Fukushima
Mental health
Radiation anxiety
Nuclear power plant accident
Environmental radiation level
Great East Japan Earthquake

ABSTRACT

The present study aimed to clarify the associations among radiation exposure or psychological exposure to the Fukushima nuclear power plant accident (i.e., fear/anxiety immediately after the accident), current radiation anxiety, and psychological distress among non-evacuee community residents in Fukushima five years after the Great East Japan Earthquake, which occurred in March 2011. A questionnaire survey was administered to a random sample of non-evacuee community residents from 49 municipalities of Fukushima prefecture from February to April 2016, and data from 1684 respondents (34.4%) were analyzed. Environmental radiation levels at the time of the accident were ascertained from survey meter data, while environmental radiation levels at the time of the survey were ascertained from monitoring post data. In the questionnaire, immediate fear/anxiety after the accident, current radiation anxiety, and psychological distress were measured using a single-item question, a 7-item scale, and K6, respectively. Multilevel linear or logistic regression models were applied to analyze the determinants of radiation anxiety and psychological distress. The findings showed that environmental radiation levels at the time of the survey were more strongly associated with radiation anxiety than radiation levels immediately after the accident. Disaster-related experiences, such as direct damage, disaster-related family stress, and fear/anxiety after the accident, and demographic characteristics (e.g., younger age, being married, low socioeconomic status) were significantly associated with radiation anxiety. Environmental radiation levels at the time of the accident or survey were not significantly associated with psychological distress. Radiation anxiety largely mediated the association between fear/anxiety after the accident and psychological distress. In addition to environmental radiation levels, respondents' radiation anxiety was affected by multiple factors, such as disaster-related experiences and demographic characteristics. Radiation levels were not associated with psychological distress in non-evacuee community residents. Rather, fear/anxiety after the nuclear power plant accident may be a determinant of psychological distress, mediated by radiation anxiety.

1. Introduction

The Great East Japan Earthquake and tsunami of March 11, 2011, caused the Fukushima Daiichi Nuclear Power Plant accident. Studies conducted after the previous nuclear power plant accidents at Three Mile Island (TMI) and Chernobyl reported long-term mental health problems among community residents (Bromet, Havenaar & Guey, 2011; Bromet, 2014; Ginzburg, 1993; Havenaar, Rumyantzeva, Kasyanenko, et al., 1997; Havenaar, Rumyantzeva, van den Brink, et al., 1997; Viinamäki et al., 1995), and the perception about the

☆ This work was supported by the Study of the Health Effects of Radiation organized by the Japanese Ministry of the Environment.
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http://dx.doi.org/10.1016/j.ssmph.2017.09.002
Received 19 July 2017; Received in revised form 23 August 2017; Accepted 16 September 2017
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possible health effects of radiation exposure was found to underlie this increased psychological distress (Adams, Guey, Gluzman & Bromet, 2011; Bromet, Gluzman, Schwartz & Goldgaber, 2002; Dew & Bromet, 1993). Also, after the accident in Fukushima, the affected population's mental health problems (Oe, Fujii, et al., 2016; Yabe et al., 2014) and their associations with a perception of possible adverse health effects (Oe, Maeda, et al., 2016; Suzuki et al., 2015) or anxiety about personal radioactive contamination (Niitsu et al., 2014) were reported.

However, to date, the nature of radiation anxiety (i.e., worry and anxiety about the possible adverse health effects of exposure to radiation) and its impact on prolonged psychological distress after a nuclear power plant accident have yet to be disentangled. First, it is not clear what the determinants of radiation anxiety are after a nuclear power plant accident. It is reasonable to assume that high environmental levels of radiation contamination affect the development of radiation anxiety. However, other factors may also play a role. From surveys of evacuees from the Fukushima prefecture, it has been reported that disaster-related experiences, such as house damage, bereavement, and loss of employment, in addition to sociodemographic characteristics, such as female gender, age (both younger and older), low educational attainment (Suzuki et al., 2015), and having a spouse and children (Murakami, Nakatani & Oki, 2016), were associated with a higher risk perception for the health effects of radiation exposure. A study after the TMI accident also reported that women, younger people, and people living near the plant perceived a greater threat to their health from radiation exposure (Dohrenwend et al., 1981). Thus, cognition and perception of the harmful effects of radiation on their health may also be affected by sociodemographic, disaster-related, and social support factors. However, these studies did not adjust for environmental levels of radiation exposure.

Second, only a small number of studies examined the association between environmental levels of radiation exposure and the mental health of community residents, and the findings of those are inconsistent. In the 20 years since the Chernobyl disaster, Beehler et al. (2008) found no association between the level of caesium-137 ground contamination at the time of the survey and residents' depression and anxiety. On the other hand, Lehmann and Wadsworth (2011) did report an association between area-level dose of caesium-137 at the time of the accident and poor self-reported health at 20 years after the accident. Among evacuee residents in the Fukushima prefecture, Kunii et al. (2016) found an ecological association between area-based environmental radiation levels at the time of the survey and the proportion of residents with high psychological distress. Thus, the mediating role of radiation anxiety over the association between environmental radiation levels and poor mental health is not clear.

The aims of the present study were two-fold. First, it aimed to investigate the association of environmental radiation exposure at the time of the accident and at the time of the survey and the demographic and disaster-related variables with radiation anxiety of community non-evacuee residents of Fukushima prefecture. Second, it aimed to investigate the association of environmental radiation exposure at the time of the accident and at the time of the survey and radiation anxiety with psychological distress, controlling for demographic and disaster-related variables. Our particular interest was to clarify the link among (1) environmental radiation exposure or psychological exposure to the nuclear power plant accident (i.e., fear/anxiety immediately after the accident), (2) radiation anxiety as a mediator, and (3) psychological distress.

2. Methods

2.1. Study design and study population

In the present study, the target communities comprised 49 of the total 59 municipalities of the Fukushima prefecture, excluding restricted areas close to the nuclear power plant as designated by the Japanese government at the time of the survey. In each municipality, we randomly sampled 100 residents aged 20 to 80 years old, with double weighting for residents aged 20 to 39 years old; thus, we yielded a total of 4900 initial subjects, to whom we administered a cross-sectional questionnaire survey from February to April 2016.

2.2. Study variables

2.2.1. Psychological distress

Psychological distress was assessed using the K6 (Japanese version), a 6-item self-administered screening instrument of non-specific psychological distress over the past 30 days (Furukawa et al., 2008; Kessler et al., 2002). Items are rated on a 5-point Likert scale from 0 (none) to 4 (all the time), with a summary score ranging from 0 to 24. When individuals answered at least three items, we calculated their total scores by supplementing missing scores with the mean of the other items. We decided persons scoring 5 or more exhibited psychological distress, based on the study reporting the score of 5 as the optimal cutoff point for the Japanese version of K6 to maximize the sum of sensitivity and specificity (Sakurai, Nishi, Kondo, Yanagida & Kawakami, 2011). This was also based on previous studies of community residents conducted after the Great East Japan Earthquake using the score of 5 or more in K6 to identify cases with psychological distress (Horikoshi, Iwasa, Kawakami, Suzuki & Yasumura, 2016; Niitsu et al., 2014).

2.2.2. Radiation anxiety

We defined "radiation anxiety" as negative cognition and perception, such as worry and anxiety, of the possible adverse health effects of radiation exposure, and related psychosocial problems, such as perceived stigma and discrimination due to radiation exposure. Radiation anxiety was assessed using the 7-item Radiation Anxiety Scale developed by Umeda et al. (Kawakami, 2013; Umeda et al., 2014). The items were selected from a qualitative analysis of descriptions of worry, anxiety, and problems related to radiation exposure from community evacuee residents in the Fukushima prefecture. The scale consists of (1) I am concerned about getting a serious illness in the future due to the effects of radiation; (2) Every time I feel ill, I am afraid this is caused by radiation exposure; (3) I am concerned that radiation effects can be inherited by the next generation such as children and grandchildren; (4) I feel strong anxiety when I see news reports concerning the nuclear power plant accident; (5) I have had the experience of being discriminated against (or unfairly treated) because I lived in the area that is reported to have high levels of radiation; (6) I try not to tell others that I am a resident of that area as far as possible; and (7) I have experienced conflicts and trouble with my family members over the radiation health effects. The items were rated on a 4-point Likert scale from 1 (do not agree at all) to 4 (strongly agree), and the item scores were added together to obtain the total scale score, ranging from 7 to 28, with a higher score indicating a higher level of radiation anxiety. The Cronbach's alpha coefficient of the scale has been reported as 0.81 (Kawakami, 2013; Umeda et al., 2014), and in the present study sample it was 0.85. When individuals answered at least four items, we calculated their total scores by supplementing their missing scores with the mean of the other items.

2.2.3. Demographic characteristics

The demographic characteristics included in this study were sex, age, educational attainment, household income, household size, marital status, living arrangement, working status, and comorbid chronic conditions (chronic physical disease and mental illness under treatment). To adjust household income by household size, we divided overall household income in the previous year by the square root of the number of household members (Ichida et al., 2009) and generated three categories.

2.2.4. Disaster-related experiences

We examined two dimensions of disaster damage experienced by individuals: direct damage and disaster-related family stress. Regarding direct damage, we asked about four experiences (1. Harm of oneself, 2. Harm or death of family members, 3. Loss of job or temporary absence from work, and 4. Loss of house or property), and regarding family stress, we asked about two experiences (1. Deterioration of family relationships, and 2. Family separation). When the individuals had experienced at least one of each category, we designated them as having experience of direct damage or disaster-related family stress.

We also asked them to rate their degree of fear/anxiety immediately after the nuclear power plant accident from 1 (none) to 5 (extremely).

2.2.5. Social network

As an indicator of individual social network, we used the total score of the Japanese version of the abbreviated Lubben Social Network Scale (LSNS-6) (Kurimoto et al., 2011). LSNS-6 consists of six items asking the number of members in family and non-family networks. Items are rated on a 6-point Likert scale from 0 to 5, with a summary score ranging from 0 to 30. A higher score indicates a broader network. We also asked about membership in associations or groups, presenting 13 types of associations, such as neighborhood community association, hobby group, industry organization, and religious group. If respondents were members of at least one of those, we designated them as belonging to some groups or organizations.

2.2.6. Environmental radiation levels

In each municipality, we calculated the average environmental air dose rate of radiation (μSv/h) measured one meter above ground at the time of the survey and soon after the Great East Japan Earthquake using the data obtained from the information-disclosure site of Japan Atomic Energy Agency. To calculate the air dose rates at the time of the survey, we used the measurement results of air dose rates (daily average) nationwide and in the Fukushima prefecture from May 1, 2015 to April 30, 2016, measured by the monitoring post and real-time dosimeter (http://emdb.jaea.go.jp/emdb/portals/b139/). In calculating the air dose rate soon after the earthquake, since we were unable to obtain the same data used in calculating the current air dose rate, we used the data of the Fukushima prefecture environmental radiation monitoring-mesh investigations (http://emdb.jaea.go.jp/emdb/portals/b122/) measured by the survey meter (ambient dose equivalent rate). We used the data obtained in the first survey conducted from April 12–16, 2011. We used all the data reported at all measuring points in each municipality.

2.3. Statistical analysis

First, we calculated descriptive statistics for individual characteristics of the study population and municipality radiation levels. We then examined the relationships between individual-level independent variables and outcomes. For psychological distress, we used chi-square tests or t-tests to compare subjects who scored ≥ 5 versus < 5 on the K6. For radiation anxiety, we examined the relationships between the total score on the Radiation Anxiety Scale and independent variables using t-tests, analysis of variance, or Pearson's correlation coefficients.

Next, because our data had a hierarchical structure, with individuals nested within municipalities, we developed two-level multivariate multilevel regression models for each outcome. For radiation anxiety, we used a multivariate multilevel linear regression model, and for psychological distress, we used a multivariate multilevel logistic regression model. In the multivariate multilevel logistic regression model, we calculated the median odds ratio (MOR) instead of intra-class correlation (ICC) to quantify the variation between clusters, which can be directly compared with fixed-effects odds ratios (Larsen & Merlo, 2005; Merlo et al., 2006). In the analytical process, we added independent variables sequentially. First, we used the model with only the random intercept to assess whether there was a significant variation in radiation anxiety or psychological distress across municipalities and to reveal its size (Model 1). Then, in Model 2, we added individual-level independent variables. In Model 3, we added environmental radiation levels, with all the individual-level independent variables controlled. Because environmental radiation levels at the time of the survey and soon after the earthquake were highly correlated (Pearson's r = 0.9082), we added them separately and made Model 3A and 3B. As for psychological distress, we made Model 4A and 4B by adding radiation anxiety to Model 3A and 3B.

All statistical analyses were performed using Stata 13.0 for Windows (StataCorp LP, College Station, TX). Statistical significance was set at .05 and all tests were two-tailed.

3. Results

3.1. Sample characteristics

Among the 4900 initial subjects, valid responses were obtained from 2038 people from 49 municipalities (response rate: 41.6%), from which we ultimately used the 1684 (34.4%) who did not have missing information on any of the study variables. Table 1 displays descriptive statistics of the individual characteristics of the study population. The proportion of respondents who scored 5 or above in K6 was 29.2%, and the average score for radiation anxiety was 14.9 (standard deviation 4.4). Regarding municipality radiation levels, among the 49 municipalities surveyed, the average air dose rates at the time of the survey ranged from 0.0456 μSv/h to 0.1931 μSv/h, with mean 0.1003 μSv/h and median 0.0883 μSv/h. The average air dose rates soon after the Great East Japan Earthquake ranged from 0.0972 μSv/h to 2.0280 μSv/h, with mean 0.5617 μSv/h and median 0.3216 μSv/h.

Table 1 also compares the demographic, disaster-related, and social network characteristics, and radiation anxiety between groups with high and low psychological distress. The high distress group tended to comprise women, younger people, and those receiving treatment for mental illness. On the other hand, this group was less likely to be married, had a smaller number of family members in their household, had a smaller social network of family or friends, did not belong to groups or organizations, and did not live in their own house. Furthermore, the high distress group was more likely to have experienced direct damage and disaster-related family stress, to have felt fear or anxiety immediately after the nuclear power plant accident, and to have greater radiation anxiety.

Table 1 also reports the relationships between these individual characteristics and the level of radiation anxiety. Higher radiation anxiety was observed in the middle-aged and in people with a lower educational level, a lower income level adjusted by household size, and in those with mental illness. In contrast to the relationship with psychological distress, being married and having more family members in a household were related to higher radiation anxiety. Regarding disaster-related experiences, people who had experienced direct damage, disaster-related family stress, or had felt fear or anxiety immediately after the nuclear power plant accident showed higher radiation anxiety.

3.2. Determinants of radiation anxiety

The results of the multivariate multilevel linear regression analysis of radiation anxiety are shown in Table 2. There was significant variability in the level of radiation anxiety across municipalities as shown in Model 1. When individual-level characteristics were added, 56% of the municipality-level variance was explained (Model 2). With all the individual-level variables controlled, the air dose rate of radiation at the time of the survey explained another 33% of the municipality-level variance, and the rate soon after the earthquake explained another 24% (Model 3). Both were significantly related to individual radiation anxiety. Among the individual-level predictors, being young or middle-aged, having a lower educational level or lower household

Table 1
Demographic, disaster-related, and social network characteristics of the total sample and their relationships with psychological distress and radiation anxiety. (n = 1684).

			Psychological distress (K6 score)							Radiation anxiety				
	Total		Low (less than 5)		High (5 or above)									
	n	% / SD	n	% / SD	n	% / SD	chi2 / t	df	p	mean / r	SD	t / F	df	p
Sex														
Men	796	47.3	587	49.2	209	42.5	6.4	1	0.011	14.8	4.6	-0.8	1682	0.403
Women	888	52.7	605	50.8	283	57.5				15.0	4.3			
Age, years														
20–39	757	45.0	514	43.1	243	49.4	13.0	2	0.001	14.8	4.5	7.3	2, 1681	0.001
40–64	564	33.5	394	33.1	170	34.6				15.5	4.4			
65+	363	21.6	284	23.8	79	16.1				14.4	4.2			
Educational attainment														
Junior high school	199	11.8	150	12.6	49	10.0	3.4	3	0.337	15.3	4.5	3.5	3, 1680	0.015
High school	839	49.8	581	48.7	258	52.4				15.1	4.5			
Junior or technical college	377	22.4	266	22.3	111	22.6				15.0	4.4			
University or graduate school	269	16.0	195	16.4	74	22.6				14.1	4.2			
Household income last year (million yen)														
< 2.5	397	23.6	262	22.0	135	27.4	7.1	4	0.128	15.0	4.6	1.4	4, 1679	0.237
2.5 – 5.0	669	39.7	476	39.9	193	39.2				15.1	4.3			
5.0 – 7.5	365	21.7	269	22.6	96	19.5				14.9	4.5			
7.5 – 10.0	151	9.0	113	9.5	38	7.7				14.6	4.5			
≥ 10.0	102	6.1	72	6.0	30	6.1				14.1	3.9			
Level of household income adjusted by household size [a]														
Low	677	40.2	465	39.0	212	43.1	2.4	1	0.294	15.2	4.4	5.7	2, 1681	0.004
Middle	780	46.3	562	47.2	218	44.3				14.9	4.5			
High	227	13.5	165	13.8	62	12.6				14.1	4.1			
Marital status														
Married	1054	62.6	781	65.5	273	55.5	15.0	1	< 0.001	15.3	4.4	-4.1	1682	< 0.001
Separated, divorced, bereaved, unmarried, or unknown	630	37.4	411	34.5	219	44.5				14.4	4.4			
No. of family members in a household														
1 (oneself)	187	11.1	121	10.2	66	13.4	13.1	5	0.023	14.3	4.4	1.5	5, 1678	0.187
2	374	22.2	272	22.8	102	20.7				14.8	4.2			
3	355	21.1	238	20.0	117	23.8				14.9	4.5			
4	326	19.4	227	19.0	99	20.1				15.0	4.2			
5	209	12.4	152	12.8	57	11.6				15.2	4.8			
6 or more	233	13.8	182	15.3	51	10.4				15.3	4.6			
Mean / SD (range: 1–6)	3.4	1.6	3.5	1.6	3.3	1.5	2.4	1682	0.015	0.062				0.011
Living arrangement														
One's own house	1385	82.2	1007	84.5	378	76.8	14.0	1	< 0.001	14.9	4.4	-0.1	1682	0.913
Other [b]	299	17.8	185	15.5	114	23.2				14.9	4.5			
Working status														
Working (employed, self-employed, or part-time)	1248	74.1	890	74.7	358	72.8	0.7	1	0.418	15.0	4.4	-0.8	1682	0.440
Not working [c]	436	25.9	302	25.3	134	27.2				14.8	4.4			
Comorbid conditions (ref. none)														
Have a chronic disease under treatment	383	22.7	274	23.0	109	22.2	0.1	1	0.711	14.8	4.3	0.6	1682	0.545
Have a mental illness under treatment	70	4.2	17	1.4	53	10.8	76.4	1	< 0.001	16.5	5.1	-3.0	1682	0.003
Disaster-related experiences (ref. none)														
Direct damage [d]	527	31.3	328	27.5	199	40.5	27.1	1	< 0.001	16.3	4.5	-9.1	1682	< 0.001
Disaster-related family stress	139	8.3	72	6.0	67	13.6	26.4	1	< 0.001	18.0	4.3	-8.7	1682	< 0.001
Fear or anxiety immediately after the NPP[e] accident														
Mean / SD (score range: 1–5)	3.8	1.1	3.7	1.1	4.0	1.1	-4.5	1682	< 0.001	0.442				< 0.001
Social network														
Family and friends (LSNS-6 [f]) (score range: 0–30)	14.6	6.1	15.6	5.9	12.3	5.8	10.4	1682	< 0.001	-0.023				0.342
Belong to some groups or organizations (ref. no)	1212	72.0	901	75.6	311	63.2	26.4	1	< 0.001	15.0	4.4	-1.8	1682	0.069
Radiation anxiety (score range: 7–28)	14.9	4.4	14.3	4.3	16.5	4.4	-9.8	1682	< 0.001					

SD: standard deviation; df: degree of freedom; ref.: reference.

[a] Category of low includes household income < 2.5 if headcount in a household was three or less and < 5.0 if headcount in a household was four or more. Category of middle includes household income 2.5–5.0 if headcount in a household was one or two, 2.5–7.5 if three, and 5.0–10.0 if four or more. Category of high includes household income > 5.0 if headcount in a household was one or two, > 7.5 if three, and > 10.0 if four or more.

[b] Rented house, temporary house, disaster restoration house, or acquaintance's or relative's house.

[c] Leave of absence, student, full-time housewife, or seeking employment.

[d] Correspond to any of the following: 1. Harm of oneself, 2. Harm or death of family members, 3. Loss of job or temporary absence from work, or 4. Loss of house or property.

[e] Nuclear Power Plant.

[f] Lubben Social Network Scale -6.

Table 2
The association between individual- and community-level characteristics and radiation anxiety applying multilevel linear regression analysis adjusting for area-level radiation levels. (n = 1684).

Dependent variable: Radiation Anxiety	Model 1 (null model)			Model 2			Model 3A			Model 3B		
	Coef.	SE		Coef.	SE	p	Coef.	SE	p	Coef.	SE	p
Intercept	14.97	0.21		6.53	0.65		5.16	0.74		6.01	0.67	
Compositional effect												
Sex (ref. men)				-0.38	0.19	0.053	-0.37	0.19	0.056	-0.37	0.19	0.054
Age (ref. 65+)												
20–39 years old				0.70	0.33	0.036	0.69	0.33	0.039	0.70	0.33	0.036
40–64 years old				0.84	0.30	0.005	0.86	0.30	0.004	0.86	0.30	0.004
Educational attainment (ref. University or graduate school)												
Junior high school				1.30	0.39	0.001	1.34	0.39	0.001	1.33	0.39	0.001
High school				0.73	0.27	0.007	0.75	0.27	0.006	0.74	0.27	0.006
Junior or technical college				0.60	0.31	0.056	0.61	0.31	0.050	0.61	0.31	0.050
Level of household income adjusted by household size (ref. High) [a]												
Low				0.98	0.31	0.001	0.98	0.31	0.001	0.98	0.31	0.001
Middle				0.72	0.29	0.012	0.72	0.29	0.012	0.72	0.29	0.012
Marital status (ref. Separated, divorced, bereaved, unmarried, or unknown)												
Married				0.46	0.21	0.032	0.47	0.21	0.029	0.47	0.21	0.027
No. of family members in a household				0.09	0.07	0.182	0.09	0.07	0.156	0.09	0.07	0.168
Living arrangement (ref. Other[b])												
One's own house				-0.07	0.26	0.782	-0.06	0.26	0.824	-0.06	0.26	0.832
Working status (ref. Not working[c])												
Working (employed, self-employed, or part-time)				0.00	0.23	0.998	0.01	0.23	0.973	0.00	0.23	0.993
Comorbid conditions (ref. none)												
Have a chronic disease under treatment				-0.16	0.26	0.541	-0.14	0.26	0.583	-0.14	0.26	0.586
Have a mental illness under treatment				1.10	0.47	0.020	1.08	0.47	0.021	1.10	0.47	0.019
Disaster-related experiences (ref. none)												
Direct damage [d]				0.96	0.21	< 0.001	0.89	0.21	< 0.001	0.91	0.21	< 0.001
Disaster-related family stress				2.02	0.35	< 0.001	1.96	0.35	< 0.001	1.96	0.35	< 0.001
Fear or anxiety immediately after the NPP[e] accident				1.56	0.09	< 0.001	1.55	0.09	< 0.001	1.56	0.09	< 0.001
Social network												
Family and friends (LSNS-6 [f])				-0.03	0.02	0.063	-0.03	0.02	0.076	-0.03	0.02	0.073
Belong to some groups or organizations (ref. no)				0.27	0.22	0.236	0.27	0.22	0.220	0.27	0.22	0.235
Contextual effect												
Air dose rate of radiation at the time of the survey							13.24	3.70	< 0.001			
Air dose rate of radiation soon after the Great East Japan Earthquake										0.86	0.30	0.004
Random parameters												
Community level variance / Standard Error / p-value[g]	1.53	0.41	< 0.001	0.67	0.22	0.002	0.45	0.18	0.010	0.51	0.19	0.007
Individual level variance / Standard Error	18.04	0.63		13.81	0.48		13.81	0.48		13.81	0.48	
Intra-class correlation: ICC	0.08			0.05			0.03			0.04		
Proportional changes in community level variance: PCV (compared to null model)				0.56			0.71			0.66		
Proportional changes in community level variance: PCV (compared to Model 2)							0.33			0.24		

Coef.: coefficient; SE: standard error; ref.: reference.

[a] Category of low includes household income < 2.5 if headcount in a household was three or less and < 5.0 if headcount in a household was four or more. Category of middle includes household income 2.5–5.0 if headcount in a household was one or two, 2.5–7.5 if three, and 5.0–10.0 if four or more. Category of high includes household income > 5.0 if headcount in a household was one or two, > 7.5 if three, and > 10.0 if four or more.

[b] Rented house, temporary house, disaster restoration house, or acquaintance's or relative's house.

[c] Leave of absence, student, full-time housewife, or seeking employment.

[d] Correspond to any of the following: 1. Harm of oneself, 2. Harm or death of family members, 3. Loss of job or temporary absence from work, or 4. Loss of house or property.

[e] Nuclear Power Plant.

[f] Lubben Social Network Scale -6.

[g] Calculated using Wald test.

income, being married, having mental illness, suffering direct damage from the earthquake, experiencing disaster-related family stress, and experiencing fear or anxiety immediately after the nuclear power plant accident were significantly associated with higher radiation anxiety.

3.3. Determinants of psychological distress

Table 3 presents the results of a multilevel logistic regression analysis of psychological distress. There was a significant but relatively small variability in the proportion of people with psychological distress across municipalities as shown in Model 1. When individual-level characteristics were added, 69% of the municipality-level variance was explained and the variance was no longer significant (Model 2). With all the individual-level variables controlled, we added air dose rate of radiations in Model 3. The air dose rate of radiation at the time of the survey explained another 10% of the municipality-level variance, and the rate soon after the earthquake explained another 4%. Neither of these was significantly related to individual psychological distress. Among the individual-level predictors, female gender, having a mental illness, suffering direct damage from the earthquake, experiencing disaster-related family stress, and experiencing fear or anxiety immediately after the nuclear power plant accident were significantly associated with psychological distress. On the other hand, having a broader social network of family and friends was a significant protector for psychological distress. We then added radiation anxiety to Model 3. As a result, the significant associations of experiencing disaster-related family stress and fear or anxiety immediately after the accident with psychological distress disappeared, and being married and belonging to

Table 3
The association between individual- and community-level characteristics and psychological distress applying multilevel logistic regression analysis adjusting for area-level radiation levels. (n = 1684).

Dependent variable: Psychological distress	Model 1 (null model)			Model 2				Model 3A				Model 3B				Model 4A				Model 4B			
	OR	95%CI		OR	95%CI		p	OR	95%CI		p	OR	95%CI		p	OR	95%CI		p	OR	95%CI		p
Intercept	0.41	0.35	0.47	0.46	0.21	1.02		0.38	0.16	0.92		0.43	0.19	0.98		0.22	0.09	0.54		0.23	0.10	0.53	
Compositional effect																							
Sex (ref. men)				1.28	1.00	1.63	0.052	1.28	1.00	1.63	0.050	1.28	1.00	1.63	0.051	1.36	1.06	1.74	0.016	1.36	1.06	1.74	0.017
Age (ref. 65+)																							
20–39 years old				1.43	0.93	2.20	0.102	1.42	0.92	2.18	0.110	1.43	0.93	2.19	0.106	1.32	0.85	2.05	0.210	1.33	0.86	2.05	0.207
40–64 years old				1.33	0.90	1.96	0.148	1.33	0.91	1.96	0.144	1.33	0.91	1.96	0.144	1.23	0.83	1.82	0.307	1.23	0.83	1.82	0.310
Educational attainment (ref. University or graduate school)																							
Junior high school				0.99	0.60	1.64	0.979	1.00	0.60	1.65	0.999	1.00	0.60	1.65	0.988	0.86	0.51	1.44	0.562	0.86	0.51	1.43	0.556
High school				1.24	0.88	1.74	0.226	1.24	0.88	1.75	0.219	1.24	0.88	1.75	0.223	1.14	0.81	1.62	0.451	1.14	0.81	1.62	0.454
Junior or technical college				1.13	0.76	1.66	0.545	1.13	0.77	1.67	0.540	1.13	0.77	1.67	0.540	1.05	0.71	1.56	0.806	1.05	0.71	1.56	0.808
Level of household income adjusted by household size (ref. High) [a]																							
Low				0.91	0.62	1.34	0.648	0.92	0.63	1.35	0.672	0.92	0.63	1.35	0.663	0.82	0.56	1.22	0.333	0.82	0.56	1.22	0.328
Middle				0.93	0.65	1.34	0.714	0.94	0.65	1.34	0.720	0.94	0.65	1.34	0.717	0.85	0.59	1.23	0.379	0.85	0.59	1.22	0.377
Marital status (ref. Separated, divorced, bereaved, unmarried, or unknown)																							
Married				0.81	0.62	1.05	0.112	0.81	0.62	1.05	0.114	0.81	0.62	1.05	0.116	0.76	0.58	0.99	0.045	0.76	0.58	0.99	0.045
No. of family members in a household				0.99	0.91	1.07	0.767	0.99	0.91	1.07	0.785	0.99	0.91	1.07	0.774	0.97	0.90	1.06	0.543	0.97	0.90	1.06	0.539
Living arrangement (ref. Other[b])																							
One's own house				0.76	0.56	1.04	0.084	0.76	0.56	1.04	0.085	0.76	0.56	1.04	0.087	0.76	0.55	1.04	0.091	0.76	0.55	1.04	0.091
Working status (ref. Not working[c])																							
Working (employed, self-employed, or part-time)				0.93	0.70	1.23	0.607	0.93	0.70	1.23	0.620	0.93	0.70	1.23	0.607	0.93	0.70	1.24	0.608	0.93	0.70	1.23	0.605
Comorbid conditions (ref. none)																							
Have a chronic disease under treatment				1.20	0.86	1.66	0.282	1.20	0.86	1.66	0.281	1.20	0.86	1.66	0.280	1.23	0.88	1.72	0.215	1.23	0.89	1.72	0.215
Have a mental illness under treatment				5.95	3.25	10.92	< 0.001	5.96	3.25	10.94	< 0.001	5.98	3.26	10.97	< 0.001	5.70	3.08	10.58	< 0.001	5.70	3.07	10.57	< 0.001
Disaster-related experiences (ref. none)																							
Direct damage [d]				1.66	1.30	2.13	< 0.001	1.62	1.26	2.09	< 0.001	1.64	1.27	2.11	< 0.001	1.48	1.14	1.91	0.003	1.49	1.15	1.92	0.003
Disaster-related family stress				1.69	1.14	2.52	0.009	1.66	1.12	2.48	0.012	1.67	1.12	2.49	0.012	1.33	0.89	2.01	0.167	1.34	0.89	2.02	0.163
Fear or anxiety immediately after the NPP[e] accident				1.29	1.15	1.44	< 0.001	1.28	1.15	1.43	< 0.001	1.29	1.15	1.44	< 0.001	1.08	0.95	1.22	0.221	1.08	0.95	1.22	0.221
Social network																							
Family and friends (LSNS-6 [f])				0.91	0.89	0.93	< 0.001	0.91	0.90	0.93	< 0.001	0.91	0.90	0.93	< 0.001	0.92	0.90	0.94	< 0.001	0.92	0.90	0.93	< 0.001
Belong to some groups or organizations (ref. no)				0.78	0.60	1.02	0.071	0.78	0.60	1.02	0.074	0.78	0.60	1.02	0.071	0.75	0.57	0.99	0.041	0.75	0.57	0.99	0.040
Radiation anxiety																1.12	1.08	1.15	< 0.001	1.12	1.08	1.15	< 0.001
Contextual effect																							
Air dose rate of radiation at the time of the survey								5.99	0.17	205.07	0.321					1.66	0.04	62.47	0.783				
Air dose rate of radiation soon after the Great East Japan Earthquake												1.10	0.83	1.45	0.506					1.01	0.76	1.33	0.967
Random parameters																							
Community level variance / Standard Error / p-value[g]	0.13	0.06	0.023	0.04	0.04		0.363	0.04	0.04		0.404	0.04	0.04		0.379	0.04	0.04		0.396	0.04	0.04		0.392
Proportional changes in community level variance: PCV (compared to null model)				0.69				0.72				0.70				0.70				0.70			

(*continued on next page*)

Table 3 (*continued*)

Dependent variable: Psychological distress	Model 1 (null model)		Model 2			Model 3A			Model 3B			Model 4A			Model 4B		
	OR	95%CI	OR	95%CI	p	OR	95%CI	p	OR	95%CI	p	OR	95%CI	p	OR	95%CI	p
Proportional changes in community level variance: PCV (compared to Model 2)						0.10			0.04			0.05			0.04		
Median odds ratio: MOR	1.40		1.21			1.20			1.20			1.20			1.20		

OR: odds ratio; CI: confidence interval; ref.: reference

[a] Category of low includes household income < 2.5 if headcount in a household was three or less and < 5.0 if headcount in a household was four or more. Category of middle includes household income 2.5–5.0 if headcount in a household was one or two, 2.5–7.5 if three, and 5.0–10.0 if four or more. Category of high includes household income > 5.0 if headcount in a household was one or two, > 7.5 if three, and > 10.0 if four or more.

[b] Rented house, temporary house, disaster restoration house, or acquaintance's or relative's house.

[c] Leave of absence, student, full-time housewife, or seeking employment.

[d] Correspond to any of the following: 1. Harm of oneself, 2. Harm or death of family members, 3. Loss of job or temporary absence from work, or 4. Loss of house or property.

[e] Nuclear Power Plant.

[f] Lubben Social Network Scale -6.

[g] Calculated using Wald test.

groups or organizations became significant protective factors. Radiation anxiety was significantly associated with psychological distress (Model 4).

4. Discussion

While both the environmental radiation levels at the time of the accident and at the time of the survey significantly accounted for the radiation anxiety of participants, the environmental radiation level at the time of the survey showed a greater association. After adjusting for the environmental radiation level, younger age (compared to aged 65+), lower educational attainment (compared to university or higher), low or middle household income (compared to high income), being married, having a mental disorder, experiencing disaster-related damage and family problems, and fear or anxiety immediately after the accident were significantly associated with radiation anxiety. Radiation anxiety was significantly associated with residents' psychological distress, while the environmental radiation level at the time of the accident or survey was not. Adding radiation anxiety to the model substantially decreased the association between disaster-related family problems and fear or anxiety immediately after the accident and psychological distress, indicating that radiation anxiety plays a mediating role in these associations.

While both the environmental radiation levels immediately after the nuclear power plant accident and at the time of the survey were significantly correlated with respondents' radiation anxiety, environmental radiation levels at the time of the survey were more strongly associated. The present study was conducted almost five years after the accident, and the environmental radiation levels in the air had decreased, with the mean air dose rates at the time of the survey between 0.0456 and 0.1931 μSv/h. However, community residents in Fukushima still seem sensitive to variations in these low levels of environmental radiation exposure. These residents, once psychologically sensitized to radiation exposure, may monitor small changes in radiation exposure from day to day. In addition to providing scientific knowledge that these low levels of radiation do not cause health effects and continuing to monitor their health, it may be important to control environmental radiation exposure through continuous decontamination efforts or to train residents to avoid radiation exposure even when that exposure decreases, or even becomes minimal.

Disaster-related experiences, that is, direct damage, disaster-related family stress, and fear or anxiety immediately after the nuclear power plant accident, were still significantly associated with radiation anxiety, after adjusting for environmental radiation level. In a previous study, fear or anxiety immediately after the nuclear power plant accident predicted psychological distress over the following 10 years (Dew & Bromet, 1993). A traumatic experience with fear and anxiety due to the nuclear power plant accident may change the perception and cognition of community residents, making them more sensitive to the possible health effects of radiation exposure; this may remain in place for many years as a basis for prolonged radiation anxiety. A previous study from a survey of evacuees in the Fukushima prefecture also reported that disaster-related experiences, such as house damage and bereavement, were associated with perception of health effects of exposure to radiation (Suzuki et al., 2015). Direct disaster damage due to the earthquake, such as injury or house damage, may also increase fear and anxiety over this traumatic experience, although these are not exclusively related to the nuclear power plant accident. These findings might suggest that part of radiation anxiety after a nuclear power plant accident stems from a traumatic experience in reaction to that accident. This hypothesis should be examined further in future research. As for disaster-related family stress, our radiation anxiety scale included an item on the experience of conflicts and trouble within the family in relation to radiation health effects. Thus, the observed association may be artificial.

Respondents who were married and had lower educational

attainment and lower household income reported greater radiation anxiety, consistent with previous findings (Murakami et al., 2016; Suzuki et al., 2015). Married community residents may be concerned not only about themselves, but also about their families. People with lower educational attainment and lower income may have limited ability to access the relevant information or assess the possible health effects of a given radiation exposure. In the present study, older respondents reported less radiation anxiety. A previous study among evacuees of Fukushima reported that older age was positively associated with concerns about immediate effect and genetic effect, but inversely associated with delayed health effect (Suzuki et al., 2015). The effect of age on radiation anxiety may depend on the type of concerns and context. The present study also found that receiving treatment for a mental illness was associated with radiation anxiety. This may be attributable to possible cognitive impairment or increased vigilance associated with mental disorders. These groups may be considered high-risk groups for radiation anxiety that require special attention in risk communication and information dissemination on radiation and health.

Environmental radiation levels were not significantly associated with respondents' psychological distress. This finding was unexpected, and inconsistent with a previous report conducted 20 years after the Chernobyl disaster (Lehmann & Wadsworth, 2011) and an ecological study of evacuees in Fukushima (Kunii et al., 2016). However, it is in line with another previous study from the Chernobyl disaster (Beehler et al., 2008), which also reported a null association. A possible reason for the observed non-significant association is that, in the present study, radiation levels were lower (almost < 2 μSv/h at the time of the accident, and < 0.2 μSv/h at the time of the survey) at the survey sites. These levels of environmental radiation exposure may not affect the psychological distress of community residents. The other possible reason is that potential confounders, such as socioeconomic status and disaster-related experiences, were not fully adjusted for in previous studies. Radiation anxiety was strongly associated with psychological distress, but it did not mediate the association between environmental radiation levels and psychological distress. Rather, radiation anxiety seems to mediate the association between fear/anxiety immediately after the accident and psychological distress. The findings further support a traumatic experience hypothesis in relation to development of radiation anxiety, suggesting that the psychopathology associated with excessive radiation anxiety stems from a traumatic experience of fear/anxiety immediately after the accident. This would contribute to understanding the nature of radiation anxiety after a nuclear power plant accident. Our analysis also indicated that radiation anxiety explains part of the association between disaster-related family stress and psychological distress. However, this might be because the question on family relationships and some items of the radiation anxiety scale were redundant.

The findings are tempered by several methodological limitations. First, the response rate was not very high (34.4%), possibly causing a selection bias. For instance, if subjects with lower psychological distress, living in a municipality with low radiation levels, were less likely to participate in the study due to their lack of interest in this problem, the association between environmental radiation levels and psychological distress may have been underestimated. Second, our assessment of environmental radiation exposure may not have been precise at the individual level. The radiation levels were calculated using a municipality as a unit, and may have differed from the specific radiation levels at the place in which a given respondent lived. It is also possible that some residents moved from their original place of residence to the place in which they were residing at the time of the survey. For these respondents, initial radiation levels at the time of the accident, which were estimated based on their current address, may not have been accurate. These measurement errors may have resulted in an underestimation of the association between radiation levels and radiation anxiety and psychological distress. Third, our study was cross sectional and there may be a reverse causality. For instance, respondents with higher psychological distress may have a negative cognition and perception of the adverse health effects of radiation, and thus rated high on the radiation anxiety scale. Fourth, the Radiation Anxiety Scale used in the present study was not fully validated. Further research is needed to replicate the present findings, with a prospective study design, applying accurate measurement of radiation levels from a monitoring post closer to the residence of each respondent and a validated scale to measure radiation anxiety.

5. Conclusions

In a questionnaire survey of a random sample of non-evacuee community residents from 49 municipalities of the Fukushima prefecture conducted five years after the Nuclear Power Plant Accident, respondents' radiation anxiety was affected not only by environmental radiation levels, but also by other factors such as disaster-related experiences, including fear/anxiety at the nuclear power plant accident, and demographic characteristics. Radiation levels were not significantly associated with psychological distress. Thus, radiation anxiety did not mediate the association. Rather, psychopathology related to radiation anxiety may stem from fear/anxiety immediately after the nuclear power plant accident.

Ethical statements

All procedures followed were in accordance with the Helsinki Declaration and its later amendments. The study protocol was reviewed and approved by the Research Ethics Committee of The University of Tokyo Graduate School of Medicine and Faculty of Medicine.

Conflicts of interest

None.

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