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Changes in the Intention to Return and the Related Risk Perception Among Residents and Evacuees of Tomioka Town 11 Years After the Fukushima Nuclear Accident

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Original Research

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Abstract

Objective: This study examined temporal trends in risk perception and intention to return to Tomioka among residents and evacuees with the aim of aiding community recovery.
Methods: Responses to questionnaires distributed in 2017 and 2021 were compared regarding demographic information, intention to return to Tomioka, desire to consult radiation experts, and risk perception such as anxiety about food consumption, drinking tap water, self-health, and genetic effects. Questionnaires were distributed to all persons registered with the Tomioka town council, both current residents and evacuees.
Results: In 2021, the proportion of responders who had already returned/ wanted to return and those who did not want to return increased by 3.2% and 6.8% respectively, and the proportion unsure about returning decreased by 10.1%. Anxiety for self-health decreased by 15.4%, for genetic effects decreased by 24.4%, for food consumption decreased by 30.9%, and the latter 2 remained significant factors among responders unsure of returning and among those who did not want to return in 2021.
Conclusions: Risk perception for food and genetic effects was significantly associated with uncertainty about returning or not returning. There is a need for continual monitoring of risk perception trends and implementation of targeted risk communication strategies.

Introduction

On March 11, 2011, a series of tsunami waves resulting from a 9.0 magnitude earthquake struck the eastern coast of Japan. The subsequent power outage at the Fukushima Daiichi Nuclear Power Plant (FDNPP) led to a shutdown of the cooling system of 3 reactors, resulting in reactor meltdowns and hydrogen explosions from units 1 to 3.[1] The Nuclear and Industrial Safety Agency rated this event as Level 7 (major accident) on the International Nuclear and Radiological Safety Event Scale,[2] which indicates a large-scale release of radioactive material with widespread health and environmental effects, that requires implementation of planned, and extended countermeasures.[3] Accordingly, the Governor of Fukushima issued an evacuation decree at 8.50PM on the same day for all persons residing within 2 km of the FDNPP, which the Prime Minister of Japan then extended at 9.23PM to all residents within 3 km. As a determinative step, the evacuation order was expanded the following day to all residents living within 20 km of the power plant. This included the town of Tomioka,[4] which is located in the 10 – 20 km belt around the FDNPP.

Risk perception is defined as the evaluation of hazards through intuitive judgement by the public.

Based on the collection of diverse information sources and the codification of past experiences, risk perception allows for a transformation of behaviors and the surrounding environment, resulting in either risk reduction or creation.[5] Nuclear power, with its unobservable, novel characteristics, and inherent capacity to cause delayed health consequences, is judged by the general public as harboring uncontrollable risks, possessing catastrophic potential, fatal consequences, and bearing an inequitable distribution of risks and benefits. The combination of the country's past experiences with atomic bombings, the complex underlying mechanisms of nuclear accidents, the accompanying delayed stochastic health effects of radiation exposure led to widespread anxiety, and dread risk among Japanese citizens following the FDNPP disaster.[6] Although the level of radiation exposure estimated to be received in evacuees of Fukushima prefecture 4 months after the accident was limited, and no appreciable radiation-related health effects were expected,[7,8] risk perception regarding consumption of food and tap water, effects on general health, and genetic effects on future generations remained

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a concern up to 6 years later.[9–11] It has been established that sociocultural background and immediate response to trauma are also fundamental drivers behind risk perception among the general public.[5,12–14] However, excessive degrees of risk perception have been linked to poor health through increased levels of psychological distress,[15,16] adverse mental health status,[17] reduced frequency of laughter,[18] and incitation of feelings of social unrest through behaviors promoting discrimination against refugees,[19,20] as well as avoidance of food products from affected areas,[21] and exaggerated notions of the dangers of the surrounding environment.[22] Additionally, risk perception and health status dictate decision-making such as the intention to return (ITR) to hometowns by evacuees.[14]

Previous studies have demonstrated an inverse correlation between high degrees of radiation risk perception and the desire to return to Tomioka and Okuma towns after the FDNPP disaster.[23,24] We consider the present study unique in that it evaluates the change in risk perception and the resulting relationship to the affected populations' intentions to return over time (between 2017 and 2021) in a specific town, unlike the study of Hagen *et al.*[25] Several studies have measured statistical change in risk perception among a subpopulation residing in a contaminated area who were exposed to the nuclear accident and to continuous and targeted risk communication strategies during the recovery phase of the disaster. However, unlike the studies of Suzuki *et al.*,[26] Ito *et al.*,[27] and Kohzaki *et al.*,[28] the present study was conducted 6 and 10 years after the disaster rather than in its immediate aftermath. Thus, the results are more indicative of responders' longer-term behaviors and views, and of what factors, if any, play a role in the change of perception of risk and ITR among this specific subpopulation.

All residents of Tomioka were evacuated until April 2017, when the Japanese government lifted the evacuation order, barring the 'difficult-to-return' zones of Tomioka. Recovery efforts, including decontamination of environmental radionuclides and reconstruction of the town infrastructure, were spearheaded by the Tomioka town office in the interest of facilitating the return of its residents. Based on published evidence of reduced radiation-related anxiety and fear among participants in small-group consultations and explanations/ seminars with scientific experts,[29–31] similar community recovery efforts were organized by involved stakeholders at Tomioka town, and comprised of crisis and risk communication sessions, regular publication of periodicals, the establishment of a satellite research office, environmental monitoring, a 'food inspection center' that allowed residents to measure radionuclide levels in locally sourced produce, and stationing of a public health nurse for individual consultations.[32] The pace of population growth ensured that Tomioka town would fulfil its hope of increasing its population to at least 2000 by March 2022, 5 years after the evacuation order was lifted. However, as of 2021, the number of former residents among this new population remained limited at 11%. This is in contrast to the 63% return migration that occurred within 13 months, in 12 counties located within 100 miles of the path of Hurricane Katrina, after an 85% evacuation rate.[33] Similarly, after forced evacuation resulting from the 2010 Mt. Merapi earthquake in Indonesia, the return rate was 52% among survey respondents, and another 17% were in transition to return 16 months after the disaster.[34] Since 2017, questionnaires that measure risk perception and evacuees' ITR have been distributed to current residents of Tomioka and to the evacuation addresses of current evacuees (who are still registered with the Tomioka town council). We considered that it was necessary to review the effectiveness of ongoing risk communication activities and to identify potential areas for improvement as the population of the town increased. The present study aims to examine the change in risk perception and ITR between 2017 and 2021. The results of this study will guide risk communication strategies and the long-term community recovery effort in Tomioka town.

Methods

Participants

The assessment in this study is based on survey responses that were collected from residents and evacuees from Tomioka town in September, 2017.[23] Additionally, in November 2021, we distributed questionnaires to all residents and evacuees who were able to receive mail from the municipal office. The study participants were all residents and evacuees of Tomioka town aged ≥ 18 years who held resident cards as of October 2021. (Supplementary Table 1. Current location of evacuees by February 1, 2023)

Ethical issues

The basis and purpose of the study were explained in a letter attached to the questionnaire, along with a privacy notice. Consent to participate was voluntary, and it was explained that participants who choose not to participate would face no disadvantages. Written informed consent was obtained from all participants through the return postage of the questionnaire. Participation was anonymous and individuals could not be identified. No minors participated in the study. All study protocols were approved by the ethics committee of Nagasaki University Graduate School of Biomedical Sciences (Approval No. 21082702, September 6, 2021).

Questionnaire

The questionnaire used in the present study was based on that developed and distributed among Tomioka residents and evacuees in 2017.[23] Questions included demographic information (age, sex, currently living with a child or grandchild < 18 years old or not), ITR to Tomioka, and desire to consult radiation experts. We asked residents whether they were reluctant to eat food produced and collected in Tomioka, and to drink tap water from Tomioka. We also asked questions to evaluate subjective risk perception about the potential health effects of radiation exposure, such as the risk of cancer to themselves, and genetic effects in the next generation caused by living in Tomioka. Responses were in the form of yes/ no or multiple choice as appropriate. Questions regarding ITR and risk perception were scaled using a 4-point scale (1 = Strong agreement, 2 = Probably yes/ A lot, 3 = Probably no/ A little, 4 = Strong disagreement). We chose to capture risk perception and related behaviors through Lindell's 4-point Likert scale.[35]

Statistical analysis

The present study analyzed the change in risk perception and ITR among Tomioka residents and evacuees, between the responses received in 2017 and those received in 2021. Responses were set as user missing if they were incomplete or inconsistent (if multiple responses were inappropriately selected), and we conducted pairwise exclusion of missing values. Responders were divided into 2 cohorts according to the year of response. 'Age' was converted from the decade of life to young (< 60 years) and elderly (≥ 60 years) residents. 'ITR' was converted from the 4-point scale into 3 categories as follows: ITR (+) (already returned or wanted to return), unsure (about returning), and ITR (–) (did not want to

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Table 1. Demographic characteristics, ITR, and risk perception

Variable	Reference	The 2017 survey[1,2]	The 2021 survey[1]	*P*-value*
Sex	Male	1104 (49.2)	1382 (48.2)	0.499
	Female	1142 (50.8)	1486 (51.8)	
Age	< 60 years	826 (36.7)	837 (29.2)	< 0.001*
	≥ 60 years	1422 (63.3)	2033 (70.8)	
Living with children	Yes	441 (20.0)	444 (15.5)	< 0.001*
	No	1759 (80.0)	2416 (84.5)	
Intention to return (ITR)	ITR (–)	1249 (57.0)	1559 (63.8)	< 0.001*
	ITR Unsure	753 (34.4)	594 (24.3)	
	ITR (+)	190 (8.7)	292 (11.9)	
Desire to consult radiation experts	No	1589 (72.9)	2535 (88.7)	< 0.001*
	Yes	590 (27.1)	324 (11.3)	
Anxiety about eating food produced in Tomioka town	No	441 (19.7)	1452 (50.6)	< 0.001*
	Yes	1800 (80.3)	1420 (49.4)	
Anxiety about health effects of radiation exposure	No	718 (32.1)	1356 (47.5)	< 0.001*
	Yes	1518 (67.9)	1499 (52.5)	
Anxiety about genetic effects in the next generation	No	604 (27.5)	1478 (51.9)	< 0.001*
	Yes	1593 (72.5)	1369 (48.1)	

[1]N (%)
[2]Matsunaga H, Orita M, Iyama K, *et al*. Intention to return to the town of Tomioka in residents 7 years after the accident at Fukushima Daiichi nuclear power station: a cross-sectional study. *J Radiat Res*. 2019;60(1):51-8.
*= *P* -value < 0.05

return). 'Risk perception' was similarly converted from the 4-point scale to either yes or no.

Demographic characteristics were compared between the groups using the chi-square test and missing data were noted. Variables significantly associated with each of the ITR (+), unsure, and (–) categories were then identified in both groups. Significant factors were analyzed using logistic regression, and odds ratios with 95% confidence intervals (95% CI) were obtained. Data analysis was performed using IBM SPSS Statistics version 28 (IBM Corp., Armonk, New York, USA). *P*-values < 0.05 were considered statistically significant.

Results

Demographic characteristics

The response rate was 27.3% (2269 responses) in the 2017 survey,[23] and 34.0% (2899 responses) in the present 2021 survey.

The proportion of elderly responders was 70.8% in 2021 and 63.3% in 2017,[23] ($P < 0.001$). Most responders were not living with children or grandchildren under the age of 18 years at the time of the survey (80.0% and 84.5% in 2017 and 2021,[23] respectively, $P < 0.001$). The groups did not differ significantly based on sex (Table 1. Demographic characteristics, ITR, and risk perception).

ITR

In 2017, 8.7% of responders were categorized as ITR (+), 34.4% as ITR unsure, and 57.0% as ITR (–).[23] In 2021, these proportions changed to 11.9%, 24.3%, and 63.8% for ITR (+), ITR unsure, and ITR (–), respectively ($P < 0.001$).

Risk perception and desire to consult radiation experts

In 2017, 80.3% of responders stated that they had anxiety regarding the consumption of food produced in Tomioka,[23] whereas only 49.4% of responders reported this feeling in 2021 ($P < 0.001$). Concerning anxiety about health effects resulting from exposure to radiation in Tomioka, 67.9% reported feeling this anxiety in 2017,[23] and 52.5% in 2021 ($P < 0.001$). Anxiety regarding the genetic effects of radiation exposure in Tomioka town was experienced by 72.5% of residents in 2017,[23] and 48.1% in 2021 ($P < 0.001$). In 2017, 72.9% of residents did not have the desire to consult radiation experts,[23] which increased to 88.7% in 2021 ($P < 0.001$).

Variables associated with ITR

In 2017, the demographic variables of sex, age, and living with children, as well as the desire to consult with radiation experts were significantly associated with ITR.[23] Relative to the ITR unsure and ITR (–) groups, the ITR (+) group consisted mostly of males (55.8% vs. 52.6% and 46.2%, $P = 0.004$), the elderly (74.6% vs. 66.9% and 59.54%, $P < 0.001$), and responders currently not living with children (90.9% vs. 80.3% and 78.1%, $P < 0.001$). The desire to consult radiation experts was 35.8%, 36.5%, and 20.2% among the ITR (+), ITR unsure, and ITR (–) groups, respectively ($P < 0.001$) (Table 2. Variables associated with ITR in 2017 and 2022).

In 2021, the demographic variables of sex and desire to consult with radiation experts were significantly associated with ITR. The ITR (–) group consisted mostly of females (55.3%), whereas more male responders were either ITR (+) (52.2%) or ITR unsure (51.3%) ($P = 0.005$). The proportions of responders who had the desire to consult with radiation experts were 15.2%, 15.4%, and 8.6% in the ITR (+), ITR unsure, and ITR (–) groups respectively ($P < 0.001$).

Proportionally, elderly responders in the ITR (+), ITR unsure, and ITR (–) groups were 74.7%, 68.5%, and 69.8% respectively, and most responders (81.7%, 83.8%, and 83.7%) who were ITR (+), ITR unsure, and ITR (–) respectively, were not living with children at the time, but these variables were not significantly associated with ITR in 2021 (Table 2. Variables associated with ITR in 2017 and 2022).

Risk perception and ITR

In 2017, the proportions of ITR (+), ITR unsure, and ITR (–) responders who reported having anxiety about the consumption of food produced in Tomioka were 61.0%, 79.5%, and 84.0%, respectively ($P < 0.001$).[23] In 2021, these proportions were 45.2%, 55.3%, and 52.4% ($P = 0.018$). Risk perception for food was significantly associated with ITR in 2017 and 2021.

Regarding risk perception for self-health, 36.4%, 63.8%, and 75.3% of ITR (+), ITR unsure, and ITR (–) residents in 2017 reported feeling anxiety regarding the effects of radiation exposure in Tomioka town on their health ($P < 0.001$).[23] In 2021, these proportions were 51.0%, 57.3%, and 52.6%. Risk perception about health was significantly associated with ITR only in 2017.

In 2017, the proportions of ITR (+), ITR unsure, and ITR (–) responders who reported feeling anxiety regarding the genetic effects of radiation exposure in Tomioka were 46.7%, 71.5%, and 77.0% respectively ($P < 0.001$).[23] In 2021, these proportions

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Table 2. Variables associated with ITR in 2017 and 2022

		The 2017 survey[1,2]				The 2021 survey[1]			
Variable	Reference	ITR (+)	ITR Unsure	ITR (–)	***P* - value**	ITR (+)	ITR Unsure	ITR (–)	***P* - value**
Sex	Male	106 (55.8)	395 (52.6)	575 (46.2)	0.004*	151 (52.2)	304 (51.3)	694 (44.7)	0.005*
	Female	84 (44.2)	356 (47.4)	669 (53.8)		138 (47.8)	289 (48.7)	858 (55.3)	
Age	< 60	48 (25.4)	249 (33.1)	505 (40.5)	< 0.001*	73 (25.3)	187 (31.5)	469 (30.2)	0.154
	≥ 60	141 (74.6)	504 (66.9)	741 (59.5)		216 (74.7)	407 (68.5)	1084 (69.8)	
Living with children	No	160 (90.9)	580(80.3)	957 (78.1)	< 0.001*	236 (81.7)	496 (83.8)	1298 (83.7)	0.667
	Yes	16 (9.1)	142 (19.7)	269 (21.9)		53 (18.3)	96 (16.2)	252 (16.3)	
Desire to consult with radiation experts	No	115 (64.2)	459 (63.5)	966 (79.8)	< 0.001*	245 (84.8)	500 (84.6)	1415 (91.4)	< 0.001*
	Yes	64 (35.8)	264 (36.5)	245 (20.2)		44 (15.2)	91 (15.4)	133 (8.6)	
Anxiety about eating food produced in Tomioka town	No	73 (39.0)	152 (20.5)	197 (16.0)	< 0.001*	160 (54.8)	265 (44.7)	738 (47.6)	0.018*
	Yes	114 (61.0)	590 (79.5)	1037 (84.0)		132 (45.2)	328 (55.3)	814 (52.4)	
Anxiety about health effects of radiation exposure	No	119 (63.6)	268 (36.2)	305 (24.7)	< 0.001*	141 (49.0)	252 (42.7)	733 (47.4)	0.099
	Yes	68 (36.4)	473 (63.8)	928 (75.3)		147 (51.0)	338 (57.3)	813 (52.6)	
Anxiety about genetic effects in the next generation	No	96 (53.3)	208 (28.5)	279 (23.0)	< 0.001*	158 (55.4)	281 (47.8)	805 (52.1)	0.072
	Yes	84 (46.7)	522 (71.5)	936 (77.0)		127 (44.6)	307 (52.2)	739 (47.9)	

[1]N (%)
[2]Matsunaga H, Orita M, Iyama K, *et al*. Intention to return to the town of Tomioka in residents 7 years after the accident at Fukushima Daiichi nuclear power station: a cross-sectional study. *J Radiat Res*. 2019;60(1):51-58.
*= *P* - value < 0.05

were 44.6%, 52.2%, and 47.9%. Risk perception regarding genetic effects was significantly associated with ITR only in 2017.

Logistic regression

The first model of logistic regression analysis revealed that anxiety regarding consumption of food produced in Tomioka was independently associated with ITR in both 2017 and 2021. Compared to ITR (+) residents, ITR unsure responders had 2.5 higher odds ratio (95% CI, 1.7 - 3.6) in 2017 of having anxiety regarding consumption of food produced in Tomioka and 1.5 times higher odds ratio (95% CI, 1.1 - 2.0) in 2021. ITR (–) responders had 4 times higher odds ratio (95% CI, 2.8 - 5.7) in 2017 of having anxiety regarding consumption of food produced in Tomioka, whereas the odds ratio was 1.4 times higher (95% CI, 1.1 - 1.8) in 2021 (Table 3). Younger ages had 1.8 times higher odds (95% CI, 1.3 - 2.6) of being associated with ITR (–) in 2017, whereas age did not remain significant in 2021.

The second model revealed that compared to ITR (+) responders, those who were ITR unsure had 3.4 times higher odds ratio (95% CI, 2.3 - 4.9) of having anxiety regarding health effects on themselves, those who were ITR (–) had 7.3 times higher odds ratio (95% CI, 5.1 - 10.5) in 2017, and anxiety about health effects of radiation exposure was independently associated with ITR in 2017. Nevertheless, in 2021, anxiety about health effects of radiation exposure was not associated with ITR.

The third model of logistic regression analysis revealed that in 2017, responders' anxiety about genetic effects on the next generation was independently associated with ITR in both the ITR unsure and ITR (–) groups compared to the ITR + group. In 2021 however, anxiety about genetic effects was independently associated with ITR only in the ITR unsure group. All models of logistic regression revealed that the desire to consult radiation experts remained significantly lower among ITR (–) responders in 2017 and in 2021 (Table 3. Logistic regression models).

Limitations

Limitations of the present study include its cross-sectional design, which prevented us from deriving any causal relationship between risk perception and ITR over time. Due to the nature of the disaster, since 2011, various stakeholders have been involved in the rehabilitation of Fukushima. Thus, residents and evacuees have been subjected to multiple rounds of surveys, evoking feelings of 'survey fatigue' with time, which is a possible contributing factor towards the limited response rate for our voluntary questionnaire. As a measure to counteract this low response rate and increase the sample size, we mailed our surveys to all households within Tomioka and also to secondary evacuation addresses outside the town among registered evacuees.[36] However, surveys conducted in surrounding municipalities have displayed similar response rates.[13,23,37–39] There is also an inherent selection bias in those who decided to respond to the survey. The responses were more reflective of responders aged 60 years or older (63% in the 2017 survey and 71% in the 2021 survey) than a reflection of all Tomioka residents. As of 2021, the actual population aged > 65 years in Tomioka town was 32%.[40] It has been hypothesized that as the elderly have stronger feelings of attachment to their hometowns, they are more likely to be involved in rehabilitation efforts such as surveys, compared to the younger population, who are more likely to migrate and establish community ties elsewhere.[41] In addition, the responders were heterogeneous between the time points, which made it difficult to determine the long-term effectiveness of risk communication strategies. There is a need to also explore other factors relevant to risk perception among evacuees and residents after a disaster. Regarding face and content validity of our questionnaire, the included questions underwent multiple rounds of evaluation by 2 independent experts in the field of radiation risk communication, who checked whether the questions satisfactorily covered all aspects of the constructs being measured. The questionnaires were also vetted by the local town council regarding the appropriateness of the questions and the adequacy

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Table 3. Logistic regression models

Model	Variable	Reference	2017 survey[1]		2021 survey	
			ITR Unsure	ITR (–)	ITR Unsure	ITR (–)
Model 1	Age	Young	1.4 (1.0 - 2.0)	1.8 (1.3 - 2.6)*	1.4 (1.0 - 1.9)	1.3 (1.0 - 1.7)
	Consult with experts	Yes	0.8 (0.6 - 1.2)	0.4 (0.2 - 0.5)*	0.9 (0.6 - 1.4)	0.5 (0.3 - 0.7)*
	Anxiety about eating food produced in Tomioka town	Yes	2.5 (1.7 - 3.6)*	4.0 (2.8 - 5.7)*	1.5 (1.1 - 2.0)*	1.4 (1.1 - 1.8)*
Model 2	Age	Young	1.5 (1.0 - 2.1)	1.9* (1.3 - 2.8)*	1.4 (1.0 - 1.9)	1.3 (1.0 - 1.8)
	Consult with experts	Yes	0.7 (0.5 - 1.1)	0.3* (0.2 - 0.4)*	0.9 (0.6 - 1.4)	0.5 (0.3 - 0.7)*
	Anxiety about health effects of radiation exposure.	Yes	3.4 (2.3 - 4.9)*	7.3 (5.1 - 10.5)*	1.3 (1.0 - 1.7)	1.2 (1.0 - 1.5)
Model 3	Age	Young	1.4 (1.0 - 2.1)	1.9 (1.3 - 2.7)*	1.4 (1.0 - 1.9)*	1.3 (1.0 - 1.8)
	Consult with experts	Yes	0.8 (0.6 - 1.2)	0.3 (0.2 - 0.5)*	0.9 (0.6 - 1.3)	0.5 (0.3 - 0.7)*
	Anxiety about genetic effects in the next generation	Yes	2.8 (2.0 - 4.0)*	4.6 (3.3 - 6.5)*	1.4 (1.0 - 1.9)*	1.3 (1.0 - 1.6)

Reference group is ITR+
[1]Matsunaga H, Orita M, Iyama K, *et al*. Intention to return to the town of Tomioka in residents 7 years after the accident at Fukushima Daiichi nuclear power station: a cross-sectional study. *J Radiat Res*. 2019;60(1):51-8.
*P - value < 0.05

of the instructions in the context of survey responder ability. All experts were native speakers and fluent in the local language. Minor corrections and fine-tuning of the questionnaire were done according to comments and suggestions received. This questionnaire was constructed based on previous published research carried out on a similar sample,[23] thus not necessitating a pilot study. However, we could not perform construct validity analysis on this questionnaire, and thus the magnitude of the role of the underlying latent construct is not completely known, which could have resulted in information bias. To reduce this bias, we framed our questionnaire as closely as possible to similar previously published surveys that have measured risk perception and driven behavior in similar samples.[23,38,42] Although there is no singular or standardized tool to measure risk perception, we chose Lindell's 4-point Likert scale for its generalizability, comparability across responders, its validation in our target sample specifically,[35,43] and based on its use in the government-led Fukushima Health Management Survey.[15]

Discussion

The present study examined the changes in risk perception and ITR between 2017 and 2021 among residents and evacuees of Tomioka town after the FDNPP disaster. From 2017 to 2021, the magnitude of risk perception reduced significantly for food (from 80.3% to 49.4%), health effects (from 67.9% to 52.5%), and genetic effects (from 72.5% to 48.1%). In determining ITR in 2021, logistic regression models revealed that anxiety for health effects was no longer significant, whereas anxiety for genetic effects remained significant among ITR unsure responders, and food anxiety remained significant among ITR unsure and ITR (–) responders.

From 2017 to 2021, although the odds ratio of risk perception for consumption of food produced in Tomioka reduced from 2.5 to 1.5 among ITR unsure responders, and from 4.0 to 1.4 among ITR (–) responders, its significance in deciding ITR persisted. Environmental studies have revealed that radiocesium (^{134}Cs,^{137}Cs) was the primary radionuclide contaminant among the land surface and crops in the aftermath of the FDNPP accident.[44] Measured in Fukushima city (around 50 km from the nuclear power plant) in March 2012, the effective doses of^{134}Cs and^{137}Cs were 0.44 μSv/ month among vegetables bought from the market and 2.60 μSv/ month among locally-grown vegetables, which conferred minor ingestion-related lifetime-attributable risks for all solid cancers.[44] The same study reported effective^{134}Cs and^{137}Cs doses of 0.19 μSv/ month in an uncontaminated area (Tokyo, approximately 230 km from the power plant) measured during the same time period, which resulted from other natural radionuclides in the diet; e.g., potassium 40 (^{40}K) and polonium 210 (^{210}Po). Similarly, in Tomioka in 2019, radiocesium concentrations measured from local produce were much lower than the standard or public dose limits.[45] In the same year, despite relatively high external median air dose levels in the difficult-to-return zones, radionuclide concentrations were low in indoor and outdoor air, and in surface soil in areas in which the evacuation order had been lifted.[46] Nevertheless, residents persistently reported anxiety about consumption of locally produced food; while Japanese citizens (especially those living outside Fukushima), living with children, cognizant of food inspections, and aware of inspection specifics, remained concerned about radioactivity in vegetables and were averse to purchasing Fukushima-produced food products.[21,23,47] 11 years after the FDNPP accident, these residents are unaccepting of the low radiation risk and still perceive purchasing Fukushima-produced food products as dangerous.[48]

To alleviate this anxiety among its residents, the Tomioka town office established a 'food inspection center' that allowed residents to measure radionuclide levels in locally sourced produce. A study that examined the effect of implemented radiological countermeasures on subjective well-being and anxiety of Fukushima residents 5 years after the FDNPP disaster, found that although the food inspection facility had low participation and utilization rates compared with the remaining dose monitoring countermeasures, 79% of participants deemed the facility as highly useful. However, the study also reported a deterioration in self-rated health among these participants, which was not observable for other countermeasures.[49] To allow for the complete rehabilitation of residents so they can live their daily lives in peace and free of radiation-related anxiety, the cultivation of a practical radiological culture is essential.[50] The latter is defined by the International Commission on Radiological Protection (ICRP) as the provision of resources aimed at improving 'the knowledge and skills enabling citizens to make well-informed choices and behave wisely in situations involving potential or actual exposures to ionizing radiation.'[51] The food inspection center is an example of a space

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run by experts where residents can conduct dose measurements, read, understand the results, and then arrive at an independent decision regarding their risk perception. Collectively, it is imperative to reinforce the message of safety in the consumption of Fukushima-produced food products for a re-invigoration of the local economy through welcoming of residents and visitors.

Regarding anxiety about genetic effects, although the proportion of residents expressing this anxiety reduced by 24.4% from 2017 to 2021, 48.1% of the 2021 cohort persistently reported high-risk perceptions of genetic effects. Risk perception for genetic effects remained a significant factor in determining ITR among those unsure about returning in 2017 and 2021. In 2017, 74.9% of ITR unsure residents who were living with children had anxiety regarding the genetic effects of future generations ($P = 0.028$), but there was no significant association of living with children in 2021, indicating either a possible generalization of risk perception amongst all residents or a reduction in the magnitude of anxiety among those living with children. Tallying with our results, the 2018 Fukushima health survey revealed that 53% of evacuees consistently reported high-risk perceptions of the genetic effects of radiation,[26] and in Kawauchi village, where return rates were 80% in 2017, 46.1% of residents in 2021 maintained a high-risk perception of genetic effects.[23,52] In its 2020/ 2021 report, the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) determined that there was no evidence for the occurrence of genetic effects as a result of the doses exposed by Fukushima residents during the FDNPP accident.[53] The average external radiation dose among Tomioka residents was found to be 0.5 mSv per 4 months,[39] as measured by the Fukushima Health Management survey between March and July 2011; however, risk perception regarding radiation effects remained high among residents 7 years later.[23] Therefore, it is evident that the formation of risk perception is dependent on alternative, extraneous factors apart from presented scientific data, and this anxiety about genetic effects among Tomioka residents must continue to be monitored.

Concurrent with Murakami *et al.*,[54] the factors of age, sex, and living with children did not play a role in determining ITR in 2021, and the influence of risk perception about health and genetic effects in deciding ITR diminished in significance over time. The number of residents who wished to consult with radiation experts decreased over time for all groups. Although the desire to consult with radiation experts remained significant for determining ITR in the present study for both years, the proportion of residents who responded affirmatively to this question reduced over time, indicating a reduction in risk perception. However, various studies have established that an individual's perception of risk is dependent on additional diverse factors such as past experiences, reaction to trauma, and evacuation status, as well as recent bereavement,[26,55] mental health status,[26] psychological distress,[15,17,56] and age.[23] Other factors include sex,[23,57] employment status,[26] socioeconomic status, and educational attainment.[26,58] Our results demonstrated the presence of radiation-related anxiety in half of the 2021 cohort, indicating the chronic and unpredictable nature of risk perception, and its related health consequences. 19 years after Chernobyl, evacuee mothers reported impaired well-being, elevated risk perceptions, and poor mental health in the preceding year due to the enduring impacts of the disaster on their lives.[59] These perceptions were retained in their children, who reported similar poor health compared to controls,[60] implying that among survivors, disaster-related high-risk perceptions and mental health effects are lingering and persistent. These disaster-related effects might manifest in the form of safety behaviors, including intolerance of uncertainty and increased perceptions of anxiety through paying selective attention to risks. Safety behaviors (including consulting radiation experts and measuring radioactivity levels of food) are actions that involve the seeking of reassurance against anxiety and are performed to evade emotional distress.

Disaster-related risk communication strategies must evolve with time and should be of a multi-pronged nature. Information providers must first assess and improve residents' health literacy and trust amongst the local authorities before disseminating scientific material. More so, it has become evident that resident involvement in all aspects of decision making is necessary for community recovery.[61] It is crucial for stakeholders to conduct targeted and customized risk communication for each demographic of the population,[62,63] and improve the methods of communication strategies with holistic measures of familiarity and ingenuity, based on residents' needs and concerns.[64] There is an urgent need to formulate a systematic method for capturing risk perception and its change over time. Ultimately, it is crucial to respect residents' ITR wishes, as the decision is representative not solely of risk perception but of multiple factors such as the social network, town infrastructure, and employment opportunities, among others.[13,65]

Conclusion

Risk perception for food and genetic effects remains a factor in deciding ITR among Tomioka residents. There is a need for continual risk communication through promoting health literacy among evacuees and improving trust in experts through targeted and multi-pronged strategies.

Supplementary materials. To view supplementary material for this article, please visit https://doi.org/10.1017/dmp.2023.58

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Ethical standard. The study was conducted in accordance with the Declaration of Helsinki and approved by the ethics committee of Nagasaki University Graduate School of Biomedical Sciences (approval No. 21082702, 6 September 2021). Informed consent was obtained from all subjects involved in the study

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