

Risk perception regarding implementation of iodine thyroid blocking during a nuclear disaster of mothers living near a nuclear power station in Japan

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Abstract. Pre-emptive evacuation orders following the accident at the Fukushima Daiichi Nuclear Power Station (FDNPS) in March 2011 and subsequent regulatory limits regarding contaminated food, milk, and water minimized the external and internal radiation exposure doses of nearby residents. However, with regard to implementation of iodine thyroid blocking (ITB), residents were confused because no information on the matter was released by the central and/or local governments. Based on lessons learned from the FDNPS accident, many countries have revised their guidelines regarding ITB during nuclear disasters. To adequately revise such guidelines and ensure effective ITB implementation during a nuclear disaster, however, residents' perceptions of ITB must be clarified. In this study, the perception of risks associated with ITB was investigated in mothers residing near the Sendai Nuclear Power Plant (SNPP) in Kagoshima Prefecture, Japan. Of the 520 mothers surveyed, 467 (89.8%) expressed anxiety regarding the administration of potassium iodine (KI) to their children. Logistic regression analysis revealed that the mothers' anxiety regarding the administration of KI to their children was positively correlated with their wish to consult an expert about KI and their hesitation to let their children eat foods produced in Fukushima, and negatively correlated with having confidence about administering KI to their children. Careful communication of potential risks to mothers residing near nuclear power plants is thus critical for implementing effective ITB in children.

Key words: Iodine thyroid blocking, Nuclear disaster, Risk perception, Stable iodine

DURING A DISASTER at a nuclear power station, large amounts of many radionuclides can be released into the environment, such as ^{131}I , ^{134}Cs , and ^{137}Cs [1, 2]. Inhalation of contaminated air and ingestion of contaminated food and drinking water may lead to internal radiation exposure and uptake of radioactive iodine, mainly by the thyroid [1]. Radioactive iodine is of particular public health concern, as it is taken up into the thyroid gland in the same manner as non-radioactive iodine [1]. The Chernobyl nuclear accident increased the incidence of thyroid cancer in children under 15 years of age [3]. In Ukraine and Belarus, the incidence of childhood thyroid cancer increased because the governments had not

restricted milk and food and did not distribute stable iodine [1-5]. However, by distributing stable iodine and by milk regulation, the incidence of thyroid cancer did not increase significantly in Poland [6]. The implementation of iodine thyroid blocking (ITB), food and drinking water restrictions, and evacuation are widely used in radiation emergency preparedness plans [1, 7].

Kim *et al.* reported that the 1,080 children in Iwaki City had a thyroid equivalent dose of less than 30 mSv [8]. Although the large-scale ultrasound screening of children in Fukushima Prefecture of Japan showed an increasing incidence of thyroid cancer, it was concluded that this was not the effect of radiation [8-13]. Early control of food and drinking water and evacuation reduced the health effects in residents due to internal exposure [7, 12].

On the other hand, insufficient information was provided by the national and local Japanese governments regarding the prophylactic use of stable iodine, which caused confuse among the public [14]. Although several

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local governments distributed potassium iodide (KI), systematic prophylaxis was not implemented, because of time pressure and insufficient information and explanation about KI [13-15]. Health authorities and public health professionals need to carefully implement ITB, considering the balance of the benefits and the harms of taking KI [1, 15]. In addition, residents living near a nuclear facility need to have correct knowledge about KI (*e.g.* timing of taking KI, risk of adverse effects) [1, 15, 16].

After the accident at FDNPS, the Nuclear Regulation Authority (NRA) of Japan revised the recommendations regarding stable iodine (KI) prophylaxis during a nuclear disaster [16, 17]. In the revised recommendation, the residents living within a 5 km radius of a nuclear facility (precautionary action zone: PAZ) is distributed KI at the peace time. On the other hand, the residents living within 5–30 km radius of a nuclear facility (urgent protective action planning zone: UPZ) is distributed KI during evacuation at the time of nuclear accident [16, 17]. Moreover, after the accident at FDNPS, a jelly formulation for infants is developed and added an option [17].

Recently, the World Health Organization revised the guidelines for thyroid blocking with stable iodine [1]. These guidelines stated that “the comprehensive stable iodine implementation plan for preparedness and response should also include arrangements for training of health professionals and emergency workers on risk communication, to raise public awareness (*e.g.* provision of leaflets, organizing campaigns) to avoid unjustified use of stable iodine and giving false reassurance to the

affected population” [1]. In this regard, it is important to assess the current perception of risks among residents near nuclear power plants in order to implement an appropriate risk communication strategy. It is particularly important to evaluate risk perception among mothers, since they are responsible for the prophylaxis for their children. Therefore, in this study, the perception of risks associated with KI prophylaxis (ITB) among mothers residing in proximity to the Sendai Nuclear Power Station (SNPS) in Kagoshima Prefecture, Japan, was investigated.

Materials and Methods

Study participants

The survey was conducted between October 2018 and January 2019 in Satsuma-sendai City, located within the 30 km UPZ of the SNPS (31° 50' 1" N, 130° 11' 22" E), Kagoshima Prefecture, Japan (Fig. 1). A self-administered questionnaire about the perception of risks associated with stable iodine was sent to 1,088 mothers residing near the SNPS with children aged 0–3 years, in cooperation with the Satsuma-sendai City Office. Responses were obtained from 765 of the 1,088 mothers (70.3%). After excluding 245 incomplete responses, the responses from 520 mothers were included for analysis. This study was approved by the ethics committee of Nagasaki University Graduate School of Biomedical Sciences (No. 18070602).

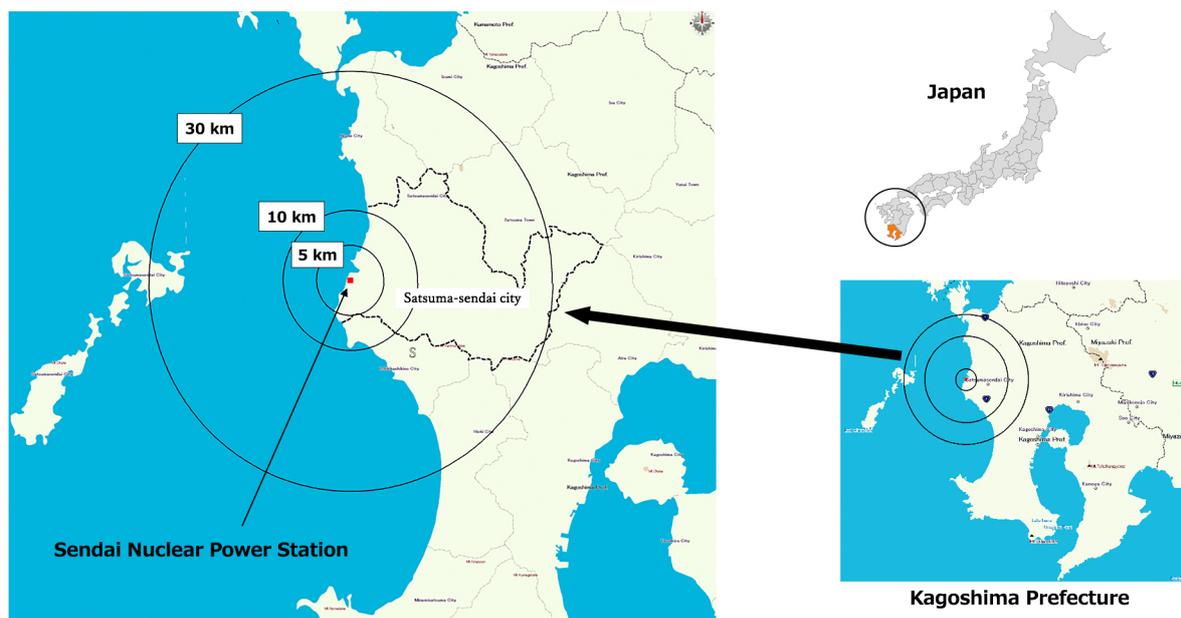


Fig. 1 Locations of Satsuma-sendai City and Sendai Nuclear Power Station

Questionnaire

The self-administered questionnaire was based on our previous studies [18, 19]. The questionnaire included items about the mothers' anxiety regarding the administration of KI to their children, having information about KI, participation in a meeting about KI, knowledge regarding the timing of administering KI to children, desire for a consultation with experts about KI, a history of already taking KI, desire to obtain KI, and confidence about administering KI to their children (Supplementary Table 1).

Statistical analysis

Chi-squared tests were used to assess potential associations between anxiety regarding KI administration and demographic characteristics and with perception of risks associated with KI use. Logistic regression analysis was used to calculate odds ratios (ORs) to identify factors

independently associated with anxiety about KI administration. *P* values <0.05 were considered significant. Variables were input by forward selection (likelihood ratio). The question about "residence area" was excluded from the logistic regression analysis because of the complete separation of the participants in the relevant area. IBM SPSS Statistics, version 25 (IBM, Japan, Tokyo), was used for statistical analyses.

Results

Of the 520 mothers, 20 (3.8%) resided in the PAZ, 361 (69.4%) in the UPZ, and 13 (2.5%) resided more than 30 km from the SNPS; 126 mothers (24.2%) did not know their residence area (Table 1).

Overall, 467 of 520 mothers (89.8%) reported anxiety regarding the administration of KI to their children, 411 mothers (79.0%) had not received information regarding

Table 1 Characteristics of the mothers living in Satsuma-sendai city (*n* = 520)

		Number (%)
Mothers' age	10s	2 (0.4)
	20s	154 (29.6)
	30s	311 (59.8)
	40s	53 (10.2)
Children's age	0 years	217 (41.7)
	1 year	105 (20.2)
	2 years	93 (17.9)
	3 years	105 (20.2)
Number of children	One	169 (32.5)
	More than one	351 (67.5)
Mothers' home town	Satsuma-sendai city	274 (52.7)
	Outside Satsuma-sendai city	167 (32.1)
	Outside the prefecture	79 (15.2)
Family composition	Nuclear family	481 (92.5)
	Extended family	39 (7.5)
Residence area related to nuclear power station	PAZ	20 (3.8)
	UPZ	361 (69.4)
	30 km~	13 (2.5)
	I don't know	126 (24.3)
Working mother	Yes	218 (42)
	No	302 (58)
Child goes to kindergarten	Yes	240 (46.2)
	No	280 (53.8)
Breastfeeding	Yes	231 (44.4)
	No	289 (55.6)
Using social media to obtain information about living	Yes	332 (63.8)
	No	188 (26.2)

administration of stable iodine preparations, 499 (96.0%) had never participated in a session explaining KI prophylaxis, 485 (93.3%) did not know the proper timing for administering KI to their children, 418 (80.4%) had no knowledge of the period of KI availability, 396 (76.2%) responded that KI administration was suitable for internal exposure to radiocesium, as well as radioiodine, 231 (44.4%) thought their children would suffer adverse

health effects from living in Fukushima, and 264 (50.8%) reported that they would hesitate to let their children eat foods produced in Fukushima (Table 2).

The responses of mothers who expressed anxiety (anxiety-positive) about the administration of KI to their children were compared with those of mothers who did not express such anxiety (anxiety-negative) (Table 2). Compared with anxiety-negative mothers, a significantly

Table 2 Profiles of mothers who reported anxiety about the administration of KI to their children and those who did not

	Have anxiety about the administration of KI to their children		<i>p</i>	
	Yes (<i>n</i> = 467)	No (<i>n</i> = 53)		
Mothers' age	10s	2 (0.4%)	0 (0%)	0.60
	20s	138 (29.6%)	16 (30.2%)	
	30s	282 (60.4%)	29 (54.7%)	
	40s	45 (9.6%)	8 (15.1%)	
Children's age (1–3 years)	274 (58.7%)	29 (54.7%)	0.58	
Number of children (more than one)	315 (67.5%)	36 (67.9%)	0.94	
Mother' home town (Satsuma-sendai city)	251 (53.7%)	23 (43.4%)	0.15	
Family composition (Nuclear family)	429 (91.9%)	52 (98.1%)	0.10	
Residence area	PAZ	20 (4.3%)	0 (0%)	0.035
	UPZ	328 (70.2%)	33 (62.3%)	
	30 km~	13 (2.8%)	0 (0%)	
	I don't know	106 (22.7%)	20 (37.7%)	
Working mother	198 (42.4%)	30 (37.7%)	0.51	
Child going to kindergarten	216 (46.3%)	24 (45.3%)	0.89	
Breastfeeding	209 (44.8%)	23 (41.5%)	0.65	
Using social media to obtain information about living	295 (63.2%)	37 (69.8%)	0.34	
Have information about KI	97 (20.8%)	12 (22.6%)	0.75	
Participated in a meeting explaining KI	20 (4.3%)	1 (1.9%)	0.40	
Wish to consult an expert about KI	98 (21.0%)	4 (7.5%)	0.02	
Already have KI	30 (6.4%)	1 (1.9%)	0.19	
Want to obtain KI	280 (60.0%)	26 (49.1%)	0.13	
Know the proper timing for administering KI to their children	30 (6.4%)	5 (9.4%)	0.41	
Have confidence about administering KI to their children	83 (17.8%)	20 (37.7%)	0.001	
Know it is necessary not only to take KI, but also to evacuate	463 (99.1%)	51 (96.2%)	0.06	
Know the period of KI availability	90 (19.3%)	12 (22.6%)	0.56	
Know that KI is not suitable for internal exposure to radiocesium	116 (24.8%)	8 (15.1%)	0.12	
Know that Japan is an "iodine-rich" area	272 (58.2%)	35 (66.0%)	0.27	
Child has allergy	38 (8.1%)	3 (5.7%)	0.53	
Have anyone who can administration KI to your child when you are absent	328 (70.2%)	37 (69.8%)	0.95	
Believe their children could have adverse health effects from living in Fukushima	210 (45.0%)	21 (39.6%)	0.46	
Hesitate to eat foods produced in Fukushima	184 (39.4%)	13 (24.5%)	0.03	
Hesitate to let their children eat foods produced in Fukushima	246 (52.7%)	18 (34.0%)	0.01	

Table 3 Logistic regression analysis of mothers expressing anxiety about the administration of KI to their children

Variable	Units	OR (95% CI)	p
Wish to consult an expert about KI	Yes/No	2.95 (1.03–8.50)	0.044
Have confidence about administering KI to their children	No/Yes	2.74 (1.49–5.07)	0.001
Hesitate to let their children eat foods produced in Fukushima	Yes/No	1.91 (1.04–3.52)	0.037

OR, Odds ratio; CI, confidence interval

higher proportion of anxiety-positive mothers wished to consult experts regarding KI ($p = 0.02$), residence area ($p = 0.035$), hesitated to eat foods produced in Fukushima ($p = 0.03$), and hesitated to let their children eat foods produced in Fukushima ($p = 0.01$). In contrast, compared with anxiety-negative mothers, a significantly lower proportion of anxiety-positive mothers expressed confidence about administering KI to their children ($p = 0.001$).

Logistic regression analysis revealed that the mothers' anxiety regarding the administration of KI to their children was positively correlated with their wish to consult an expert about KI ($OR = 2.95$, $95\% CI = 1.03$ – 8.50 , $p = 0.044$), and hesitation to let their children eat foods produced in Fukushima ($OR = 1.91$, $95\% CI = 1.04$ – 3.52 , $p = 0.037$), and negatively correlated with having confidence about administering KI to their children ($OR = 2.74$, $95\% CI = 1.49$ – 5.07 , $p = 0.001$) (Table 3).

Discussion

Following the FDNPS accident, Japan's national guidelines regarding ITB were revised and protocols for the pre-distribution of KI to areas within PAZs and post-accident distribution to areas within UPZs were outlined [16, 17]. The nation's first pre-distribution of KI was carried out in 2014 in Kagoshima Prefecture [16]. Nuclear disaster prevention training was performed in the area around the nuclear facility every year, including simulation of the distribution and taking of KI at the time of an emergency. Participants in the training were the PAZ and UPZ residents. However, in the present study, almost 90% of the mothers surveyed expressed anxiety regarding the administration of KI to their children during a nuclear disaster. In addition, 93.3% of the mothers did not know the proper timing for administration of KI, 80.4% did not know the period of KI availability, and 76.2% were not know that KI is not suitable for internal exposure to radiocesium. These results suggest that mothers' anxiety regarding administering KI to their children during a nuclear disaster could be due to a lack of sufficient knowledge regarding KI prophylaxis.

The results of logistic regression analysis revealed that the mothers' anxiety regarding the administration of KI

to their children was positively correlated with their wish to consult an expert about KI and hesitation to let their children eat foods produced in Fukushima, and negatively correlated with having confidence about administering KI to their children. During the accident at the FDNPS, KI was distributed in Miharu town, Fukushima Prefecture [15]. The distribution rate in Miharu town was 94.9%, but only 63.5% of the residents took the KI. The major reasons for not taking KI included concerns about safety, other reasons such as insufficient information regarding the effects and adverse effects of KI, and insufficient information on how to take KI. In an emergency situation, people cannot make decisions in a normal strategic manner because of time pressures and ambiguity [20]. Residents living near nuclear facilities should have sufficient prior knowledge about KI prophylaxis to make swift and effective decisions during an emergency.

Since wishing to consult an expert regarding KI was independently associated with mothers' anxiety over administering KI to their children during a nuclear disaster, risk communication between experts and residents near nuclear facilities concerning KI prophylaxis is critical for enhancing residents' understanding.

Mothers usually have difficulty giving children (especially infants) medicine because of the taste and form of the medicine and unpleasant experiences [21, 22]. Boztepe *et al.* reported that 19.3% of parents have difficulties giving medicine to children, 19.4% of children refuse to take pills, and 24.5% of children refused to take liquid medicine [23]. Mennella *et al.* reported that 58.2% of children refused to take medicine and reject medication primarily for taste reasons [24]. In the present study, 82.2% of mothers said they had anxiety about the administration of KI and were not confident about giving tablets or jelly medicine to children correctly, which was higher than in previous studies. One possible reason is that KI is a rare drug and is to be used only in a nuclear emergency, so that there are more difficulties and rejection. The optimal administration timing is 24 hours before and up to 2 hours after the expected onset of exposure to radioactive iodine, but it is still reasonably effective even up to 8 hours [1, 15]. During a

nuclear emergency, children may not be able to take KI within the proper timing, which can lead to the mother's anxiety becoming stronger than usual. Therefore, we need to educate mothers about other radiation protection actions, as well as ITB.

Recent studies in Fukushima Prefecture showed that almost half of the residents reported anxiety over potential adverse health effects among their children and offspring, and they hesitated to let their children eat foods produced in Fukushima [18, 19]. In the present study, many Japanese even outside Fukushima still experience anxiety over potential adverse health effects due to the accident at the FDNPS. It was also found that hesitation of mothers to let their children eat foods produced in Fukushima is independently associated with anxiety regarding the administration of KI to their children. This result is inconsistent with the other results, since it is reasonable that mothers who hesitate to let their children eat foods produced in Fukushima would be eager to administer KI to their children. It is possible that mothers have vague anxieties about issues related to radiation, which might have caused these inconsistent results. Better communication of risks associated with ITB in combination with correct information regarding the health effects of radiation exposure will be useful for enhancing the understanding of residents of areas near nuclear facilities.

There are several limitations to this study. The study was conducted only among mothers residing near the SNPS and included only mothers with children aged 0–3 years, which could cause selection bias. To the best of our knowledge, this is the first study on the perception of

risks associated with ITB in residents residing near the nuclear power plant. Further studies are thus needed to clarify the factors associated with perception of ITB risks during a nuclear disaster among residents living near nuclear facilities.

In conclusion, wishing to consult experts regarding KI, having confidence concerning the administration of KI to their children, and hesitating to let their children eat foods produced in Fukushima were independently associated with anxiety over the administration of KI to children among mothers residing near the SNPS in Japan. These results indicate that establishing an effective ITB system for children during a nuclear disaster will require implementation of a procedure to adequately communicate information pertaining to risks based on the individual risk perceptions of parents.

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Disclosure

The authors declare that there are no conflicts of interest.

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Supplementary Table 1 Details of questionnaires

Questions	Answers
1. How old are you?	() years old
2. How old is your child?	() years old
3. Do you have any other children?	1. Yes (number of children:) 2. No
4. Where do you live?	1. Satsuma-sendai City 2. Outside Satsuma-sendai City 3. Outside Kagoshima Prefecture
5. What is your family composition?	1. Nuclear family 2. Extended family
6. Where do you live in relation to the nuclear power station?	1. PAZ (within 5 km) 2. UPZ (5–30 km) 3. More than 30 km 4. I don't know
7. Are you working?	1. Yes 2. No
8. Does your child go to kindergarten?	1. Yes 2. No
9. Are you breastfeeding?	1. Yes 2. No
10. Do you use social media to obtain information?	1. Yes 2. No
11. Do you have information about KI?	1. Yes 2. No
12. Have you ever participated in a meeting about KI?	1. Yes 2. No
13. Do you wish to consult an expert about KI?	1. Yes 2. No
14. Have you already taken KI?	1. Yes 2. No
15. Do you wish to obtain KI?	1. Yes 2. No
16. Do you know the proper timing for administering KI to your children?	1. Yes 2. No
17. Do you have confidence about administering KI to your children (jelly type and pill type)?	1. Yes 2. No
18. Do you have anxiety about administration of KI to your children?	1. Yes 2. No
19. Do you know it is necessary not only to take KI, but also to evacuate?	1. Yes 2. No
20. Do you know the validated period of KI?	1. One day 2. One month 3. One year
21. Do you think that KI is suitable for protection against internal exposure by radiocesium?	1. Yes 2. No 3. I don't know
22. Do you think that Japan is an "iodine-rich" area compared to other countries?	1. Yes 2. No
23. Does your child have allergies?	1. Yes 2. No
24. Is there anyone who can administer KI to your child in your absence?	1. Yes 2. No
25. Do you think living in Fukushima Prefecture will affect your child's health in future?	1. Yes 2. Probably yes 3. Probably no 4. No
26. Do you hesitate to eat foods produced in Fukushima Prefecture?	1. Yes 2. Probably yes 3. Probably no 4. No
27. Do you hesitate to let your children eat foods produced in Fukushima Prefecture?	1. Yes 2. Probably yes 3. Probably no 4. No

PAZ, precautionary action zone

UPZ, urgent protective action planning zone

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