Usefulness of the whole-body counter for infants and small children (BABYSCAN) as a risk communication tool after the Fukushima Daiichi nuclear power plant incident

By Masaharu Tsubokura,*1,*2,*3,#,*† Yuko Nabeshima,*4,# Michio Murakami,*5 Tsuyoshi Nemoto,*6 Toshiyuki Kambe,*7 Saori Nonaka,*7 Yuki Shimada,*8 Yurie Kobashi,*2 Akihiko Ozaki*1,*9 and Tomoyoshi Oikawa*8

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Abstract: Responding to the radiation-related concerns of parents/guardians with infants/small children is an important public health issue for regional recovery after radioactive contamination. This study summarizes the results of a systematic internal contamination screening of infants/small children, aged 0–6 years, using BABYSCAN and individual counselling sessions with physicians about radiation concerns from 2014 to 2018 in Minamisoma City. Of 3,114 participants, no one was found to have internal contamination with radioactive caesium with a detection limit of 50 Bq/body. The questionnaire survey showed a decreasing trend of concerns about food contamination and playing outside as possible causes of internal contamination over time. Because people’s concerns were diverse in counselling sessions, individual responses are required. This study showed that examinations using BABYSCAN provide an opportunity for direct dialogue between the parents/guardians of infants/small children and experts. This can be considered a model case for risk communication conducted by the local government after a radioactive contamination incident.

Keywords: WBC, internal contamination, risk communication, infants, screening

Introduction

Although radiation protection primarily aims to manage and control exposure to ionizing radiation in order to prevent deterministic effects and reduce the risks of stochastic effects to a reasonably achievable extent,1,2 the measures undertaken by authorities after radioactive contamination are not limited to just controlling the dose and contamination.3,4 Authorities need to help residents understand the situation, support their lives, and promote information sharing and discussion for decision making.5 These activities include providing timely, clear, and practical information; risk communication; and counselling by experts as well as encouraging self-defence measures.6–9

The governmental response to infants/small children and their parents/guardians after radioactive contamination is a critical issue for several reasons.10 First, children tend to be more radiosensitive than adults.11 Second, parents/guardians tend to have serious radiation concerns.12–14 Third,
perceptions of radiation risk to children can give rise to social issues such as discrimination.\textsuperscript{15} However, little information is available on how the authorities should intervene in the public sphere.

The Fukushima Daiichi nuclear power plant incident in March 2011 caused radioactive contamination of the surrounding areas. Although internal contamination of the residents after the Fukushima incident could be kept low through the management of food contamination from an early stage,\textsuperscript{16} parents/guardians were, naturally, worried about the health of their children and were concerned whether their children had been exposed to radiation in any form.\textsuperscript{17} In particular, after the incident, parental requests for internal contamination examinations of their children and parental anxiety concerning their children’s health were high.\textsuperscript{18} There was an increase in internal contamination examinations of children in addition to high levels of Fukushima food evasion by the parents/guardians of children.\textsuperscript{19} The concern for radiation exposure was manifested in a desire for regular assessment of internal contamination levels among the parents/guardians of children.\textsuperscript{20} However, the lower body mass of children than that of adults means that radiation intake cannot be detected by the currently used whole-body counter (WBC) that is programmed to detect $\geq 250$ Bq/body among adults.\textsuperscript{21}

Under these circumstances, Hayano and colleagues developed an innovative WBC capable of accurately measuring internal contamination levels in infants/small children.\textsuperscript{22} The novel BABYSCAN is specially designed so that children can lie down while being scanned, and the device is capable of detecting $\geq 50$ Bq/body.\textsuperscript{23,24} Specifically, BABYSCAN was introduced in Minamisoma City in July 2014, when the government of Minamisoma City launched the systematic internal contamination screening for infants/small children in Fukushima. Possibly, the most important feature of BABYSCAN is that the results are available almost immediately after the screening and can be discussed with the caregivers while receiving appropriate reassurances about the infant’s/child’s health.

The purposes of the present study are 1) to assess the level of internal contamination among infants/small children and 2) to clarify the degree and contents of parents/guardians’ concerns related to radiation exposure. This study gives us important insights into appropriate interventions as part of the administration’s radiation protection provided to infants/small children and counselling provided to parents/guardians experiencing high levels of anxiety about radiation exposure.

**Material and method**

**Settings and participants.** The study’s participants were infants/small children, aged 6 months–6 years, who lived in Minamisoma City or whose parents/guardians (one or both) had lived in Minamisoma City at the time of the incident. Because Japan’s fiscal year (FY) starts in April, the screening targeted children who had not reached the age required for attending elementary school in every study year. The city office sent an invitation to all parents/guardians at the beginning of each FY, and participation was voluntary. The applicants could undergo the screening only once a year.

**BABYSCAN.** BABYSCAN is a WBC optimized for measuring internal contamination levels in infants/small children (height less than 130 cm). The examinee lies on a bed in the BABYSCAN for 4 min; during this time, the emitted $\gamma$ rays are detected by four sodium iodide detectors. The minimum detectable activities for both $^{134}$Cs and $^{137}$Cs are less than $\sim 3$ Bq/kg across all ages.\textsuperscript{23} More detailed product information has been published elsewhere.\textsuperscript{25}

**Screening programme and counselling.** The levels of internal contamination with radioactive caesium (Cs), $^{134}$Cs and $^{137}$Cs, and potassium-40 were assessed among the participants. Radioactive Cs is one of the most problematic short-to-medium-lifetime fission products after nuclear incidents and is known to be representative of total internal radiation doses in the existing exposure situation after Fukushima.\textsuperscript{16}

After the screening, a physician explained the results to each parent/guardian and offered a counselling session to discuss their concerns about radiation in their daily life. This consultation was offered to all participants who were undergoing the screening for the first time or the participants who wanted it after the second screening. The consultation was offered individually in a partitioned room in the outpatient clinic area of the hospital and took 5–15 min for each participant. In addition to one doctor explaining the results, one person in charge of the measurement and three office staff conducted the screening.

**Self-report exposure risk assessment questionnaire.** A self-report exposure risk assessment questionnaire was completed by the parents/guardians. This questionnaire contained questions about
their current address, their living area before the Fukushima incident, and the degree of concerns about internal contamination and preferences in food consumption.

The degree of concerns about internal contamination was reported in terms of how much the respondent worried about local food products, water and dust and playing outside as possible causes of internal contamination. The response to each item was rated on a five-point Likert scale (i.e., very caring, caring, neither, not care much, and not care at all).

Regarding the preferences in food consumption, the questionnaire also examined the methods that parents/guardians used to acquire the following seven food products: rice, meat, fish, vegetables/fruits, mushrooms, milk, and infant formula. Each question had the following four choices: (1) preference type I: purchasing food products at a supermarket based on origin (Fukushima or non-Fukushima), (2) preference type II: purchasing food products at a supermarket without consideration of origin, (3) preference type III: consuming local farm foods or homegrown foods that did not undergo radiation inspection, or (4) preference type IV: consuming local farm foods or homegrown foods that did not undergo radiation inspection. Considering origin while acquiring food at the supermarket was one of the best markers of anxiety regarding potentially contaminated food products. The items about water consumption asked whether the respondent (1) avoids tap water and uses only bottled water for drinking or cooking, (2) uses tap water, or (3) uses well water. A questionnaire that had already been used in other WBC screenings in Fukushima was also applied in the present screening.

**Data analysis.** We used the database from the Minamisoma Municipal General Hospital to obtain participants’ age, gender, address, total body burden of Cs, questionnaire results, and record data on the counselling. Part of the data in the present study (total body burden of Cs in FY2014 and FY2015 have already been published in a previous study).

1. To assess internal contamination levels among infants/children, we assessed the detection rate of radioactive Cs.
2. To identify the transition of concerns about internal contamination, we examined the change in the proportions of parents/guardians with high degree of concerns about internal contamination (very caring and caring) across the FYs 2014–2018 using the Cochran–Armitage trend test. Likert scale categories of very caring and caring and not caring much and not caring at all were consolidated and presented as single categories. The trend tests were performed for the following eight categories: water, rice, meat, fish, vegetables/fruits, mushrooms, milk, and dust and playing outside.

3. To identify the changes in food-acquiring preferences, the percentages of each acquiring preference type (I–IV) across the FYs were assessed using the Cochran–Armitage trend test. Because of the limited number (less than 2%, except for rice and vegetables/fruits) of participants who consumed local farm foods or homegrown foods (preference types III and IV), preference types II, III, and IV were consolidated into a single category. The trend tests were performed for the following seven food products: rice, meat, fish, vegetables/fruits, mushrooms, milk, and infant formula. The change in the proportions of participants who avoided tap water and used only bottled water for drinking and cooking was also assessed across the years using the Cochran–Armitage trend test.

**Qualitative analysis of the key topics in the counselling sessions.** We recorded the key topics of concerns expressed by parents/guardians in their counselling sessions with a physician. The authors read the topics and assigned initial coding. A coding framework was developed by YN and MM with different majors (YN: internal medicine, MM: risk science), and the codes were then combined into categories. Themes were refined through discussions and were checked against the written topics and the overall dataset. YN and MM independently reviewed the coding, categories, and themes and then discussed them; any discrepancies were resolved through discussions. Data management and coding were performed using Microsoft Excel, 2016 (Redmond, WA, U.S.A.).

To examine the consistency and the difference between counselling and questionnaire results, we used the Cohen’s κ consistency test and chi-square test, respectively. The following four points were examined: 1) consultation about water versus concern about water, 2) consultation about food versus concern about mushroom, 3) consultation about food versus concern about vegetables/fruits, and 4) consultation about inhalation/touching dust versus concern about dust/playing outside. The five levels of concern in the questionnaire were consolidated into two categories for analysis (very caring and caring versus the other three levels). For the κ consistency test, data from FY2014 were used.
All analyses were performed using STATA/MP V.13.1 (Stata Corp., College Station, TX, U.S.A.), R version 3.6.1 (R Foundation for Statistical Computing, Vienna, Austria), and IBM SPSS Statistics 24 (International Business Machine Corp., Armonk, NY, U.S.A.). P values < 0.05 were considered statistically significant.

Ethics approval. The Institutional Review Board of the Minamisoma Municipal General Hospital and the Fukushima Medical University approved the study (authorization numbers 1-04 and 3065, respectively). Written informed consent was obtained from all the next of kin, caretakers, or guardians on behalf of the infants/small children enrolled in this study.

Results

During the study period, a total of 3,117 infants/small children were screened using BABYSCAN. Only 3 of them refused to participate in the study; therefore, 3,114 infants/small children were enrolled in this study. The characteristics of the participants are shown in Table 1. Among eligible residents, 21.8% were screened.

Almost the same number of male (50.3%) and female (49.7%) infants/small children took part in the screening. Only 12.8% of the parents/guardians who had lived in the evacuation order zone in Minamisoma City before the incident, and the number of parents/guardians who had lived outside Minamisoma City before the incident increased each year. The largest number of participants (82.6%) lived inside Minamisoma City at the time of examination. The number of participants living inside Fukushima/outside Minamisoma City and outside Fukushima decreased year after year, and only nine participants (2.3%) lived outside Fukushima in FY2018.
No internal contamination with radioactive Cs was detected, which meant that all participants’ internal contamination levels were below 50 Bq/body. Assuming that the participants had a constant daily intake of Cs after the nuclear incident, these results translate to a maximum effective dose of 37 µSv/y, even for newborn babies, including radioactive dose contributed by $^{134}$Cs contribution. During the screening process, no accident or harm to the participants was reported.

Figure 1 shows the results of the questionnaire items on the concerns about water, foodstuffs, and dust and playing outside as possible causes of internal contamination. Of the eight categories, parents/guardians were most worried about mushrooms in FY2014 (75.5%), whereas they were least concerned about dust and playing outside (51.4%). In FY2014, approximately 70%–80% of parents/guardians cared about water, rice, vegetables and fruits, mushrooms, and fish. However, the proportion of parents/guardians who were concerned about internal contamination showed significant decreasing trends year after year (Cochran–Armitage trend test: $P < 0.001$ for all eight categories).

Table 2 shows food product-specific acquiring preferences, which were also compared among FYs. In FY2014, while approximately 70%–80% of parents/guardians acquired food products at a supermarket based on origin (preference type I), except for milk and infant formula, the highest value was noted for mushrooms, at 83.0%. However, by FY2018, fewer residents considered the origin of food products (Cochran–Armitage trend test: $P < 0.001$ for all seven categories). The proportion of parents/guardians who used only non-Fukushima-produced rice, vegetables/fruits, meat, and milk decreased more quickly than that of those who used fish and mushrooms. The proportion of the parents/guardians who use bottled water for drinking and cooking has been decreasing ($P < 0.001$); however, 61.4% of them...
still used bottled water for drinking in FY2018 (Table 2).

In total, 2,011 parents/guardians received a counselling session with a physician at their first participation in the screening. Table 3 shows the numbers of categorized concerns according to the themes. ‘Nothing special’ was the most common at 24.8%, followed by ‘food’ and ‘water’ at 8.1% and 6.9%, respectively. Regarding the consistencies and differences between counselling and questionnaire
results, the $\kappa$ values and the P values of chi-square test were, respectively, 0.03 and 0.068 in (1) consultation about water versus concern about water, 0.028 and 0.071 in (2) consultation about food versus concern about mushroom, 0.054 and 0.003 in (3) consultation about food versus concern about vegetables/fruits, and 0.068 and 0.001 in (4) consultation about inhalation/touching dust versus concern about dust/playing outside.

Discussion

This study suggests that the internal contamination screening of infants/small children using BABYSCAN and the radiation counselling of parents/guardians by physicians could be implemented safely and both of these interventions offer high-quality radiation consultation opportunities. Over the course of 5 years, 3,117 infants/small children visited the hospital, and more than 20% of targeted children visited during this period. In addition, the programme was able to provide basic radiation knowledge directly to all, hear specific concerns from 2,011 people, and respond to them. While online or telephone consultation can be used by many people, it might be difficult to hold regular lectures or offer individual face-to-face consultations with caregivers to a large number of parents/guardians as we did in this study based on BABYSCAN screening. The present approach could be used to efficiently communicate with residents about radiation exposure.

Relatively good access can be an opportunity for consultation. In this study, 80% of the examinees lived in Minamisoma City. While this is comparable with the previous research using the results of WBC, further research is necessary to investigate how to more effectively communicate with parents/guardians. The present screening could be implemented very safely because no accident or harm to the examinees was reported.

This study showed that the dose from internal radiation exposure among children aged 0–6 years in Minamisoma City was kept low irrespective of food product-specific preferences. This finding is comparable with the previously reported results for adults and children in Minamisoma City. Although additional doses from foods were reported to be negligible ($\leq0.002\text{mSv/}y$ in 2014) in market basket and duplicate portion studies, the present results also showed that chronic internal exposure is well-managed through food contamination control and that internal exposure has a negligible health risk for children aged 0–6 years. Although infants/small children might have different dietary patterns from adults, internal contamination is still well-controlled.

This study showed that parents/guardians had a decreasing trend of concerns about food contamination and playing outside as possible causes of internal contamination over time, and the proportion of people avoiding Fukushima products also showed a declining trend. This downward trend is consistent with the results of internal exposure screenings using WBC in Minamisoma City for adults, pregnant women, and elementary/junior high school students. The detailed food inspection, widely publicized results, and continuous provision of the results of internal contamination screenings could all be the factors contributing to the reduction of parental anxiety.

Of note, among people who avoid consuming Fukushima products, the proportion of parents/guardians seemed to be higher than those of primary and secondary school children and pregnant women in Minamisoma City. Although parents/guardians with high anxiety levels may have participated in the present screening programme, approximately 20%–30% of parents/guardians avoided Fukushima products even in FY2018, 7 years after the incident. It will be necessary to continue providing radiation information and continuous responses to such residents. This BABYSCAN screening and counselling might be considered a successful method in terms of efficiently gathering high-anxiety groups of residents and counselling them.

Regarding the contents of the counselling session, there was significant consistency between counselling and questionnaire results. However, the proportion of parents/guardians who discussed concerns with physicians was lower than that of those who showed concerns in the questionnaire: for example, 15% parents/guardians expressed concerns in consultations about food versus 68% expressing concerns about vegetables/fruits in the questionnaires in FY2014. This might be because with physicians, parents/guardians discussed the topic about which they were most concerned. Although the content classified as ‘other’ accounts for 19%, the contents that parents/guardians liked to discuss varied; however, experts were able to provide detailed responses to a wide range of concerns by discussing them directly through BABYSCAN counselling. Although concerns about internal contamination have tended to ease, interests have continued. These findings suggest that it may be necessary for
authorities to continuously disseminate information on a wide range of radiation issues, not only food and water safety.

**Limitations**

There are several limitations in this study. First, participation in the internal contamination screening programme was on a voluntary basis, and less than 30% of parents/guardians with infants/small children chose to participate in the present programme. Given the nature of the voluntary-based programme, our findings might not be generalizable to the entire population in Minamisoma City. However, time trends in the differences between foods would not be seriously affected by these limitations. Because Minamisoma City is a unique city, as it was subject to various evacuation or counter-dose measures (i.e., evacuation and indoor sheltering zones designed by the central government following the accident), the levels and effects of chronic anxiety and fear of post-disaster radiation exposure among the public (including pregnant women) might be different from those experienced by people in other contaminated areas. This may potentially bias (probably over-estimate) the results of the questionnaire regarding food-acquiring preferences.

**Conclusion**

To date, the biggest challenge in minimizing the public health consequences of the Fukushima nuclear incident is the restoration of public trust in the flow of information and advice from the authorities. Consequently, local communities need to be empowered to make their own evidence-based decisions with respect to precautions, prevention, and treatment. Customized, appropriate communication is essential and needs to be carried out by trained specialists. Healthcare workers also need suitable and proper education and training on the short-, medium-, and long-term health effects of radiation. Health systems need to provide effective counselling services and social support via a cohesive team approach with a focus on people-centred care. Building on the aftermath of the Chernobyl disaster, the lessons learned from the Fukushima incident need to be fully understood and globally shared.

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**Author contributions**

All authors conceived and designed the study and take full responsibility for the integrity of the data and the accuracy of data analysis. MT, SN, TN, and TK acquired the data. YS, AO, and TO provided administrative and technical support for data collection. MM, YN, and YK prepared the figure, analysed the data (which were interpreted by all authors), and performed the statistical analysis. MM, YN, and MT drafted the article. All authors critically reviewed the manuscript for important intellectual content and provided final approval of the manuscript.

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