scientific reports

OPEN

Essential health risk communication for recovery after lifting evacuation orders following the Fukushima Daiichi nuclear power plant accident

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The Fukushima Daiichi Nuclear Power Plant, managed by the Tokyo Electric Power Company experienced a catastrophic accident in 2011 that led to widespread public anxiety regarding radiation exposure and the long-term impacts of evacuation. The recovery process has considerably varied across the affected municipalities, highlighting the need for effective and targeted risk communication to support residents in understanding these situations and making informed decisions. This study aims to examine the health risk communication strategies implemented by health and medical welfare experts in response to the lifting of evacuation orders in formerly evacuated areas. We provide an overview of the practical activities carried out by these experts, with a particular focus on the contributions of Fukushima Medical University, Hirosaki University, and Nagasaki University. Over the years, these institutions have played a key role in radiation protection and public health initiatives, guided by scientific and technical perspectives. Our findings underscore the necessity of evolving two-way communication practices that are responsive to specific needs of the recovery phase. Additionally, this study highlights the importance of integrating comprehensive health promotion activities with radiation health risk communication to ensure sustained attention to both physical and mental health. Furthermore, expert communication efforts remain essential in supporting social care professionals who are involved in the ongoing care of residents. Finally, the global sharing of Fukushima's recovery strategies is essential for providing insights that can inform future disaster preparedness efforts.

Keywords Disasters, Risk communication, Recovery

It has been 13 years since the Tokyo Electric Power Company's Fukushima Daiichi Nuclear Power Plant (FDNPP) accident caused by tsunami waves resulting from the main shock of the Great East Japan Earthquake on March 11, 2011. Radionuclides were released into the atmosphere from the damaged reactors[1]. Consequently, the surrounding municipalities and their residents were ordered to evacuate as a result of this disaster[2]. National and international institutions such as the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) suggesting no increases in the risks of cancer or related disease incidence, either presently or in the future[3–6]. UNSCEAR also noted a theoretical possibility that the risk of thyroid cancer among the group of children most exposed to radiation could increase and concluded that the situation needed to be followed

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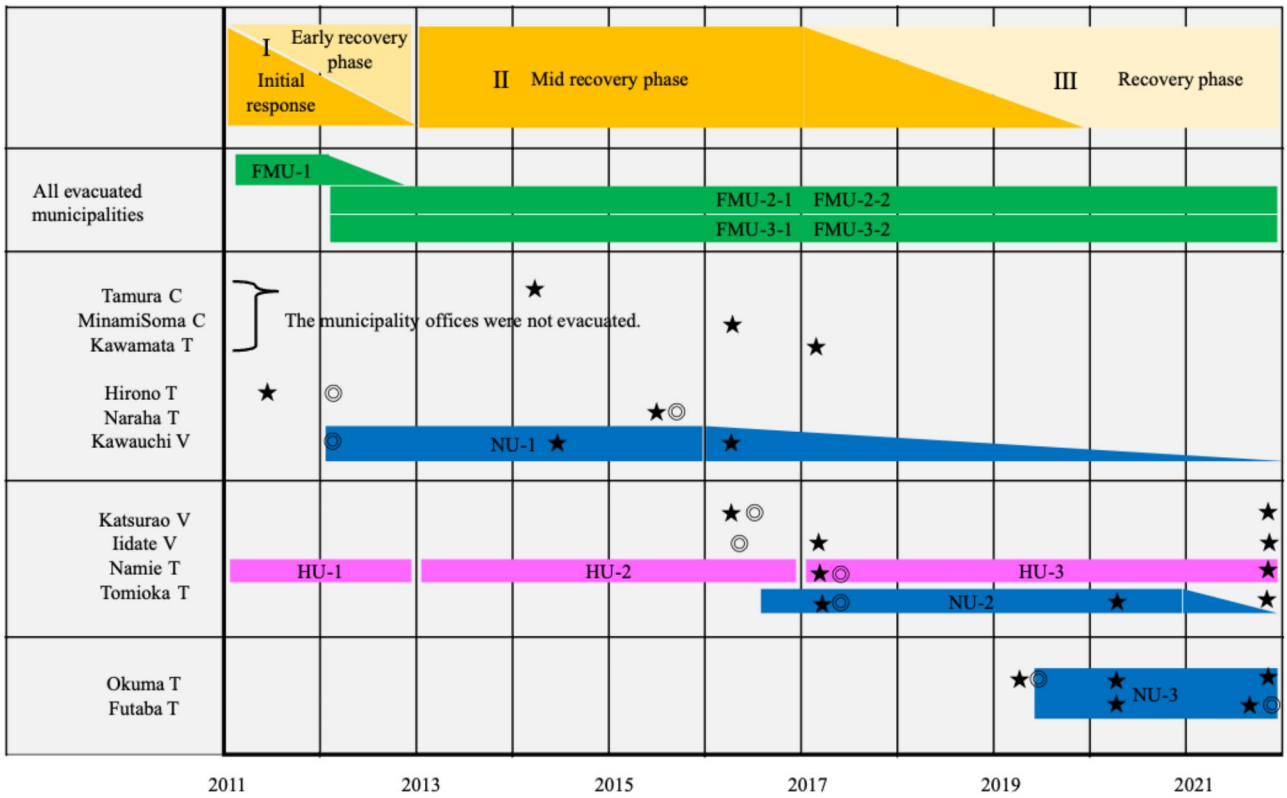

Fig. 1. Recovery phases from the immediate aftermath of the FDNPP accident to the present, the process of local recovery from lifting of the evacuation order in all municipalities in the formerly evacuated areas, and places and duration of activities of the respective institutions included in this study. ★: Timing when evacuation orders were lifted.◎: Timing when the town/village office returned to the original site.

closely and further assessed in the future. In Fukushima Prefecture, the residents' local food consumption at the time of the accident is being investigated, but it is known that in some cases the residents did not necessarily cooperate with the survey and in some cases, they ingested food that had been stored outdoors, the exposure risks by uncertainties of the doses in these cases remain a serious public concern. High levels of psychological distress and a decline in subjective well-being were observed among Fukushima residents, especially those who expressed great concern over radiation or distrust of authority[7–9]. Post-accident medical studies have revealed the exacerbation of physical illnesses, such as diabetes and hyperlipidemia, especially in evacuees[10–12]. In response to these situations after the accident, health and medical welfare experts have exerted considerable effort to communicate with evacuated residents regarding radiation and health risks associated with the incident, and collaboration with residents has been promoted.

In August 2022, the evacuation zone, including the specific reconstruction and revitalization sites within the difficult-to-return zone in 20% of the area of Futaba town, the host of FDNPP, was lifted. Subsequently, the town office returned its base of operations to the town in September 2022[13]. Futaba town is the last municipality to see an evacuation order lifted and return its base of operations among the 11 municipalities subjected to such orders in the wake of the disaster[14]. This achievement is considered a milestone in Fukushima's recovery phase. Murakami et al. systematically reviewed studies and activities related to risk communication among Japanese people in the aftermath of the Fukushima disaster in 2015[2], highlighting the need for continued systematic evaluation of effective risk communication activities. However, no report has been published offering an overview of the effective risk communication activities required for the recovery process from the lifting of evacuation orders in all formerly evacuated municipalities (12 municipalities). Given that 13 years have passed, and the recovery status varies considerably across municipalities, additional future support is considered necessary based on the local recovery phase from a long-term perspective. Therefore, this study aimed to provide an overview of the activities of research institutes, including measures to reduce radiation health concerns and health management during nuclear disasters, in order to clarify the risk communication activities required for the recovery process from lifting of evacuation orders in all formerly evacuated municipalities after the FDNPP accident.

Results

Initial response and early recovery phase

FMU, the only medical university in Fukushima Prefecture (Fig. 1, FMU-1), immediately shifted to emergency care, accepting only seriously injured patients immediately after the earthquake. The hospital had no water or petrol supply. Owing to a lack of information on the damage to the FDNPP caused by the tsunami, the hospital

also had to manage radiation surveys and the acceptance of severely exposed patients. The university has been enhancing its medical support for local residents and has developed medical activities such as mental health care in evacuation centers inside and outside the evacuated municipalities, measures against infectious diseases, and rehabilitation for older individuals. Since May 2011, the FMU teams have been providing individual health consultations, "Yorozu Sodan," to evacuated residents and medical services to the population facing various difficulties due to the evacuation and related health concerns. Thus, the need for a long-term response to disaster medicine, including the health effects of radiation exposure and mental health, was clarified. Additionally, FMU established relationships with all evacuated municipalities.

In June 2011 (Fig. 1, FMU-3-1), the Fukushima Health Management Survey (FHMS) was launched to estimate the external exposure doses of individuals in Fukushima Prefecture and ascertain their health status, which is essential for disease prevention, early detection, and treatment[15]. The goal is to protect and promote the long-term health of Fukushima's residents. Fukushima Prefecture is responsible for implementing the FHMS, and FMU is commissioned to conduct surveys, as advised by the Fukushima Prefectural Oversight Committee for the FHMS, which is composed of experts. The FHMS consists of a basic survey and four detailed surveys: thyroid ultrasound examination, comprehensive health checks, mental health and lifestyle surveys, and pregnancy and birth surveys. Amid growing concerns about radiation exposure, Fukushima Prefecture's early initiation of the large-scale health surveys provided a sense of reassurance to many residents, while there was criticism regarding the methodology and transparency of the surveys. As part of ongoing discussions, the Japanese name of the FHMS has been revised following deliberations within the prefectural assembly, reflecting efforts to address concerns and refine its framework. Regarding the health effects of radiation, opinions among scientists were divided, leaving residents caught between conflicting information about "safety" and "danger."

HU, which is located in Aomori Prefecture (Fig. 1, HU-1), dispatched teams to Fukushima Prefecture to conduct environmental radioactivity surveys and perform radioactivity contamination tests for the surface of the human body and radioactive iodine in the thyroid glands of evacuees from March to July 2011. It was a timely activity, yet the information was flooded with unfamiliar terms such as μSv, becquerel, and internal exposure, and the unstable post-disaster situation, making it extremely difficult to cooperate with the residents. In fact, in a survey conducted in the Tsushima district of Namie town in April 2011, only 17 residents participated, indicating that it was difficult to obtain their cooperation. From May to August 2011, the team also supported the residents in their temporary re-entry into the evacuation zone in Minami-Soma City, Kawauchi Village, and Hirono Town, conducted exposure screening. The residents, especially the children, were worried about staff wearing Tyvek suits all over their bodies and unfamiliar measuring equipment. Even if it is for radiation protection measures for the workers, it is understandable that residents would feel fear when they see staff wearing Tyvek suits in evacuated sites. The residents are still wondering why staff wearing Tyvek suits did not tell them to evacuate at the time. The HU team addressed these fears by engaging in conversations and staying close to them to help ease their feelings[16].

In September 2011, HU agreed to cooperate with Namie Town, where approximately half of the area was designated as a restricted zone[17] and commenced radiation health risk communication through consultations and lectures with local residents and stakeholders. The Namie town office mandated environmental radiation monitoring, identification of residents' radiation doses, chromosome analysis for the retrospective assessment of residents' radiation doses, and health consultations with public health nurses and others familiar with radiation medicine. These experts stationed on a frontline for recovery efforts made it possible to keep track of the needs of local residents and questions from the public, thereby facilitating radiation health risk communication. In other words, while identifying the needs of residents and local governments, experts stationed at the frontline of the community have responded by consulting with experts at their own university or by asking various experts from other fields (education, agriculture, mechanical engineering, industry, law, veterinary medicine, etc.). These activities were not intended to simply reassure residents but also included efforts such as supporting plaintiff groups in national compensation lawsuits. It was noteworthy that a backup system was gradually established and comprehensive cooperation for recovery with experts from various fields and local governments was developed. Residents were apprehensive about the duration of their evacuation and the effects of radiation due to the accident. It is thought that they were also conflicted about whether they would return or not. Although feeling anxious is a natural stress response for emergency preparedness, a high stress response can put a strain on the body.

The HU team communicated with residents to acknowledge their feelings and alleviate their anxiety. During this phase, the team attempted to engage in dialogue about basic knowledge regarding radiation and health risks, as well as provide frontline information from the affected areas. Throughout this process, great care was taken to ensure that the communication was never coercive or pushy. Additionally, for residents outside the designated evacuation zones who voluntarily evacuated, the team made every effort to respect their decision. Information was provided with caution to ensure that administrative decisions or scientific conclusions were not imposed in a way that would undermine their personal choices. Communicating radiation risks to evacuated residents in close cooperation with relevant stakeholders was considered necessary to support their decision-making.

NU, located in Nagasaki Prefecture (Fig. 1, UN-1), has been supporting radiation emergency medicine at FMU immediately following the FDNPP accident. Since December 2011, the NU team has actively participated in reconstruction efforts undertaken by Kawauchi village, where the village office returned to in March 2012. In April 2013, NU and Kawauchi village signed an agreement for comprehensive cooperation in the restoration and revival of the local community[18]. The Kawauchi Village Reconstruction Promotion Base was established as a university satellite facility. During consultations on health and radiation, residents often ask how they should interpret the various figures. Residents who returned to the village often asked questions, such as whether water and rice were safe for consumption. They drink water from wells and often eat homegrown rice and vegetables for self-consumption. The teams address the villagers' questions and concerns about radiation exposure in everyday

life such as living and eating. This base works closely with the village office to measure radioactivity in the soil and food, offering radiation health consultation services based on the measurement data. The team conducted door-to-door visits to provide consultations. The team measured the air dose rates in the homes of villagers and in the surrounding areas and brought back soil and vegetable samples for radioactivity measurements. Subsequently, the team presented these measurements to the villagers and explained what each figure indicated. For example, when considering the internal exposure dose due to food intake, it tells that not only the measured radioactivity of food, but also the amount ingested is taken into account in the assessment. This measuring individual radiation doses by door-to-door visits will lead to an overall dose assessment and risk assessment that will identify trends for the entire community. The results obtained have been given back to each individual and have also been explained to the community in a manner that did not identify the individual. The villagers often comment that they feel reassured if they can understand the levels of radioactivity in local soil and homegrown vegetables for self-consumption.

Mid-term recovery phase

HU (Fig. 1, HU-2) established a satellite facility in the Nihonmatsu office of the Namie town Hall in July 2013. Since 2015, public health nurses have been stationed there to provide health consultations and respond to questions raised by residents, including support for dosimeter lending. In addition, HU emphasizes visiting residents rather than waiting for them to visit.

In 2016, small-scale interactive meetings with residents regarding radiation issues were held in temporary and reconstructed public housing in Fukushima Prefecture, providing an environment where town residents could voice their questions and concerns regarding radiation. These activities needed to be conducted before Namie town returned to its original location. These approaches should be performed by establishing a base of operations in the Nihonmatsu office of the Namie town Hall and stationing staff on-site facilitated effective support for radiation exposure using specialist knowledge.

NU established the Research and Support Center for the Future of Fukushima in May 2014 (Fig. 1, UN-2), implementing a university-wide structure dedicated to Fukushima's reconstruction. In September 2016, NU signed an agreement on comprehensive cooperation with Tomioka town to utilize the experience gained in Kawauchi village and established the Nagasaki University-Tomioka Town Reconstruction Promotion Base within the Tomioka town office. After the accident, Tomioka town steadily undertook rebuilding efforts, including decontamination, and in April 2017, 6 years after the nuclear accident, the residents began to return[19]. However, in an advance survey of residents' intentions, only 13.9% of 13,900 residents wished to return, with 5.4% in their teens and 20s, indicating a low proportion of younger residents intending to return. Anxiety about radiation exposure likely contributed, along with various social factors. Currently, the town is making progress in building a foundation for full-scale reconstruction. Therefore, ensuring safety and security through initiatives such as measuring radioactive substances in food is crucial. However, we acknowledge that pre-shipment measurements alone have limitations in ensuring radiation safety. Thus, transparency in measurement results and continuous monitoring are also essential.

The team conducted a survey in 2017 to identify factors related to residents' intentions to return and their perception of radiation exposure risk and found that concerns regarding the health effects of exposure upon returning to their hometowns were related to residents' return intentions[19]. The relationship between residents' intention to return and their physical and mental health status was also analyzed. It was suggested that, although residents wanted to return to Tomioka town, their concerns about the risk of radiation exposure from returning and depression due to their inability to return affected their intention to return[20]. Residents exhibited various perspectives, including those who have already returned to Tomioka town, those wanting to return, and those who wish to rebuild their lives outside their original place of residence, such as the evacuation site. Health-risk communication activities to support residents' decision-making, including their intention to return, were considered necessary.

After the FDNPP accident (Fig. 1, FMU-2-1), residents experienced a sense of loss of family and home, anxieties about life with no clear vision of the future, and stress from living in evacuation centers and temporary housing. These experiences underscored the necessity for addressing the psychological effects caused by the accident. Over time, the need for mental health care support became more complex and increased; however, it became evident that there was a shortage of health and welfare professionals to meet the growing needs. Concerns also arose regarding the exhaustion of stakeholders in all evacuated municipalities, such as relevant staff who had been dedicated to recovery-related work for a long period. The FMU team considered it necessary to respond to the mental health care support needs of stakeholders in all formerly evacuated municipalities, particularly during the accelerated return of municipalities and residents. The implementation of measures by local authorities to promote the return resulted in the division of stakeholders in the health and welfare sector into two groups: professionals who remained in the evacuation area and those who returned to the returning municipalities. This division substantially increased the workload on stakeholders. Dealing with the exhaustion of local stakeholders and residents was also a key issue, and communication activities by experts, such as municipal officials, were required to facilitate support for local stakeholders.

For the FHMS, the main results of health examinations revealed an increase in the number of evacuees with obesity[21,22]. While some of the results have not yet been fully shared with the respective local municipalities, FMU remain committed to continuing their efforts to ensure that these findings are effectively communicated. The results were disseminated to the population through public information papers from each municipality. Based on the dissemination of these results, the FMU team collaborated with all municipal offices to organize health lectures in temporary housing and for returning residents. This period coincided with previous studies revealing not only residents' concerns about the health effects of radiation exposure but also the effects of long-

term evacuation on their health[23,24]. Support activities that took into account the living conditions of individual residents and how they could modify their lifestyle within the constraints caused by the evacuation were required.

Recovery phase

In municipalities with a low return rate of residents, such as Tomioka town, Namie town, Okuma town, and Futaba town, previous studies have shown that those who continue to evacuate outside the prefecture experience poorer mental health[25] (Fig. 1, FMU-2-2). Therefore, FMU provides remote support services for out-of-prefecture evacuees. In municipalities where residents have returned home, the number of new residents is also increasing rapidly, indicating that psychological care is also required for new residents. Essential aspects of psychological care related to daily life during the local recovery process include support for out-of-prefecture evacuees and local stakeholders and enhanced support for new residents.

Continuing to share the results of the FHMS with all the formerly evacuated municipalities is necessary (Fig. 1, FMU-2-3). In municipalities where the return has progressed, the situation has improved, and the FMU team has more opportunities to visit municipalities and explain directly to local residents; however, in municipalities where the return has not progressed, individual evacuees are still seeking housing independently, making it difficult to provide direct support to local residents who continue to be displaced in the evacuation area. Disseminating the results of the FHMS to residents in cooperation with all formerly evacuated municipalities, where the return rate is low, remains a future challenge.

In March 2017 (Fig. 1, HU-3), following the lifting of the evacuation zone in Namie town, the HU team relocated its base to the original Namie town Hall. One of the challenges for returning residents to their daily lives is rebuilding their communities. Salon-style risk communication activities, Apple Salon. have been practiced, which also contribute to rebuilding communities. Recognizing that the community among the town's residents had collapsed after their return due to long-term evacuation, the project supported the building of community bonds among the town's residents and with the town hall through door-to-door visits and salon activities, with an emphasis on building trusting relationships with the residents. The same approach has also been adopted for new migrants, helping them participate in the community and providing them with information about Namie town. In particular, it was considered extremely important to return the results of HU's activities to the residents in order to enhance their awareness regarding HU's activities, providing feedback to HU on the residents' request.

In July 2020 (Fig. 1, NU-3), NU signed an agreement on comprehensive cooperation with Okuma town, the host town of the FDNPP, to contribute to the development of a vital community by addressing various challenges to the town's revitalization. The Nagasaki University-Okuma Town Reconstruction Promotion Base was established in the Okuma town office. In December 2021, the university also agreed on comprehensive cooperation with Futaba town, the last town in Fukushima prefecture to lift its evacuation order after the accident, and established the Nagasaki University-Futaba Town Reconstruction Promotion Base within the Futaba town office. The conclusion of the agreement and the establishment of the base followed those of Kawauchi village in 2013, Tomioka town in 2016, and Okuma town in 2020. In both Okuma and Futaba towns, the NU team provided individual assistance to local residents in preparation for lifting the evacuation order on specific reconstruction and revitalization base areas. Additionally, after lifting the restriction, the NU team provided measures to reduce radiation concerns among the population and build new communities through radiation health risk communication activities. Currently, radiation monitoring and health risk communication activities are required to lift evacuation orders for difficult-to-return zones that remain in both towns.

Discussion

To encourage residents affected by the disaster to make informed decisions regarding their daily lives and activities through the provision of radiation-related knowledge and practice of self-performed dose measurements, risk communication is crucial in the early emergency and recovery phases of the 2011 FDNPP accident. Appropriate and targeted risk communication can help residents understand the situations they are confronted with and make informed decisions[26]. We summarized the risk communication activities by health and medical welfare experts required for the recovery process from lifting of evacuation orders in all formerly evacuated municipalities owing to the FDNPP accident to offer valuable insights for future disaster preparedness. The three universities, FMU, HU, and NU, conducted a long-standing activity that is a practical measure of radiation protection and public health for affected residents from scientific and technological perspectives in cooperation with the central government, local municipalities, and various experts. This study revealed the continuous development of two-way communication adapted to the needs of the recovery phase. Previous studies have reported the importance of correctly communicating radiation health risks based on public health ethics and scientific evidence[26–28]. When experts send messages to the public regarding radiation risk, an appropriate manner of risk communication with deep consideration of each individual's situation is important[1,29], and risk communication is only effective when there is trust[30]. Both HU and NU demonstrated good models of how even remote universities can provide tailored support by setting up satellite offices in evacuated municipalities with on-site staff. HU and NU models can build a relationship of trust by having experts stationed in the municipality, suggesting that close cooperation with local authorities can be achieved and effective risk communication activities can be developed.

From the early phase of the accident, the residents have been living away from their homes as evacuees for a long time, facing challenges such as separation of family members, devastation of hometowns, and collapse of communities[31,32]. Residents are also facing health concerns associated with radiation exposure and various anxieties related to rebuilding their lives in an environment that is radioactively affected[33,34]. These challenges are complex, and with the passage of time since the accident, the recovery phases have varied even within the evacuated municipalities. Notably, in Kawauchi village, 80% of the residents have already returned to their homes 10 years after the incident and have almost recovered[35]. Namie and Tomioka towns, where individuals started returning in 2017, are in the midst of recovery, with over 2000 residents living in the town[36]. Conversely,

Futaba town, despite being part of the areas with evacuation orders lifted in August 2022 and having the town office returned, still has a large portion of the area designated as a difficult-to-return zone[14]. Hence, to continue addressing the radiation health concerns of residents and respect individual decision-making, disaster-related risk communication strategies must evolve with time and employ a multi-pronged nature[37]. Our results indicate that small-scale, face-to-face consultation services are now being developed to address more individual cases. In the future, whether or not residents choose return to their homes, creating an environment in which people can consult experts on radiation exposure and health without hesitation will be crucial.

Additionally, residents across all formerly evacuated municipalities have expressed anxiety regarding physical and mental health and daily life. As FMU has continued to do, our study highlighted that providing long-term care for the mental and physical health of residents is necessary to lay the foundation for a long recovery process and address disaster medicine, including the health effects of radiation exposure. A previous study identified mental health as the largest public health problem caused by the Chernobyl accident. Since mental health is a leading cause of disability, physical morbidity, and mortality, health monitoring after radiation accidents such as Fukushima should include standard measures of well-being[38,39]. Similarly, a strong association between radiation risk perception and psychological distress was reported in the aftermath of the Fukushima disaster[7]. Other effects, such as a lack of intention to return or leave work, diminished perception of safety in the environment, and food avoidance, refer to avoidance of radiation-related matters[40]. A longitudinal study analyzing healthcare needs in areas affected by the Great East Japan Earthquake evacuation demonstrated changes in disease patterns between 2014 and 2020[41]. In recent years, the NU team have been organizing bus tours in cooperation with community groups for evacuees from Tomioka, Okuma, Futaba town at their evacuation sites. The team plans these tours to give participants a look at the reconstruction of the town, including its infrastructure, and radiation exposure levels. It is deemed important to be able to learn the recovery efforts in Tomioka, Okuma, Futaba town without having to explain much, and for residents and experts to carefully share this experience. It is believed that careful decision-making support that does not push evacuees into the corner is needed. Supporting activities to take care of physical and mental health in the long term and comprehensive health promotion activities in collaboration with radiation health risk communication are crucial. Supporting activities to take care of physical and mental health in the long term and comprehensive health promotion activities in collaboration with radiation health risk communication are crucial.

Our study findings indicate that the target group for experts' risk communication activities and public health is not only the local population but also the stakeholders directly involved in the evacuated municipalities. The International Commission on Radiological Protection recommends adopting a co-expertise process during the medium recovery phase. The purpose of this process is to share the local situation and scientific expertise among experts, professionals, and local stakeholders to a better understanding of the situation and improve living and working conditions[42]. Infrastructure re-development, creation of local jobs, and restoration of daily life-related systems are expected to be provided in the recovery phase, which can help people decide whether to return to their homes. Stakeholders are expected to be representatives of community associations, local government officers, doctors, public health nurses, nurses, and nursing care workers. These stakeholders, directly involved in evacuated municipalities, can help people decide whether to return home. Activities by stakeholders, such as the co-expertise process, are essential for effectively implementing measures in a collaborative manner to address all health issues, including radiation exposure. In particular, it is important that stakeholders have sufficient competence to comprehensively meet people's needs. The Ministry of the Environment of Japan has established the Support Center for Radiation Risk Communication Consultants to support the activities of counselors, stakeholders, and the staff of Fukushima Prefecture and various municipalities. The center supports various activities held by municipal officials and consultants in Fukushima Prefecture, such as workshops and opinion exchange meetings. Continuing expert communication activities to support social care professionals involved in resident care remains crucial. Through the collaboration of radiation protection experts who will work with the population over the long term and stakeholders implementing local projects, it is important to contribute to developing self-help mechanisms for the affected population, which can complement the measures promoted by responsible organizations such as national and local authorities.

While we strive to provide valuable insights and lessons learned from the Fukushima recovery efforts, we acknowledge several limitations inherent in this study. The unprecedented scale and urgency of the Fukushima Daiichi nuclear disaster necessitated immediate and adaptive responses, often prioritizing the safety and well-being of affected individuals over research-focused methodologies. Consequently, it was not feasible to implement systematic or standardized data collection or evaluation frameworks during the recovery process. Moreover, the data presented in this study are based on the best efforts of various authorities and organizations responding to the disaster in real-time, rather than pre-designed research protocols. This limits the generalizability and replicability of the findings and the ability to apply conventional qualitative or quantitative analysis frameworks.

Despite these constraints, we believe that documenting and sharing these experiences is crucial for global disaster preparedness and recovery efforts. We hope that this manuscript serves as a resource for understanding the challenges and strategies involved in large-scale disaster recovery, even in the absence of ideal research conditions. Furthermore, we are fully aware that not everyone may consider all the activities undertaken by these three universities to be 100% scientifically, ethically, or socially correct. The process of recovery from a nuclear accident involves diverse perspectives, including debates on the legitimacy of nuclear power itself. We do not claim that our activities are universally right for everyone. This study focused on the risk communication activities of health and medical welfare professionals who directly addressed health risks associated with the accident at the community level. However, it is important to acknowledge that several other entities, beyond medical professionals, e.g., lawyers, were also involved in providing information and conducting communication activities both within and outside Fukushima Prefecture. This broader involvement presents certain limitations to the study.

Current FDNPP accident-related topics, such as the decommissioning of melted-down reactors and the commencement of the discharge of advanced liquid processing system-treated water into the sea in August 2023[43,44], will continue to be closely related to the local population in Fukushima Prefecture. Therefore, it is necessary to understand the consultation needs of local residents and provide effective health risk communication. Future challenges for practical risk communication activities include how to communicate directly with residents who continue to evacuate as the return of affected municipalities progresses and how to contribute to health, welfare, and medical services in new communities in returned municipalities where the return rate is not high[45]. A number of residents are still living away from their homes as evacuees. They face difficulties related to health concerns about radiation exposure and various anxieties about rebuilding their lives. On the other hand, a number of residents have returned to municipalities where evacuation has already been lifted, and they are still grappling with the conflict of having to build new towns while some evacuation-ordered zones have not been lifted. Such a complex situation brought by the FDNPP accident cannot be clearly understood as one side is right and the other side is wrong in society where diverse values are respected. Such conflicts and divisions should be mediated, e.g., support measures for evacuees facing difficulties due to evacuation should not be denied, as well as individual well-being should not be threatened due to the fragility of the communities in affected area. Considering the various difficulties faced by residents, experts need to collaborate with stakeholders in the affected areas, live together with residents, and continue risk communication based on objective dose and health risk assessments. Then, it is considered important to fully respect the decisions of individuals, regardless of whether they decide to return or not. Assessing the effectiveness of risk communication activities and sharing Fukushima's recovery efforts globally is essential to improve preparedness for future disasters.

Conclusion

Our results showed the distinctive activities of three universities in implementing radiation protection and public health initiatives for the affected population. These results highlight the importance of continually developing two-way communication strategies tailored to the evolving needs of the recovery phase. They also emphasize the significance of integrating comprehensive health promotion efforts with radiation health risk communication to ensure sustained focus on both physical and mental health. Additionally, this study highlights the crucial role of expert communication in supporting social care professionals involved in resident care. The results of this study are valuable for understanding the impact of sustained expert communication activities on long-term community engagement.

Materials and methods

The risk communication activities required for the recovery process in all formerly evacuated municipalities identified in this study were selected based on the following criteria: (1) continuous implementation in Fukushima Prefecture from immediately after the FDNPP accident to the present (March 2023), (2) alignment with the needs of the affected population of all formerly evacuated municipalities, and (3) execution by health and medical welfare experts. This led to the identification of the activities conducted by health and medical welfare experts from three universities: Fukushima Medical University (FMU), Hirosaki University (HU), and Nagasaki University (NU). The study was conducted in accordance with the agreements between the universities and municipalities. The rationale and purpose of the study were explained to each municipality (Tamura city, Minamisoma city, Kawamata town, Hirono town, Naraha town, Kawauchi village, Katsurao village, Iitate village, Namie town, Tomioka town, Okuma town and Futaba town). After writing the manuscript of this study, we reported its contents to the local government. We believe that carefully sharing the contents of our manuscript with the local governments helps to strengthen the relationship of trust between the local governments and the universities.

In this study, we divided the recovery phase from the immediate aftermath of the accident to the present into the following three phases.

Initial response and early recovery phase from the time of the accident to the reorganization of the evacuation order zone; from March 2011 to April 2013

The central government issued evacuation orders to residents living near the plant immediately after the accident[46]. In the areas where the potential annual cumulative radiation dose estimated from the air dose rate exceeded 20 mSv, the area outside the 20 km radius of the plant was determined as the "planned evacuation zone," and the area within 20 km of the plant was determined as the "restricted area" and access was prohibited in principle. This led to 12 municipalities under evacuation orders, of which nine towns and villages relocated their town functions outside the town and village. Therefore, evacuation orders in most municipalities continued, and no return was possible, except in Hirono town and Kawauchi village.

Mid-term recovery phase from the reorganization of evacuation zones to targeting lifting of the evacuation orders "zone in preparation for lifting of the evacuation order" and "restricted residence area"; from March 2013 to March 2020.

In December 2011, three reactors that had meltdowns in March 2011 had officially reached "cold shutdown." To facilitate the return of residents and to promote the reconstruction and rehabilitation of the area, the central government reorganized the restricted areas and divided the evacuation zone into three zones: "zone in preparation for lifting of the evacuation order," "restricted residence area," and the "difficult-to-return zone." Subsequently, the evacuation order areas in the Miyakoji area of Tamura city, Kawauchi village, Naraha town, Katsurao village, Minami Soma city, the Yamakiya area of Kawaamata town, Iitate village, Namie town, Tomioka town, Okuma town, and Futaba town were lifted in 2020, and evacuation orders in all areas, except the difficult-

to-return zone, were lifted[47]. Therefore, evacuation orders were lifted in sequence with the reorganization of zones, and most municipalities began to return.

Recovery phase from the establishment of "specific reconstruction and revitalization sites" in the difficult-to-return zone to the lifting of "specific reconstruction and revitalization sites"; from september 2017 to april 2023.

Since 2017, the central government has newly established the "specific reconstruction and revitalization site" within the difficult-to-return zones and defined areas where people can live within the difficult-to-return zones, which were supposed to restrict residency in the future[47]. The evacuation orders on the specific reconstruction and revitalization site in Katsurao village and Okuma town were lifted in June 2022 and Futaba town in August 2022, with Futaba town being the last of the nine evacuated towns and villages to have its town office return. Consequently, most municipalities have returned and are now addressing regional reconstruction, regeneration, and daily life issues. This period coincides with most municipalities returning to their homes and striving to regain normal daily life through local reconstruction.

The description of the results is based on the risk communication activities required by the experts of the respective institutions in local recovery from lifting of the evacuation order in all municipalities in the formerly evacuated areas. The focus is on each institute, the recovery phase, and the activities that have been required ("changes in risk communication activities according to the recovery process" and "future challenges in risk communication activities").

Data availability

The datasets used and/or analysed during the current study available from the corresponding author on reasonable request.

Received: 18 October 2024; Accepted: 14 March 2025
Published online: 01 April 2025

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Acknowledgements
We thank all those who cooperated with us, especially Dr. Masaharu Maeda, Dr. Tetsuya Ohira, Dr. Mika Sato and Mr. Keita Akakura from Fukushima Medical University; Dr. Ruriko Kidachi from Aomori Chuo Gakuin University; Dr. Mayumi Shimizu, Dr. Teruko Horiuchi, Ms. Mayumi Meijo, and Ms. Michiko Ohtani from Hirosaki University.

Author contributions
Orita, Tanaka and Amir wrote the main manuscript text and Matsunaga, Kashiwazaki, Xiao, Akata, Miura, Kashiwakura, Ito, Abe, and Tamaki collected data for the research paper. Takamura, Tokonami, and Tsubokura supervised the project. All authors reviewed the manuscript.

Funding
This study was supported by the Research project on the Health Effects of Radiation organized by the Ministry of the Environment, Japan.

Declarations

Competing interests
The authors declare no competing interests.

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