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Mortality risk associated with nuclear disasters depends on the time during and following evacuation of hospitals near nuclear power plants: An observational and qualitative study

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ABSTRACT

This study aimed to examine the factors correlated with emergency evacuations on patients' prognosis in hospitals severely affected by the Fukushima Daiichi nuclear power plant (FDNPP) accident in March 2011, and to recommend measures mitigating potential health risks among them in future disasters. Seven hospitals within a 20-km radius of the FDNPP were designated as the evacuation zone, of which three hospitals located within a 5-km radius were examined. Information regarding hospital emergency evacuation among the three hospitals from previous literature and official reports were integrated and interview outcomes of staff at each hospital were qualitatively analyzed using thematic analysis. Our thematic analysis identified four themes: insufficient preparedness for disaster, difficulty of patient evacuation, insufficient materials, and insufficient information. Comparison of the three hospitals located within a 5-km radius of the FDNPP revealed that hospitals with several patients or those with a high proportion of bedridden or critically ill patients faced more difficulty in emergency evacuation and experienced higher fatalities. In addition to individual evacuation plans, for future preparedness, external and public organizations should prepare disaster responses such as procedures to integrate information on the status of each medical facility and measures to support them individually.

Abbreviations: DMAT, Disaster Medical Assistance Team; EPZs, emergency planning zones; FDNPP, Fukushima Daiichi Nuclear Power Plant; GEJE, Great East Japan Earthquake; JSDF, Japan Self-Defense Forces; PAZs, precautionary action zones; TMI, Three Mile Island; UPZs, urgent protective action planning zones.

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1. Introduction

The fundamental goal of healthcare providers is to support the health of medically and socially vulnerable patients. Considering their inability to independently access healthcare, vulnerable populations such as the elderly, those with disabilities, and hospitalized patients are at a high risk of poor physical, psychological, and social health outcomes [1,2]. Recent disasters have posed challenges to public health authorities in protecting and maintaining healthcare access to vulnerable populations during emergency situations [3,4]. This necessitates consolidating past experiences and improving future disaster countermeasures, including regional evacuation plans and medical care provision systems for vulnerable individuals.

Previous studies have demonstrated the potential adverse impacts of emergency evacuation on vulnerable populations during disasters [5–7]. Meanwhile, as sheltering-in-place (no evacuation) was also found to have high mortality risk [8], these contradictory facts make the decision making regarding evacuation during a disaster even more difficult. When an evacuation decision is made, institutionalized patients in hospitals and nursing homes are unable to evacuate without assistance, thus necessitating equipment and technical support for healthcare-related facilities to conduct safe emergency evacuation. Maxwell assessed the organizational responses of four hospitals located within a 20-mile radius from the power plant during the 1979 nuclear accident at Three Mile Island (TMI) [9]. Detailed emergency activities were classified into five categories as follows: census reduction, staffing, administrative response, emergency/critical care services, and hospital evacuation and transportation. All four hospitals conducted emergency evacuation of their patients; however, severely ill patients were retained in the risk zone. Furthermore, despite the Chernobyl disaster of 1986 involving the largest release of radioactive materials in history, there is inadequate information available on the evacuation of hospitalized patients in radiation-contaminated areas during the accident. Therefore, there is limited documentation on the implementation of emergency evacuation for hospitalized patients, particularly those with critical illness, from past nuclear accident scenarios.

On March 11, 2011, the Great East Japan Earthquake (GEJE) struck the northeastern part of Japan and triggered a tsunami that caused a nuclear accident at the Fukushima Daiichi Nuclear Power Plant (FDNPP). The Japanese Government eventually ordered the mandatory evacuation of residents living within a 20-km radius of the FDNPP [10]. Following the evacuation directives, all residents in the aforementioned areas had to evacuate and the vulnerable population, including inpatients, those with disabilities, and institutionalized elderly individuals, were no exception [11]. In the medium to long term, an increase in mortality in aged care facilities located within a 20–30 km radius of the FDNPP was reported due to the unexpected and sudden evacuations following the accident [5–7]. Furthermore, in the emergency evacuation of psychiatric inpatients, in addition to the underlying psychiatric conditions, evacuation distance and patient condition with older age and physical complications impacted their long-term mortality [12,13]. Meanwhile, in the short term, the Japan Self-Defense Forces (JSDF) provided secondary emergency assistance for hospitals outside the evacuation zone (within 20–30 km radius of the FDNPP) in transporting patients, and no deaths were reported during their transportation; however, there were shortages of human and material resources both inside and outside the hospitals [14,15]. Contrarily, emergency evacuations within the 20-km radius were more urgent and conducted in more severe circumstances than those outside the zone [16–18]. Previous literature reported that approximately 2200 inpatients and nursing home residents were forced to emergently evacuate from the area [19–22], and at least more than 50 older adults among them lost their lives during the evacuation because of the physical burden caused by emergency evacuations [23–25]. However, there is limited information available on the characteristics and factors that particularly affected the prognosis of patients due to emergency evacuations in hospitals near the FDNPP.

We aimed to evaluate and compare the situation and factors associated with emergency evacuations and the short-term prognosis of patients in all three hospitals located within a 5-km radius of the FDNPP. These three hospitals were located very close to the nuclear power plant and required urgent evacuation, and also contained many seriously ill patients; they are therefore worthy of evaluation for future disaster preparedness. From this study, we aimed to propose measures directed at minimizing potential health risks among institutionalized patients during forced evacuation in future disasters using qualitative methods.

2. Material and methods

2.1. Study setting and patients

Prior to the FDNPP accident, areas within a 10-km radius of nuclear power plants were designated as “emergency planning zones” (EPZs) [26]. Within each EPZ, local governments, emergency managers, and public health providers collectively conducted disaster prevention measures to protect their residents in the event of a nuclear accident. However, following the FDNPP accident, the Japanese government issued mandatory evacuation orders regardless of the administrative setup. Responding to the FDNPP accident, the Nuclear Regulation Authority of Japan designated areas within a 5-km and 5.30-km radius of nuclear power plants as “precautionary action zones” (PAZs) and “urgent protective action planning zones” (UPZs), respectively.

The Fukushima Daiichi and Daini nuclear power plants were severely damaged by the tsunami, which followed the earthquake at 2:46 p.m. on March 11, 2011. At 9:23 p.m. on that day, the Japanese central government issued an evacuation order for residents within a 3-km radius of the FDNPP [27]. At 5:44 a.m. the following day, the evacuation zone was further extended to areas within a 10-km radius of the FDNPP. At 6:25 p.m., the government further extended the evacuation order zone to a 20-km radius of the FDNPP. Regarding the Fukushima Daini nuclear power plant, located approximately 11.5 km south of the FDNPP, evacuation orders were issued at 7:45 a.m. on March 12 for areas within a 3-km radius and at 5:39 p.m. for areas within a 10-km radius.

The evacuation directive initially issued by the Japanese government immediately after the FDNPP accident was classified into the following categories: (i) an evacuation zone, located within a 20-km radius of the FDNPP, and (ii) an emergency evacuation preparation zone located between 20 and 30 km from the FDNPP. Immediately after the accident, forced emergency evacuations were

performed at all seven hospitals located in the evacuation zone. Of these seven hospitals, three hospitals, namely the Futaba Hospital (Okuma Town, Fukushima Prefecture), the Futaba Kosei Hospital (Futaba Town, Fukushima Prefecture), and the Fukushima Prefectural Ono Hospital (Okuma Town, Fukushima Prefecture), were located within a 5-km radius of the FDNPP (Fig. 1). Among these three hospitals, emergency evacuations were conducted in a particularly urgent manner. In this review, we evaluated and reviewed the emergency evacuations of hospitalized patients at these three hospitals. None of the three hospitals had a pediatric department at the time of the FDNPP accident, and although children and newborns are naturally vulnerable, they were not included in this study.

2.2. Study design and data collection

We collected information on the results of emergency hospital evacuations conducted at the three hospitals in 2011 during the FDNPP accident. To objectively evaluate those evacuations, we reviewed articles previously published by peer-reviewed medical journals [20,23,24] and official reports published by the Japanese government and private investigation committee on the accident [28,29]. We also collected basic information about these hospitals, including the hospital type, the number of beds and patients during the accident, and the number of deaths during and immediately after the evacuations. Whereas we included the number of deaths 3 months after the FDNPP accident at the Futaba Kosei Hospital, those at the remaining two hospitals were not included because of the unavailability of verifiable data.

2.3. Interview

We conducted semi-structured interviews with the medical and office staff at these hospitals, as well as the administrative, JSDF, and Disaster Medical Assistance Team (DMAT) staff, to assess the credibility of the gathered information. A total of seven interviewers (TS, SN, AO, AH, TZ, and MT among the authors of this article) interviewed 36 subjects. The interviews were conducted between October 1, 2020 and March 16, 2021. In the semi-structured interviews, in addition to what happened during the evacuation, the interviewers asked interviewees the following questions:

- What were the medical challenges imposed on the patient during the evacuation?
- What were some of the non-medical challenges imposed on the hospital staff as well as the patients?
- What methods and support do you need to solve these problems?

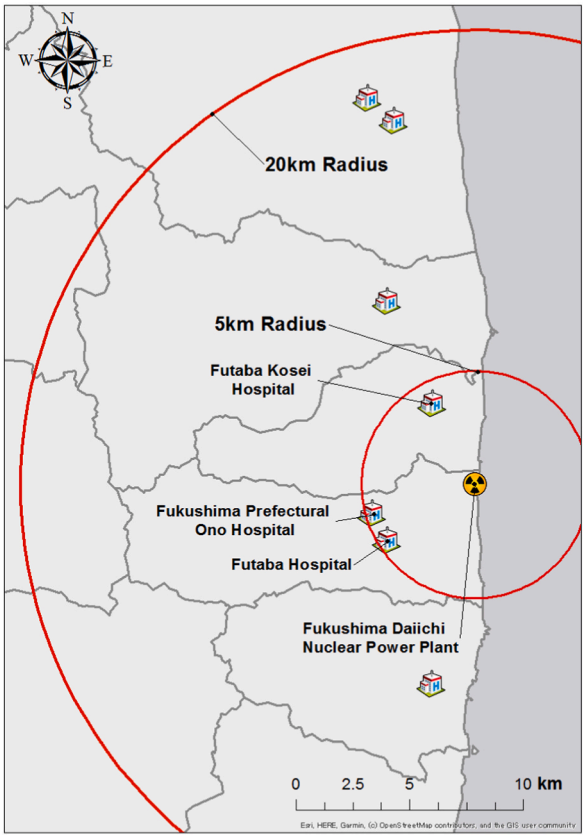

Fig. 1. There were seven hospitals located within a 20-km radius of the FDNPP, which were issued evacuation orders by the government immediately after the accident. Of these seven hospitals, three hospitals, namely the Futaba Kosei Hospital (Futaba Town, Fukushima Prefecture), the Futaba Hospital, and the Fukushima Prefectural Ono Hospital (Okuma Town, Fukushima Prefecture), were located within a 5-km radius of the FDNPP.

These three questions were considered the most efficient and meaningful based on a discussion among all authors, to elicit the challenges in hospital evacuation at the time of the FDNPP accident and lessons learned for the next disaster from the interviewees. The duration of each interview was approximately 1 h to ensure that the information power was sufficient. Each interview was transcribed, anonymized, and shared with the research group, who ensured consistency with previously published findings.

2.4. Analysis

Among the interviews conducted, interviews with seven participants involved in the evacuation of the three hospitals and the interview transcripts compiled in a book on the evacuation of Futaba Hospital were categorized and analyzed [30]. Initial analysis including code and theme generation was conducted by TS and MT. Theme definition and naming were performed by all authors. Table 1 shows the characteristics of seven participants who were interviewed. Thematic analysis was used to understand the troubles and difficulties of emergency evacuation in the three hospitals. Thematic analysis is a method used for the systematic identification and organization of patterns of meaning (themes) across a dataset [31]. It is suitable for research studies that seek to make sense of shared meanings and identify unique experiences.

2.4.1. Comprehension

Interviews were read repeatedly to establish initial interpretations and patterns.

2.4.2. Initial coding

Initial coding was done to structure the interview data. Three main research questions were considered for coding in this study. Codes were created for each of the research questions as below. 38 codes were generated (e.g., “Means of patient transport”, “Floating destination”, “Insufficient labor force”, and “Chain of command for evacuation instructions”).

2.4.3. Theme search

The data were analyzed and the codes were categorized into potential themes (Appendix 1).

2.4.4. Theme consideration

Themes were identified in the process through which participants experienced trouble during the emergency inpatient evacuation, the problems and concerns they had during the evacuation, and what they did to solve these problems.

2.4.5. Theme definition and naming

During this stage, authors returned to the excerpts of collated data to refine each theme and ensure a coherent explanation. A consensus was reached among the authors. Theme 1 “insufficient preparedness for disaster” referred to insufficient preparedness for evacuating inpatient and no assumption for a large-scale radiation disaster. Theme 2 “difficulty of patient evacuation” described the difficulty during emergency hospital evacuation for hospital staff, evacuation supporter, and inpatients. Theme 3 “insufficient resources” regarded depleting both human and medical resources during emergency hospital evacuation. More specifically, requisite materials could be different in each setting such as before and during evacuation. Finally, Theme 4 “insufficient information” considered lack of chain of command and control of the hospital evacuation during the disaster.

2.5. Ethical considerations

This study was approved by the Institutional Review Board of Minamisoma Municipal General Hospital (approval number: 2–07) and Fukushima Medical University (approval number: 2019–269). All interviewees of this study were informed about the potential discomfort or adverse events they could experience while participating in this study, and they provided informed consent for the study. The study was performed in accordance with the principles of the Declaration of Helsinki.

3. Results

3.1. Emergency evacuation in hospitals located within a 5-km radius of the FDNPP

3.1.1. Futaba Hospital

A total of 338 patients were admitted to the Futaba Hospital on the day of the disaster (i.e., March 11, 2011). Of these, over 20 patients required parenteral nutrition via a venous catheter, over 40 patients required enteral tube feeding, and over 100 patients were unable to move independently. In addition, despite minor structural damage to the hospital buildings, the earthquake caused severe infrastructure damage. Following the government evacuation order at 5:44 a.m. for residents living within a 10-km radius of the

Table 1
Characteristics of the participants.

	Occupation	Position	Sex	Involved hospital
Particiapant 1	Nurse	None	Female	Futaba Kosei Hospital
Particiapant 2	Occupational therapist	None	Male	Futaba Hospital
Particiapant 3	Japan Self Defense Force	Colonel	Male	Futaba Hospital
Particiapant 4	Medical doctor (Cardiology)	Director	Male	Fukushima Prefectural Ono Hospital
Particiapant 5	Office work	General affairs	Male	Fukushima Prefectural Ono Hospital
Particiapant 6	Pharmacist	None	Male	Fukushima Prefectural Ono Hospital
Particiapant 7	Medical doctor (Internal Medicine)	Director	Male	Futaba Kosei Hospital

FDNPP on March 12, the hospital authorities struggled to arrange an emergency patient evacuation. On the afternoon of March 12, 2011, 209 patients who could move independently were evacuated using a coach bus, that was requested for by the hospital director from the local government that morning. The hospital staff made several requests to the prefectural police, fire station, and the JSDF, who provided evacuation support in the nearby vicinity to coordinate transportation assistance; however, the request was not accepted, and the evacuation was significantly delayed.

Consequently, the hospital was forced to provide continuous healthcare with few caregivers remaining in the hospital and a disrupted infrastructure. In particular, electricity disruption forced the caregivers to manually perform sputum aspiration using a syringe, and the lack of manpower led to insufficient care. These circumstances resulted in the death of four patients at the hospital prior to evacuation. Thirty-four patients were evacuated by a coach bus provided by the JSDF on March 14, 2011. However, three patients died during the evacuation, whereas 11 patients died on the day of evacuation. Of the 90 patients left at the hospital until the evacuation by the JSDF between the mornings of March 15 and 16, 2011, 24 died during or shortly after their transfer to the destination facilities. In the process of emergency evacuation, 39 patients died and one patient with dementia went missing. The first evacuation by a coach bus was controlled by the hospital's own staff, while subsequent evacuations were led by the JSDF team. In the evacuations conducted by the JSDF, poor communication in advance led to some patients being left behind. A drill for a radiation-related disaster had not been implemented before the accident.

3.1.2. Futaba Kosei Hospital

As of March 11, 2011, 136 patients were admitted to the Futaba Kosei Hospital. While the electricity supply was continuous, the water and gas supply were temporarily interrupted by the earthquake but were quickly restored. Following the evacuation order issued on the early morning of March 12, the hospital officials decided to evacuate patients who could move independently using coach buses and trucks provided by the JSDF. On the afternoon of March 12, the hospital director received information from the Fukushima Prefecture Disaster Task Force about the seriousness of the situation at the FDNPP, and eventually decided to evacuate all patients, including those who were seriously ill or unable to move independently. From the evening of March 12 to early morning the following day, all patients were evacuated using JSDF helicopters. The patients and hospital staff were grouped together for safe evacuation. Thus, all patients were successfully evacuated by the morning of March 13. In contrast, four patients, including ones with terminal cancer, lost their lives before the evacuation was completed. The evacuation was mainly controlled by the hospital's own staff, while evacuations by the JSDF helicopter were supported by members of the JSDF. Nuclear emergency preparedness training and disaster drills had been implemented once a year, but the drill only involved limited hospital staff and FDNPP workers.

3.1.3. Fukushima Prefectural Ono Hospital

Only 46 patients were admitted to the Fukushima Prefectural Ono Hospital during the disaster because it had planned to merge its function with the Futaba Kosei Hospital, and both hospitals had reduced their number of inpatients. Despite the exact number being unknown, the hospital staff who participated in the interview reported that there were <10 patients who could not move independently. The hospital's infrastructure, including gas, power, and water supply, was initially disrupted owing to the earthquake, but the electricity supply was resumed from emergency power generators. Since the hospital building was partially damaged, the staff assembled all patients in a less damaged area and continued to provide care. The hospital was designated as a medical institution for initial radiation exposure; therefore, the staff requested the local prefectural government to arrange patient transport during an emergency meeting at the off-site center (regional response headquarters) of the FDNPP in Okuma Town at approximately 3:00 a.m. on March 12, 2011. At approximately 7:00 a.m. on that day, two large buses arrived at the hospital, and all 46 inpatients were successfully evacuated by 8:15 a.m. The patients who could walk independently were evacuated using buses, whereas those who could not were evacuated using personal vehicles of the hospital staff and ambulances provided by the local fire station. On the morning of March 12, all patients were transported to the medical facility in Kawauchi Village, located in an area outside the 20-km radius of the FDNPP. None of the patients died during evacuation. As of March 14, 2011, the final destination of hospital transfer for all patients was coordinated, and subsequently all hospital employees were discharged as part of the layoffs. The evacuation was essentially controlled by the hospital's own staff. Nuclear emergency preparedness training and disaster drills had been implemented once a year, but the drill only involved a limited number of hospital staff and FDNPP workers.

3.2. A qualitative analysis results

Our thematic analysis identified four themes: insufficient preparedness for disaster (Themes 1), difficulty of patient evacuation (Theme 2), insufficient materials (Themes 3), and insufficient information (Theme 4).

The datasets from Theme 1: Insufficient preparedness for disaster revealed a lack of preparedness for the radiation disaster itself and for hospitals to evacuate all patients and staff in the event of a disaster. The national government and its disaster preparedness guidelines did not anticipate that such a large-scale disaster would necessitate evacuation at medical institutions including hospitals and nursing homes. In addition, Theme 2: Difficulty of patient evacuation demonstrated that difficulties in emergency evacuation from hospitals depends on the status of the patient, mild or severe, and that the difficulties experienced by staff and the evacuation supporters in a radiation-released disaster are distinct from those in a normal disaster. Furthermore, Theme 3: Insufficient materials and Theme 4: Insufficient information highlight the fact that medical resources and information were inadequate in hospitals before the evacuation began and during the process of emergency evacuation from hospitals in the radiation-released disaster.

3.2.1. Theme 1: insufficient preparedness for disaster

Medical professionals interviewed noted that their hospitals were poorly prepared for radiation hazards.

"The assumption was that radioactive contamination in Japan would only occur at or slightly beyond the nuclear power plant site, and that a situation that would force the evacuation of a hospital was unlikely." (Participant 7)

"The hospital had implemented the nuclear emergency preparedness training and disaster drills, designated as a regional evacuation action plan for the sake of form. The drill did not involve the actual hospital staff, patients, nor cooperated with the local community." (Participant 2)

Therefore, in the actual evacuation of the hospitals, workers faced various problems such as the handling of medical records and selection of receiving hospitals.

"*There was no disaster manual at the time. Furthermore, medical records were paper, and there was confusion regarding how to transport patients and how to handle medical records.*"(Participant 1)

"We were not informed where we would be evacuated to and began to move." (Participant 4)

"The situation could have been different if a partnership with the recipient of the evacuation had been established in advance." (Participant 2)

3.2.2. Theme 2: Difficulty of patient evacuation

Several interviewees noted various difficulties in the evacuation of critically ill patients, including the inability to secure transportation and maintain care before and during the evacuation, which could have directly led to the death of patients.

"Traveling for hours with people who were seriously ill in the seats of a sightseeing bus was in itself quite stressful and hard on their bodies. In fact, several patients died during the trip." (Participant 3)

"After the evacuation by sightseeing bus, the critically ill patients remained in the hospital. However, no subsequent evacuation vehicles came to the hospital." (An interview book from Futaba Hospital)

The interviews revealed that the evacuation of mildly ill patients presents different kinds of difficulties than the evacuation of critically ill patients, such as difficulties in selecting patients who can evacuate independently and the process of moving large groups of patients.

"Our hospital had many people with chronic mental illnesses, some of whom were socially hospitalized. In other words, we had the largest number of beds. This may have been a difficult factor in the evacuation." (Participant 2)

"For evacuating by sightseeing bus, as many physically strong people as possible had had to be selected." (An interview book from Futaba Hospital)

Staff involved in the evacuation and evacuation supporters noted that it was difficult to secure means of transportation and select necessary medical materials during the confusing acute phase of a disaster.

"At the very least, we should bring this antibiotic, etc., consulted with doctors, and determined which medications we need to bring with." (Participant 6)

"In the evacuation, we took the minimum amount of medicine with us, but left the medical records at the hospital due to their bulkiness." (An interview book from Futaba Hospital)

"The evacuation of all patients was successfully completed merely by luck. Our hospital was able to arrange patient transport and transfer location with the off-site center in the early stage and immediately following the disaster, because one of the hospital staff was accidentally at the center during the disaster." (Participant 6)

3.2.3. Themes 3: insufficient resources

The hospitals faced a shortage of personnel and medical supplies prior to commencement of the evacuation. More specifically, this referred to the difference of the requisite materials in each setting such as before and during evacuation.

"There was no replenishment of medical staff, of course." (Particaipant 1)

"The most nerve-wracking event during the night was suctioning. Since electricity was not available, electric suctioning device did not work, so we had to repeatedly attach a tube to a syringe and suction." (An interview book from Futaba Hospital)

"Because the water supply was not available, the patients were encouraged to defecate on a portable toilet, which the nursing staff then flushed into a nearby creek." (An interview book from Futaba Hospital)

Even during the evacuation, there was a shortage of personnel and supplies for patient transport.

"It was difficult to move patients because there were no stretchers or other supplies and not enough personnel to move them." (Participant 1)

"We really didn't have enough staff to get the patients on and off the bus. There were times when the number of patients did not match up, or patients almost got on the wrong bus. We had to be very careful in such cases." (Participant 2)

The lack of maintained infrastructure, particularly electricity and water, affected the continuity of patient care.

"The water supply was ruined and we had dirty water. Electricity was generated by the hospital's own generator, but there was no heating, and it was extremely cold." (Participant 1)

"On the night of the day, we had to care for critically ill patients in the absence of electricity, and we used candlelight to adjust the speed at which the IV drips fell." (An interview book from Futaba Hospital)

"One of the critically ill patients needed oxygen, but ran out." (Participant 6)

3.2.4. Theme 4: insufficient information

Due to the cutoff of communication methods and the disruption of infrastructure, information related to the nuclear accident was not conveyed to the hospitals, which had a negative impact on the internal chain of command and cooperation with outside organizations that aimed to support them in the hospital evacuation.

"Since there was no contact from the outside and we did not believe the plant was in crisis, we thought it would be better to wait for the situation to be resolved rather than to move inadvertently." (Participant 7)

"The story changed two or three times: "We don't have to evacuate now," or "We will evacuate after all."" (Participant 1)

"If we (the rescue team) had known even some of the information about the hospital's situation before we left, we could have prepared many things, but we had no information." (Participant 3)

3.3. Comparison of factors associated with evacuation in all three hospitals within a 5-km radius of the FDNPP

Table 2 outlines the background of the three hospitals within a 5-km radius of the FDNPP on March 11, 2011. The Futaba Hospital is a private hospital, whereas the Futaba Kosei Hospital and the Fukushima Prefectural Ono Hospital are publicly funded and had limited number of inpatients prior to the accident; this is because they were scheduled to merge their functions by the end of March 2011. Contrarily, the majority of inpatients admitted at the Futaba Hospital were psychiatric patients, with a considerable proportion being bedridden. In addition, the number of hospital staff was relatively smaller than the number of patients (Table 2).

Table 3 summarizes the detailed timing of evacuations and means of transportation at the three hospitals. The evacuation order for residents within a 10-km radius of the FDNPP was issued at 5:44 a.m. on March 12, 2011, a day after the GEJE and a subsequent tsunami. While emergency hospital evacuation in the Futaba Kosei Hospital commenced in the afternoon of March 12 following the advice of the Fukushima Disaster Task Force, the remaining two hospitals initiated the evacuation of patients in the morning directly following the government's evacuation order. Furthermore, The Futaba Kosei Hospital had undisrupted infrastructure, including electricity, gas, and water supply, whereas the others had completely lost all infrastructure. The above-mentioned differences in the status of hospital infrastructure may have led to different timings of evacuation decisions.

Despite completing the evacuation of all patients from the Fukushima Prefectural Ono Hospital within 30 min, evacuations from the Futaba Hospital and the Futaba Kosei Hospital took approximately 24 h and 83 h, respectively. Thus, 39 patients (11.5%) and four patients (2.9%) died at the Futaba Hospital and the Futaba Kosei Hospital, respectively, during or immediately after the evacuation. However, no deaths directly attributed to the emergency evacuation were registered at the Fukushima Prefectural Ono Hospital. According to the publicly available records on evacuation-related deaths at the Futaba Kosei Hospital, the mortality among evacuated inpatients increased during longer-term follow up, with 17 deaths (12.5%) occurring at 3 months after the accident. All three hospitals were located within a 5-km radius of the FDNPP; however, they lacked specialist expertise in nuclear disaster management and control, and had rarely conducted adequate nuclear emergency preparedness training and disaster drills.

4. Discussion

This study reported on the emergency hospital evacuation process implemented at three hospitals within a 5-km radius of the FDNPP, and analyzed the difficulties experienced during the hospital evacuations using thematic analysis techniques. Our thematic analysis revealed that hospitals located near the FDNPP were not fully prepared to evacuate patients in the event of a radiation-released disaster; that taking into account the characteristics of both mildly and severely ill patients during evacuation was a major concern in emergency evacuation; and that the means of patient transportation, human and material medical resources, and

Table 2
Background of the three hospitals within 5 km of the Fukushima Daiichi nuclear power plant.

	Futaba Hospital	Futaba Kosei Hospital	Fukushima Prefectural Ono Hospital
Hospital type	Private	Private/Public[a]	Public
Distance from the FDNPP, km	4.6	3.9	4.7
Number of bed, n	350	260	150
Type of bed, n	Psychological	General/Psychological	General
Number of inpatients, n	338	136	46
Number of bedridden or immobile inpatients, n (%)	129 (38.1%)	40 (29.4%)	<10 (<21.7%)
Number of staff in hospital, n	65	150	89

[a] Futaba Kosei Hospital was a hospital established by Fukushima Prefectural Agricultural Cooperatives.

Table 3
Evacuation details and disaster preparedness in three hospitals within the 5-km radius of the FDNPP.

	Futaba Hospital	Futaba Kosei Hospital	Fukushima Prefectural Ono Hospital
Factors that led to the final decision to evacuate	evacuation instruction from the government	advice from the Disaster Task Force	evacuation instruction from the government
Transportation measures used in emergency evacuation	bus, JSDF vehicles	bus, JSDF vehicles, JSDF helicopter	bus, ambulance, private car
Infrastructural supply (water, electricity, and gas)	all disrupted	transiently disrupted (water and gas)	all disrupted
Time of evacuation instruction	5:44 a.m., March 12		
Time of evacuation decision	8:00 a.m., March 12	6:40 a.m., March 12[a]	6:00 a.m., March 12
Time of evacuation initiation	2:00 p.m., March 12	8:30 a.m., March 12	7:40 a.m., March 12
Time of evacuation completion	0:35 a.m., March 16	8:00 a.m., March 13	8:10 a.m., March 12
Time required for evacuation, hour	82.5	23.5	0.5
Medical management during evacuation	interrupted	continued	continued
Number of fatalities during or immediately after evacuation, n (%)	39 (11.5%)	4 (2.9%)	0 (0%)
Number of fatalities at 3 months after the accident, n (%)	unknown	17 (12.5%)	unknown
Drill for radiation related disaster	none	implemented once a year	implemented once a year
Availability of experts for radiation	none	none	none

[a] Futaba Kosei Hospital first decided to evacuate a part of patients who could move, and then made the decision to evacuate all patients at p.m. March 12.

information communication were likely to be insufficient during the evacuation process. Future disaster countermeasures in hospitals will need to take these factors into account. Furthermore, a comparison of factors associated with evacuation in the three hospitals revealed that the mortality risk of inpatients increased with prolonged evacuation duration, hospital scale, and the number of critically ill patients admitted to the hospital. After integrating this information, the mortality risks and substantial physical difficulties of forced emergency evacuation for critically ill patients hospitalized in large medical facilities following the nuclear disaster would provide valuable insights to all stakeholders to make decisions and support safe and effective emergency evacuation in the event of a future emergency.

The thematic analysis showed that the three hospitals located within 5-km radius of the FDNPP had been poorly prepared for radiation hazards, particularly for urgently evacuating all staff and all patients in a short time period. Indeed, the Japanese government and its disaster preparedness guidelines had not anticipated that such a large-scale disaster would necessitate evacuation of medical institutions before the FDNPP accident occurred. This is because, although Japan is a disaster-prone country, it has suffered many disasters such as earthquakes and floods, and disaster preparedness was based on the assumption that a large-scale radiation disasters was unlikely to occur. Thus, to date, very limited research has been available on the difficulties that may arise during complete evacuations of a hospital in an emergency setting, including during radiation-released disasters. Furthermore, since external support is more readily available for earthquake and flood disasters than for radiation disasters, the response may have been inadequate for radiation disasters, which tend to deplete both human and material medical resources in the affected areas. In this qualitative study, the analysis elucidated that taking into account the characteristics of both mildly and severely ill patients during evacuation is imperative in emergency evacuations, and that the means of patient transportation, human and material medical resources, and information communication are likely to be insufficient during the evacuation process. The results of the current study indicated that the greater such difficulties are, the greater the potential for adverse health effects on hospitalized patients, highlighting the importance of not depleting resources and, if they are likely to be depleted, replenishing them externally before they are completely depleted. In future hospital preparedness for radiation-released disasters, in addition to the need to prepare an evacuation plan in advance while taking these factors into consideration, support from outside organizations that actually compensate for these factors in the field is necessary.

In disaster-specific hospital evacuations following a nuclear disaster, the mortality risk of inpatients may increase with prolonged evacuation duration, hospital scale, and the number of critically ill patients admitted to the hospital. Of all emergency hospital evacuations following the FDNPP, the most tragic situation was observed at the Futaba Hospital. Thematic analysis suggests that the failure to maintain care for critically ill patients and the inability to secure transport may have contributed to the mortality of critically ill inpatients. In Japan, psychiatric patients are commonly hospitalized for several years to decades [32]. Moreover, considering their low medical input requirements, relatively fewer medical staff are assigned to their care. During the accident, approximately half of the inpatients at the Futaba Hospital were hospitalized long term and were relatively stable, whereas the hospital had a large number of total inpatients and bedridden critically ill patients, which may be attributed to the prolonged evacuation duration and greater evacuation difficulty. Medical facilities with a large number of beds and a large proportion of critically ill inpatients should have disaster-specific evacuation measures to operate effective emergency evacuation in such settings.

Following the FDNPP accident, the organizational responses established by hospitals after the TMI accident were partially effective, as observed during the evacuation at the Futaba Kosei Hospital [9,24], although evacuation imposes physical and psychological burdens to hospitalized patients. Regarding the method of emergency hospital evacuation conducted in the hospital, the officials initially evacuated ambulatory inpatients (census reduction), distributed well-trained staff for the necessary care of severely ill patients (staffing), and gained vital information from the local community. On the other hand, it became clear that the communication of

information from the hospitals to the Disaster Control Headquarters and the communication of the disaster situation to the hospitals was inadequate, resulting in situations where evacuation instructions could not be established. Even under such circumstances, despite the Futaba Kosei Hospital housing over 100 inpatients, an appropriate hospital organizational response during the disaster supposedly minimized the death and burden of patients and facilitated completion of the evacuation within 24 h. Nevertheless, four patients died during the evacuation from the hospital, despite the efficient evacuation, thereby suggesting an enormous physical and psychological burden experienced by critically ill patients during forced hospital evacuation.

The deaths of hospitalized patients attributed to the evacuation could be categorized into the following groups according to the time of death: (i) the hyperacute phase during and immediately after the evacuation and (ii) the subacute phase that persisted for a certain period after the evacuation. According to a report on deaths recorded by the Futaba Kosei Hospital, four patients (2.9%) died during and immediately after the evacuation, whereas 17 (12.5%) died within 3 months of evacuation. As stated by an interviewee, the hospitals had not anticipated and practiced a large-scale hospital evacuation in a nuclear disaster setting, which may have substantially contributed to patient death. In addition, a similar phenomenon was observed among patients evacuated from nursing homes within 20–30-km radius of the FDNPP [5–7]. Death in patients during and immediately after the evacuation may be attributed to the direct physical and psychological damage from the evacuation. In contrast, the stress of patient transfer, such as changes in the care environment and insufficient handover about inpatient care, may be related to the long-term mortality associated with the evacuation. In response to the FDNPP accident, the Cabinet Office initiated programs to establish practical disaster management and hospital evacuation protocols at several sites of the nuclear power plants in Japan [33]. Despite the need for further implementation strategies, it is important for hospitals to develop plans in advance to reduce the mortality risk of critically ill patients, such as evacuation procedures and transfer location in case of forced evacuation [34].

With the considerably high risk of death associated with emergency hospital evacuation, particularly among critically ill patients, the option of shelter-in-place (indoor evacuation or no evacuation) is also important. However, a shelter-in-place decision was out of choice during the FDNPP accident because of the physical and infrastructure damage to the buildings caused by a series of disasters, including devastating earthquakes and tsunamis. Furthermore, sheltering-in-place itself also reported to have high mortality risk [8]. Thus, it would have been an option only for severe radiation contamination; however, emergency evacuation was imperative considering the absence of concrete plans for indoor evacuation and interrupted medical support from other organizations outside the disaster area during the FDNPP accident. Medical facilities in the PAZ are close to nuclear power plants, and it is difficult to integrate the real-time situation immediately following a nuclear disaster. This necessitates addressing challenges regarding shelter-in-place, such as securing external support and who will be responsible for decision making during evacuation management.

Moreover, several variables other than the radiation dose are involved in the decision-making process for emergency hospital evacuation during a nuclear disaster, except in the presence of extremely high air radiation dose rates. Owing to the complete disruption of infrastructure caused by the disaster, two hospitals were unable to provide continued care to their inpatients; therefore, they had no choice but to initiate emergency hospital evacuation immediately following the government's request. Meanwhile, one hospital accepted emergency patients and provided healthcare because of an undisrupted infrastructure, until they decided to initiate evacuation following an advice from the Fukushima Disaster Task Force. In other words, the following strategies must be achieved and maintained for a medical facility to choose shelter-in-place: 1) maintaining hospital infrastructure; 2) securing external resources, including medical supplies, medication, and healthcare personnel; and 3) independent communication measures to integrate information from public institutions. Emergency hospital evacuation is inevitable when any of the above-listed conditions are not achieved. To date, the ideal roles of each stakeholder in deciding whether to evacuate or shelter-in-place for emergency hospital evacuation are as follows: the government and local governments integrate disaster information and promptly provide it to hospitals, which will then integrate this information with the situation of the hospitals and their support organizations to decide whether to evacuate or shelter-in-place. The logistical support organizations for evacuation and sheltering may include the Self-Defense Forces, the military, and civilian support groups, which are all realistic options. On the other hand, it may be useful to have an organization that simulates various factors in advance and assists in decision making regarding evacuation under what circumstances.

This study is the first academic research regarding the details and difficulties of the emergency hospital evacuation which took place at hospitals located within a 5-km radius of the FDNPP. It would have been desirable to describe basic information on all hospitalized patients at all three hospitals; however, due to the confusion at the time of the disaster, information on patients who were hospitalized at that time was available for only one of the hospitals. Furthermore, at the time this study began, approximately 10 years had passed since the disaster and there was no access to medical records.

5. Conclusion

Immediately following the FDNPP accident, hospitals located near the FDNPP had not been fully prepared to evacuate patients in the event of a radiation-released disaster. As a result, the hospitals had difficulty in taking into account the characteristics of both mildly and severely ill patients during emergency evacuation, and securing the means of patient transportation, human and material medical resources, and information communication in the evacuation process. Further, hospitals with several patients or those with a high proportion of bedridden or critically ill patients faced more difficulty in emergency evacuation. Thus, higher mortality risks were observed in hospitals located within a 5-km radius of the FDNPP. Despite the need for further assessment, individual hospitals should construct evacuation plans for future disaster preparedness. External organizations, including public authorities, should prepare disaster responses at certain latitudes, such as procedures to integrate information on the status of each medical facility and measures to support their evacuation.

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Credit author statement

Sawano T and Tsubokura M contributed to the conception and design of the research. Sawano T drafted the article. Sawano T and Tsubokura M conducted the analysis and Kotera Y supervised the analysis. All authors performed critical revision of the article for intellectual content, were involved in interpretation of the cases, and approved submission of the article.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Ozaki A received financial support from Medical Network Systems, Inc. For purposes unrelated to this work. The other authors declare no competing interests.

Data availability

The authors do not have permission to share data.

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Appendix A. Supplementary data

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