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PAPER

Comparison of mortality patterns after the Fukushima Daiichi Nuclear Power Plant radiation disaster and during the COVID-19 pandemic

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Abstract

The initial health impact caused by radiation disasters can be broadly classified into direct and indirect effects. Though no direct health hazards caused by radiation, such as acute radiation injury, were observed following the Fukushima Daiichi nuclear power plant accident, indirect deaths have been reported, including those caused by initial emergency evacuation and relocation, medical disruption, and psychological and social health effects. However, these indirect health effects have not been prioritised for addressal. We evaluated the radiation disaster experience with that of the coronavirus disease (COVID-19) pandemic that emerged while facing the challenges from the radiation disaster. Most of the health effects of COVID-19 are directly associated with infection, but indirect health effects of various scales and entities have been reported. The two disasters have similarities in terms of the strain on community healthcare and the large number of deaths. Adapting the measures implemented in the acute to subacute phases of the COVID-19 disaster to radiation disasters may help improve management following future radiation disasters. Based on the experience and findings during the COVID-19 pandemic, the pattern of deaths in radiation disasters can be divided into five major groups: direct deaths, and four indirect patterns of deaths due to a deteriorating supply-demand balance (a hospital-level problem), collapse of the healthcare system (a community-level problem), death due to neglect alongside underlying disease, and diseases other than direct invasion. From the similarities between the two disasters, three main issues should be prioritised as initial emergency evacuation measures in a radiation disaster: emergency exposure medicine, the establishment of a medical system, and protection of death with dignity. The validity of these priority issues needs to be verified in future research.

1. Introduction

Health effects caused by nuclear power plant (NPP) disasters can be broadly classified into direct and indirect effects [1]. Looking back at past major radiation disasters, in the Chernobyl NPP accident, though many direct damages were described, most of the indirect damages were described only anecdotally. However, in the Fukushima Daiichi nuclear power plant(FDNPP) accident, no direct health hazards due to radiation, such as acute radiation injury, were observed, while various indirect health effects were reported even in the

acute phase [2, 3]. Major health effects are attributed to the initial emergency evacuation and displacement, deterioration of the shelter environment, evacuation from nursing homes, and psychological and social health effects. In addition, there were also the effects of medical collapse, where lives that could normally be saved by medical care could not be saved due to a lack of medical resources [4, 5]. It is known that these effects are particularly susceptible to the socially vulnerable [6].

An important problem related to the indirect health effects is that priority issues are not always organised in the early stages of a disaster. For example, evacuation during a radiation disaster was linked to a large number of indirect deaths, immediately after the disaster, especially among hospitalised patients or those residing in medical and welfare facilities. Its absolute and relative risks have been already clarified compared to other health effects [7, 8]. However, no clear policy for disaster evacuation, especially in the event of a radiation disaster, has been established yet. This gap is because the pattern of deaths could vary depending on the type of medical and nursing home, the resources available at individual facilities, and even the distance from the NPP. Therefore, it is difficult to formulate a uniform response, even for something as simple as evacuation during a disaster [4]. This is even more evident in the case of multiple issues, such as in the shelter environment and when considering psychosocial effects. Therefore, it is important for those involved in a radiation disaster to be aware, at the very least, of the major indirect mortality patterns in the early stages of a radiation disaster.

We experienced the coronavirus disease (COVID-19) pandemic while facing these problems from the radiation disaster. Evacuation due to the FDNPP accident caused long-term changes in society. Conversely, COVID-19 also caused long-term behavioural restrictions and lockdowns, which are slightly different from evacuation but have many similarities in that they have had long-term effects on society. This experience has made it necessary to discuss how to apply the lessons of COVID-19 to future radiation disasters. However, these were two different types of crises. Therefore, before discussing countermeasures, it was important first to compare the health effects of the two disasters that occurred. Despite most of the health effects of COVID-19 being directly associated with infection, anecdotal and academic reports of indirect health effects at various scales (individual, organisational, societal, etc) and actors (medical personnel, patients, and others) have been reported and discussed. However, these discussions are not sufficient for radiation disasters. Therefore, the authors, health professionals who have been involved in routine medical care, research, and support activities for both COVID-19 and the FDNPP accident, expounded on the two disasters, which have similarities in terms of the constraints of local medical care and the large number of fatalities and adapted the measures undertaken in the early and subacute phase of the COVID-19 disaster to radiation disasters to improve the management of future emergency healthcare aspects. In this paper, we aimed to clarify the major indirect mortality patterns associated with FDNPP accidents and to organise concepts on the prioritisation of initial emergency evacuation measures based on our recent experiences and findings from COVID-19.

2. Patterns of deaths due to radiation disaster summarised in terms of the COVID-19 experience

Based on the experiences and findings from the COVID-19 outbreaks, the patterns of death in radiation disasters could be divided into five major groups, mainly comprising direct deaths and four indirect death patterns, as shown in table 1.

2.1. Deaths due to direct effects

During the COVID-19 pandemic, many reported deaths were directly attributable to COVID-19, with COVID-19 pneumonia as the commonest cause [9]. However, no direct deaths due to internal radiation exposure in the FDNPP accident, including radiation-induced cancer, have been reported until now, '11 years after the accident' [10]. In contrast, in the Chernobyl NPP accident, 134 acute radiation injuries were identified, and 28 deaths were reported within three weeks of the accident [11]

2.2. Deaths due to supply-demand imbalance: hospital-level issues

In the COVID-19 pandemic, hospital-level problems were often seen wherein patient demand exceeded capacity in terms of people, supplies, or hospital beds. The main reasons for the deterioration of the human supply-demand balance were staff infections (infection/intense contact); the increased role of informal caregivers; and mental strain. First, regarding staff infections, there have been reports in Japan and worldwide of cases where hospital/facility staff themselves have become infected or have come into close contact with infected patients, resulting in their inability to do their jobs [12, 13]. In addition, given their increasing role as informal caregivers, there have been many cases where hospital/facility staff members were forced to take time off work due to the closure of the day-care centres and schools attended by their children [14, 15]. In semi-structured qualitative interviews with 25 nurses from four hospitals in Minamisoma city, an area

Table 1. Structural comparison of radiation disasters and COVID-19 mortality patterns.

Deaths	Radiation disasters	COVID-19
	Direct deaths	
Due to direct effects	Deaths due to acute radiation injury In the Chernobyl NPP accident, 28 people died within 3 weeks from acute radiation injury, but this effect was non-existent in the FDNPP accident.	Deaths due to COVID-19 pneumonia As of 15 March 2022, there were 6.05 million deaths worldwide and 26 274 deaths in Japan due to COVID-19.
	Indirect deaths	
Due to supply-demand imbalance (Hospital-level issues)	Deaths caused by a lack of medical and nursing staff In the FDNPP accident, there was a reduction in human resources due to the evacuation of medical and nursing staff.	The main reasons for the shortage of medical and nursing staff are staff infections, their increased role as informal caregivers, and mental strain.
	Deaths caused by lack of supplies In the FDNPP accident, a lack of resources contributed to indirect deaths.	The shortage of supplies increased indirect deaths by postponing or interrupting non-COVID-19 examinations, surgeries, radiotherapy, and outpatient care and by reducing the quality of medical and nursing care.
	Deaths caused by lack of hospital beds The FDNPP accident severely reduced the supply of supplies and other necessities, making it difficult to admit new inpatients.	In Wuhan, People's Republic of China, a shortage of beds for non-COVID-19 patients contributed to an increase in indirect deaths from 22 December 2019 to 11 February 2020.
Deaths due to the collapse of the healthcare system (regional level)	Deaths in emergency transport: Deaths caused by factors on the part of the healthcare provider In the FDNPP accident, the lack of a chain of command was one of the indirect causes of death during the initial emergency evacuation of patients from the hospital.	Deaths caused by healthcare provider-related factors Command and control confusion in EMS was the cause of these deaths. In Tokyo, Japan, the survival rate of out-of-hospital cardiac arrests for which it was difficult to select a hospital to transport the patient to, decreased from 6.3% to 4.7%.
	Deaths caused by patient/family factors Lack of information and confusion increased anxiety and distrust about the potential health effects of radiation exposure, which potentially resulted in indirect mortality.	Deaths caused by patient/family factors Anxiety, fear, and mental stress in the COVID-19 pandemic were noted to increase reporting and non-cooperation with healthcare providers, which led to increased mortality.
Death due to neglect alongside underlying disease	Deaths caused by neglect Due to inadequate care or forced prolonged transportation of bedridden elderly or hospitalised patients.	(a) Due to increased burden on formal caregivers (hospital/facility) Deaths of elderly dementia and psychiatric patients due to neglect were caused by the increased burden on formal caregivers. (b) Due to increased burden on informal caregivers (at home) Indirect mortality due to neglect was caused by social isolation, stress, neglected health needs, and loss of services and support.
Deaths due to other diseases	Deaths due to exacerbation of chronic and cardiac diseases.	(a) Deaths caused by healthcare provider-related factors There were indirect deaths due to suppression of usual medical care services. (b) Deaths caused by patient/family factors There were deaths due to treatment interruption caused by refraining from seeing a doctor.

COVID-19, coronavirus disease; EMS, Emergency Medical Services

affected by the FDNPP accident, nearly two-thirds of those interviewed chose to evacuate from Minamisoma city with their families In particular, nurses with small children were the most common [16]. Regarding mental health problems, burnout occurred mainly among medical personnel engaged in COVID-19 care for a long period. Second, in terms of supplies, there was a shortage of personal protective equipment (PPE) as well as testing and treatment equipment (PCR testing, ventilators, and extracorporeal membrane oxygenation [ECMO]) [17]. For example, the shortage of PPE resulted in the postponement or interruption of examinations, surgeries, radiotherapy, and outpatient care other than activities related to COVID-19 management, as well as in a reduction in the quality of medical and nursing care [18]. Third, one of the main problems with hospital beds was their allocation within the hospital. Thus, the number of general beds decreased due to their reorganisation into dedicated COVID-19 beds, and the number of cases wherein the admissions of regular non-COVID-19 patients were restricted increased subsequently. Wuhan, in the People' Republic of China, reported that the shortage of beds for non-COVID-19 patients from 22 December 2019 to 11 February 2020 was one of the causes that contributed to the increase in indirect deaths [19].

Conversely, in the case of the FDNPP accident, indirect deaths increased after the earthquake due to the disruption of the supply-demand balance. It is highly likely that the absolute reduction in the number of medical personnel due to the evacuation, shortages of medical supplies and other necessities, and the cessation of new admissions had a significant impact as the causes of the increase in indirect deaths [4]. Thus, it is possible to discuss the similarities and differences of the COVID-19 and FDNPP accidents in terms of personnel resources, medical supplies, and hospital beds.

2.3. Deaths due to the collapse of the healthcare system: problems at the regional level

In the early stages of the COVID-19 pandemic, indirect deaths occurred despite the sustained provision of medical resources. As a community-level issue, problems during Emergency Medical Services (EMS) transport were particularly important considering the probability of death as an outcome. From the healthcare perspective, the problem emerged from confusion in the EMS command and control systems. Italy reported an increased mortality rate of non-COVID-19 patients in the Emergency Department from 1 December to 31 May 2019, attributed to decreased EMS capacity [20]. In Japan, EMS difficulties occurred most frequently from 31 January 2022 onwards; 5469 cases of transport difficulties were recorded during the week starting 6 February 2022, of which 3486 (63.7%) were non-COVID-19 patients who could be handled within the framework of the existing emergency medical system [21]. In Tokyo, 80% of the difficult-to-transport cases in January 2022 were non-COVID-19 patients. Compared to 2019, the time spent at the scene by paramedics increased from 20.7 to 22.7 min, and the survival rate of out-of-hospital cardiac arrests, wherein it was difficult to select a destination hospital, decreased from 6.3% to 4.7% [22]. Under these circumstances, the Japanese Ministry of Health, Labour, and Welfare notified the national prefectural coordination headquarters to utilise the Disaster Medical Assistance Team (DMAT) from March 2020 onward and established command and control systems [23]. In addition, considering patient/family factors, there were problems of anxiety, fear, and mental stress during the COVID-19 pandemic that may have led to increased calls from people who did not actually need emergency medical care, non-cooperation with medical personnel, and ultimately, an increase in mortality rates [24]. Therefore, EMS confusion due to the increased number of EMS calls worldwide led to increased mortality of non-COVID-19 patients, such as those with heart disease and stroke [25].

Nonetheless, confusion in the command-and-control systems was a problem for medical personnel in the FDNPP accident [26, 27]. For example, in the initial emergency evacuation of hospitals in the Precautionary Action Zone, 39 (11.5%) of the 338 patients died due to lack of command and control, mixed information, and poor communication [4]. Furthermore, there were indirect deaths in the urgent protective action planning zone due to confusion in the command-and-control system and the lack of a pre-evacuation decision process, making it difficult to maintain resources (personnel and logistics) until the decision was made to evacuate [7, 8]. Moreover, for patients/families, despite the very low dose estimates for the residents of Fukushima following the FDNPP accident, the lack of information and confusion increased anxiety and distrust about the potential health effects of radiation exposure, which could have created other serious health risks [6].

2.4. Death due to neglect alongside underlying disease

During the COVID-19 pandemic, deaths associated with neglect are especially noteworthy, as indirect deaths occurred in vulnerable populations, such as bedridden older adults and disabled individuals. Neglect was caused by the increased burden on both formal caregivers (hospitals and institutions) and informal caregivers (at home). First, in the case of formal caregivers (hospitals and institutions), deaths of older patients with dementia and of those undergoing psychiatric treatment occurred because of neglect caused by inadequate care secondary to a lack of staff due to chronic underfunding, lack of training, lack of testing and

equipment, and failure to protect the dignity of vulnerable patients [28, 29]. Next, in the case of informal caregivers (at home), there were indirect cases of neglect due to social isolation, stress, neglect of health needs, and loss of services and support, due to which deaths were reported [30].

Conversely, following the FDNPP accident, elderly facility residents and hospitalised patients who were originally in poor general condition died due to inadequate care during the initial emergency evacuation and the long travel time [4].

2.5. Deaths due to other diseases

In the COVID-19 pandemic, deaths from causes other than COVID-19 were reported due to interruptions in the scheduled treatment visits for patients with chronic diseases. For example, in the United States, the largest number of deaths from heart disease occurred in 2020, and the mortality rate increased by 4.8% from 2019 [31]. In addition, deaths due to worsening diabetes increased [32]. Causes included factors related to healthcare providers as well as patients. A factor from the healthcare provider aspect was the restriction of regular medical care services, mainly due to restrictions of medical visits to reduce nosocomial infections and the decline in hospital functioning due to a lack of medical resources [33]. Another patient-related factor was the interruption of treatment due to withholding of consultations. According to a survey conducted by the Japan Medical Association in July 2021, the percentage of those who withheld consultations was 14.6%, of which nearly half were regular consultations for chronic diseases. The main reason for refraining from seeing a doctor was the patient's own fear of infection from the hospital [34].

Similarly, indirect deaths due to an exacerbation of underlying disease were reported after the FDNPP accident and indicated an increase in chronic diseases, such as diabetes and hypertension, and deaths due to cardiac disease [35–37].

3. Discussion

In this report, we classified the patterns of deaths in the acute to subacute phases of a radiation disaster into five categories, as shown in table 1. We then compared the patterns of deaths due to the COVID-19 pandemic and due to a radiation disaster. These two different types of disasters resulted in a disruption of the supply-demand balance due to inadequate health care systems and insufficient medical staff and an increased concentration of emergency patients due to reduced hospital functions and closures. They are similar in that they failed to prevent deaths that could have been prevented by ordinary medical care, and they were major causes of indirect deaths. In addition, COVID-19 pandemic and the FDNPP post-accident situation were similar in that the discussion was not limited to simply how to save lives but also raised awareness of the importance of human dignity and patient-centred medicine. This was the first study to compare the pattern of deaths during COVID-19 and during a radiation disaster. Until now, the health effects of radiation disasters have been classified into only two categories—direct health effects and indirect health effects—which has made it difficult to organise priorities and take countermeasures. However, the similarity of mortality patterns between the two types of disasters suggests the possibility of applying the COVID-19 response measures to radiation disasters in the future.

3.1. Direct deaths due to FDNPP accident

There was a significant gap in the extent of direct deaths caused by the COVID-19 pandemic and those caused by the FDNPP accident. Although many direct deaths due to COVID-19 were reported, there is no evidence of direct deaths due to radiation after the FDNPP accident. Nonetheless, no observations of direct death after the FDNPP should be cautiously interpreted because it is difficult to completely deny the hypothesis that radiation exposure following the accident may have led to excess cancer deaths. One reason for this is a difficulty in estimating the extent to which radiation exposure may contribute to cancer development in an individual. However, the epidemiological data available so far following the 2011 Fukushima disaster rejects the hypothesis and international authorities support this evidence [3]. Given these facts, it may be reasonable to conclude that there were no or little direct cancer deaths due to radiation after the FDNPP accident. Of course, this does not imply that there is no need to prepare for radiation exposure in future nuclear accidents. Clearly, preparedness for radiation exposure as a direct hazard is important in emergency radiological care.

3.2. Maintenance of medical resources and systems

The maintenance of medical resources (human and material) during a radiation disaster is an important issue. For example, some regions in Japan established specialised hospitals for COVID-19, which enabled focused investment of medical resources to handle a larger number of patients, clarified the roles of hospitals, and reduced the number of difficult emergency transport cases through inter-hospital collaboration.

Moreover, hospitals conducted drills for donning and removing PPE and preparing for infectious disease outbreaks and undertook cooperation to ensure that the regional medical systems could respond quickly even in the early phase of the COVID-19 pandemic. In cooperation with medical institutions and public health centres, each prefecture established an organisation with participants from DMAT and experts in emergency medicine and infectious diseases to coordinate the acceptance of patients and established a chain of command for transportation coordination [38, 39]. Furthermore, measures to ensure balance in the supply and demand, financial resources, supply of medical resources from outside the disrupted area (DMAT and dispatch of medical personnel from other areas), and transport of patients to outside the disrupted area (wide-area transport of ECMO patients) were implemented. Moreover, the importance of mental health support has been recognised through the opening of day-care centres and after-school child sound upbringing programs to secure the mental peace of staff, and there has been an increase in the number of hospitals and academic societies that have implemented mental health measures. As countermeasures against fear and confusion, measures were undertaken to share information using IT, such as the Gathering Medical Information System and the Hazard Information and Management Support System for Persons Infected with COVID-19, to disclose information promptly to the public.

In contrast, after the FDNPP accident, the Nuclear Regulation Authority was established to centralise the nuclear management system and ensure its independence [40]. Furthermore, the Advanced Radiation Exposure Medical Support Center, the Core Advanced Radiation Exposure Medical Center, and the Comprehensive Support Center for Nuclear Disaster Medical Care were established to create a link with the existing emergency disaster medical care system for rebuilding the radiation disaster prevention system [41]. Though these medical systems are in place, the cooperation and division of roles between the nuclear disaster medical response team, the DMAT, and other acute care teams is unresolved and remains an issue for future disasters. In addition, psychosocial effects could be prolonged or delayed and manifest several years after the disaster. As of 9 March 2022, 25 736 evacuees have been forced to leave their homes and continue to evacuate out of the prefecture. However, specific countermeasures against depression and anxiety among those who continue to evacuate and for hospital/facility staff need to be implemented as early as possible after the disaster [42]. Lessons learned from the COVID-19 response are as follows: establishment of a command-and-control system; the coordination, collaboration, and division of roles among hospitals; and psychosocial support. These provide a possible outline for responding to a radiation disaster.

3.3. Measures to protect death with dignity

During the COVID-19 pandemic, as the number of infected patients increased rapidly and the shortage of medical resources, such as supplies, hospital beds, and human resources, became more pronounced, medical institutions were not only faced with the difficulty of balancing normal medical care and reallocating medical resources to deal with COVID-19 patients but also revealed a lack of dignity to deal with the most vulnerable groups in society. The result was indirect deaths due to neglect of vulnerable populations.

Conversely, following the FDNPP accident, deaths occurred mainly among older patients at Futaba Hospital and Futaba Kosei Hospital, which are situated within 5 km of the FDNPP, where people who were bedridden and in poor general condition died after their condition was further aggravated by the accident [43]. Although the importance of protecting dignity in times of disaster has been reported, the measures that have been implemented are insufficient, and it is difficult to determine how to actually protect the dignity in the death of these high-risk individuals. Dignity in disaster situations, which was an issue in the COVID-19 pandemic, needs to be discussed further. These discussions also need to be evaluated for future application as specific measures to protect dignity in radiation disasters.

4. Limitation

When comparing mortality patterns after the FDNPP accident to the COVID-19 pandemic, the situation was different for direct deaths because of differences in ‘hazard type’ and ‘quantitative number of deaths’. However, the major categories resulting in secondary health effects were the same. For indirect deaths, the situation after the FDNPP accident differed from the COVID-19 pandemic in that the supply of lifelines and external resources (personnel and logistics) was rapidly and completely disrupted.

5. Conclusion

This study revealed that many similarities exist between the major types of indirect deaths in the two disasters. This paper has enabled the authors to discuss the application of the lessons of COVID-19 pandemic to radiation disasters. The discussion itself goes beyond the scope of the present paper; however, it is necessary to verify the validity of this study in the next study. Though it is not the purpose of this study, it is

also possible that the application of lessons learned from the FDNPP accident to COVID-19 pandemic could be more general when the basis of the time lapse is considered. There was also a need for future research to examine the application of lessons learned from FDNPP accidents to different types of disasters.

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Conflict of interest

The authors declare no conflict of interest.

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