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Risk and preventive factors for heat illness in radiation decontamination workers after the Fukushima Daiichi Nuclear Power Plant accident

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Abstract: Risk and preventive factors for heat illness in radiation decontamination workers after the Fukushima Daiichi Nuclear Power Plant accident: Takeyasu KAKAMU, *et al.* Department of Hygiene and Preventive Medicine, Fukushima Medical University School of Medicine—Objectives: The aim of this study was to reveal factors related to heat illness in radiation decontamination workers and determine effective preventive measures. **Methods:** A self-administered questionnaire was sent to 1,505 radiation decontamination workers. The questionnaire included age, sex, duration of decontamination work, previous occupation, education provided by employers regarding heat illness, preventive action against heat illness, and subjective symptoms of heat illness during work. We included 528 men, who replied and answered all questions, in the statistical analysis. Subjective symptoms of heat illness were categorized as "no symptoms", "Grade I" and "Grade II" according to severity. A multiple linear regression model was used to determine the factors associated with the severity of heat illness. **Results:** The mean age of the subjects was 47.6 years old (standard deviation: 13.4). Of the 528 workers, 316 (59.8%) experienced heat illness symptoms (213 at Grade I and 103 at Grade II). The results of the stepwise selection revealed that age, outdoor manual labor, adequate sleep, use of a cool vest, and salt intake were selected as preventive factors, whereas living in a company dormitory or temporary housing, wearing light clothing, and consuming breakfast were selected as risk factors for heat illness. **Conclusions:** Both working conditions and living environment are associated with heat illness in radiation decontamination workers. Type of housing and sleep are also strongly related to heat illness during work. Employers should consider not only the working conditions of the employee but also the employee's daily living conditions, in order to prevent heat illness.
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Key words: Fukushima Nuclear Accident, Heat illness, Occupational health management, Radiation decontamination

On March 11, 2011, the Great East Japan Earthquake struck off the Pacific coast of Japan and, combined with the resulting tsunami, caused the Fukushima Daiichi Nuclear Power Plant accident. This led to the release of large amounts of radioactive materials, including iodine-131 (I-131), cesium-134 (Cs-134), and cesium-137 (Cs-137)[1)]. The Japanese government designated the area within a 20-km radius of the nuclear plant as a "high-alert zone". An evacuation order was put into place on April 22, 2011, and anyone other than emergency workers was prohibited to enter the zone[2)]. The government also implemented a "planned evacuation zone" for areas that were outside the 20-km radius and had an estimated cumulative radiation dose of 20 mSv/year. Areas within a 30-km radius of the nuclear plant not considered to be high-alert or planned evacuated zones were designated as "zones in preparation for emergency evacuation"[2–4)]. About 160,000 residents who lived in the high-alert and planned evacuation zones evacuated due to concern regarding radiation exposure, and those who did not evacuate continued to live with concern over health effects caused by radiation exposure[5, 6)].

Because the half-lives of the radionuclides are very long (2 years and 30.2 years for Cs-134 and Cs-137,

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respectively), the environmental radiation dose rate is estimated to decrease over a long period in the natural environment[5,7]. Past studies have shown that decontamination in the form of soil removal is thought to be an effective method for decreasing the dose rate of environmental radiation[8,9]. The Japanese Government decided to begin decontamination work to lower the radiation exposure to those residing in Fukushima and to bring a sooner end to the evacuation zone[10]. The Ministry of Environment published decontamination guidelines to provide concrete descriptions of each process of decontamination work, including removing soil, removing accumulated grass and leaf fall, and washing houses and roads[11]. Radiation decontamination work is being carried out even outside of the evacuation zone in areas not considered high-radiation dose rate areas to rid residents of any concern they may have. According to the Fukushima Labor Bureau, many more workers are engaged in such work outside of the evacuation zone than those inside.

Decontamination efforts had begun two years prior to when we started this investigation; however, the actual conditions regarding occupational health management for the radiation decontamination workers remain unknown due to multilayer subcontracting. Regarding the Fukushima Daiichi Nuclear Power Plant accident, there have been concerns raised by the workers over radiation exposure, heat illness, and stress, among others[12]. For protection of the workers, the Japanese Government introduced the "Ordinance on Prevention of Ionizing Radiation Hazards at Works to Decontaminate Soil and Wastes Contaminated by Radioactive Materials Resulting from the Great East Japan Earthquake" and the "Guidelines on Prevention of Radiation Hazards for Workers Engaged in Decontamination Works"[13,14].

During the clean-up work at the nuclear power plant, many workers experienced heat illness; thus, many countermeasures such as avoidance of working at hours of high temperature (rest time from 14:00 to 17:00) were applied[15]. The government stated that prevention of heat illness is one of the most important criteria for occupational safety management for decontamination workers[16]. For those engaged in areas not considered as having high-radiation dose rates, prevention of heat illness is of a greater concern than radiation exposure. For workers who commute long distances to resident-prohibited areas, it may be difficult to manage their daily lifestyles, even though it is important in the prevention of heat illness. The aim of this study was to reveal factors related to heat illness in radiation decontamination workers and determine effective preventive measures.

Methods

Study subjects

The Fukushima Occupational Health Promotion Center obtained information about companies engaged in radiation decontamination from the Fukushima Labor Bureau. We asked all 213 companies included in the information to join the research and asked each company to select approximately 10 workers to complete the questionnaires. Self-administered questionnaires were then sent to 1,505 radiation decontamination workers through the companies in August 2013, and all responses were returned anonymously by mail. By the end of October 2013, 651 workers (628 men and 23 women) had replied to the questionnaires. Among them, 528 men, who answered all questions, were included in the statistical analysis. The response rate was 42.5%, and the effective response rate was 35.1%.

Classification of heat illness

The questionnaire included age, sex, duration of decontamination work, previous occupation, education provided by employer regarding heat illness, preventive action against heat illness, and subjective symptoms of heat illness during work. Questions regarding subjective symptoms of heat illness during work were asked according to past studies and the "Health Care Manual for Heatstroke" of the Ministry of the Environment[17–19]. These symptoms were graded by the workers as "no symptoms", "Grade I" (heat syncope and heat cramps) and "Grade II" (heat exhaustion) according to the classification for heat illness outlined by the Japanese Congress on Neurological Emergencies[17,19]. Workers with at least one symptom of Grade I were considered as having a Grade I symptom, and workers with symptoms of both Grades I and II were considered as having Grade II symptoms[17]. The question regarding education and guidance provided by the employer was multiple choice, with possible answers including "training session (studied about heat illness during training)", "watching videos (watched a video about heat illness during training)", "physical condition check (checked physical condition daily before work)", "self-study with materials (materials regarding heat illness were provided for self-study)" and "self-study without materials (materials were not provided for self-study)"[14]. The questions regarding preventive action against heat illness were multiple choice and were quoted from the "Guidance on Occupational Safety Management" manuals[16]. The questions covered topics including "adequate sleep (enough sleep before a working day)", "breakfast consumption (daily breakfast consumption)", "moderate drinking of alcohol", "use of a cool vest", "cooling

(cooling body with refrigerant)", "light clothing", "water consumption" and "salt intake (intake of salt with water)".

Factors associated with heat illness

Type of housing was categorized into "owner-occupied house", "rental house", "company dormitory", "hotel" and "temporary housing (for evacuees)". We classified previous occupation into two groups, one of which involved "outdoor manual work", which consisted of "working at the same company prior to starting radiation decontamination", "construction", "agriculture, forestry and fisheries" and "radiation decontamination". The other group comprised participants who were not involved in "outdoor manual work". Radiation decontamination work is mainly undertaken by construction and forestry companies.

Statistical analysis

The mean and standard deviation (SD) of age and working duration were calculated for each severity of heat illness and clarified by analysis of variance (ANOVA). The percentage of workers who chose each item in the questionnaire was calculated, and the relationship between each item and the severity of heat illness was analyzed by chi-square test.

Multiple linear regression analysis was used to assess the severity of heat illness as the dependent variable, as well as the independent contributions of age, duration of decontamination work, previous occupation, type of housing, education provided by the company and preventive action against heat illness. Age and duration of decontamination work were fixed as independent variables, and the other items were selected as independent variables by a stepwise procedure. *P* values below 0.05 were regarded as statistically significant.

All statistical analyses were conducted with SPSS statistics ver. 21 (IBM Corp., Armonk, NY, USA).

Ethics

This study was approved by the Research Ethics Committees of the Japan Labour Health and Welfare Organization (Announce No. 3) and the Ethics Committees of Fukushima Medical University (Application No. 1728).

Results

The mean age of the subjects was 47.6 years old (SD, 13.4; range, 18–77). The mean duration of radiation decontamination work was 7.6 months (SD, 6.0; range, 0–30). Of the 528 decontamination workers, 316 (59.8%) experienced symptoms of heat illness (Table 1). The most common symptom was sweat, which was experienced by 243 workers (46.0%). Grade I heat illness only was experienced by 213 workers, and 103 workers experienced Grade II heat illness.

Characteristics of each grade of heat illness are shown in Table 2. Workers living in a company dormitory and temporary housing showed high prevalence of Grade II heat illness. Some workers living in a company dormitory reported "having concerns about living in the same room with another person", "I cannot relax in the dormitory", or "the dormitory is located a long distance from the city downtown area or shopping area".

Education provided by employers is shown in Table 3. All workers received some kind of instruction regarded as work-related education. "Training sessions" (74.6%) and "physical condition check" (75.4%) were the most common. A chi-square test revealed that

Table 1. Classification of heat illness by symptom

	Total n=528	Grade I n=213	Grade II n=103
Grade I			
Dizziness	35 (6.6)	10 (4.7)	25 (24.3)
Sweat	243 (46.0)	179 (84.0)	64 (62.1)
Syncope	1 (0.2)	1 (0.5)	0 (0.0)
Muscle pain	15 (2.8)	8 (3.8)	7 (6.8)
Cramp	54 (10.2)	30 (14.1)	24 (23.3)
Grade II			
Headache	46 (8.7)		46 (44.7)
Nausea/vomiting	12 (2.3)		12 (11.7)
General malaise	61 (11.6)		61 (59.2)
Muscle weakness	12 (2.3)		12 (11.7)
Distraction	19 (3.6)		19 (18.4)

Number (%). Subjects with symptoms of both "Grade I" and "Grade II" were classified as "Grade II".

Table 2. Characteristics of radiation decontamination workers

	No symptoms n=212	Grade I n=213	Grade II n=103	*p* value
Age (mean ± SD)	48.7 ± 13.1	47.7 ± 13.3	45.1 ± 14.1	0.088
Working duration (months) (mean ± SD)	8.0 ± 6.0	6.9 ± 5.9	8.2 ± 5.9	0.067
Type of housing (%)				
Owner-occupied house	84 (39.6)	55 (25.8)	26 (25.2)	<0.001
Rental house	54 (25.5)	89 (41.8)	27 (26.2)	
Hotel	15 (7.1)	13 (6.1)	7 (6.8)	
Company dormitory	59 (27.8)	55 (25.8)	39 (37.9)	
Temporary housing[a]	0 (0.0)	1 (4.7)	4 (3.9)	
Previous occupation (%)				
Same company	111 (52.4)	106 (49.8)	33 (32.0)	0.007
Construction	57 (26.9)	58 (27.2)	34 (33.0)	
Agriculture, forestry and fishery	11 (5.2)	8 (3.8)	3 (2.9)	
Manufacturing	10 (4.7)	11 (5.2)	9 (8.7)	
Sales	4 (1.9)	6 (2.8)	3 (2.9)	
Service	7 (3.3)	8 (3.8)	3 (2.9)	
Unemployed	6 (2.8)	4 (1.9)	4 (3.9)	
Radiation decontamination	0 (0.0)	1 (0.5	5 (4.9)	
Others	6 (2.8)	11 (5.2)	9 (8.7)	

[a] Temporary housing for evacuees.

Table 3. Education provided by employer

	Total n=528	No symptoms n=212	Grade I n=213	Grade II n=103	*p* value
Training sessions[a]	394 (74.6)	147 (69.3)	174 (81.7)	73 (70.9)	0.009
Watching a video[b]	489 (29.5)	67 (31.6)	51 (23.9)	38 (36.9)	0.043
Physical condition check[c]	398 (75.4)	150 (70.8)	167 (78.4)	81 (78.6)	0.130
Self-study with materials[d]	211 (40.0)	70 (33.0)	104 (48.8)	37 (35.9)	0.003
Self-study without materials[e]	16 (3.0)	8 (3.8)	4 (1.9)	4 (3.9)	0.446

Number (%) ratio of respondents in the group. [a] Studied about heat illness during training session. [b] Watched a video about heat illness during training session. [c] Had a daily physical condition check before work. [d] Materials regarding heat illness were provided for self-study. [e] Materials were not provided for self-study.

"training sessions", "watching videos" and "physical condition check" were associated with heat illness.

Preventive actions against heat illness are shown in Table 4. Water consumption was the most common preventive action and as used by 481 workers (91.1%).

The factors of living in a company dormitory, living in temporary housing, outdoor manual labor, light clothing, adequate sleep, breakfast consumption, use of a cool vest, and salt intake were selected in the model with R^2=0.104, F=6.025 and $p<0.001$. The results of the stepwise procedure revealed that age, outdoor manual labor, adequate sleep, use of a cool vest, and salt intake were preventive factors, whereas living in a company dormitory or temporary housing, wearing light clothing, and consuming breakfast were identified as risk factors for heat illness (Table 5).

Discussion

In this study, we revealed some risk and preventive factors for heat illness in radiation decontamination workers. Heat illness while working is called exertional heat illness, which is different from classical heat illness in daily life[20]. Exertional heat illness occurs in healthy young people while exercising, whereas classical heat illness is more likely to occur in the elderly, who are particularly vulnerable[21]. Our study revealed that younger workers are at a higher risk of heat illness. Heatstroke STUDY 2010 and other past studies have shown that heat illness during sports and work is more common among young and middle-aged people[20, 22, 23]. The reason why aging is a preventive factor is thought to be due to younger

Table 4. Preventive action against heat illness

	Total n=528	No symptoms n=212	Grade I n=213	Grade II n=103	*p* value
Adequate sleep[a]	392 (74.2)	163 (76.9)	160 (75.1)	69 (67.0)	0.158
Breakfast consumption[b]	359 (68.0)	129 (60.8)	161 (75.6)	69 (67.0)	0.005
Moderate drinking of alcohol	278 (52.7)	100 (47.2)	124 (58.2)	54 (52.4)	0.074
Use of a cool vest	20 (3.8)	14 (6.6)	2 (0.9)	4 (3.9)	0.009
Cooling[c]	103 (19.5)	36 (17.0)	60 (28.2)	7 (6.8)	<0.001
Light clothing	210 (39.8)	59 (27.8)	110 (51.6)	41 (39.8)	<0.001
Water consumption	481 (91.1)	187 (88.2)	199 (93.4)	95 (92.2)	0.152
Salt intake[d]	332 (61.0)	127 (59.9)	146 (68.5)	49 (47.6)	0.001

Number (%) ratio of respondents in the group. [a] Enough sleep before the working day. [b] Having breakfast every day. [c] Cooling body with refrigerant. [d] Intake of salt with water.

Table 5. Linear regression model for the severity of heat illness

	Coefficient (95% CI)	SE	β	*t* value	*p* value
Age	−0.006 (−0.010, −0.001)	0.002	−0.105	−2.489	0.013
Working duration	0.002 (−0.008, 0.013)	0.005	0.019	0.442	0.658
Outdoor manual labor[a]	−0.210 (−0.368, −0.053)	0.080	−0.111	−2.619	0.009
Use of a cool vest	−0.376 (−0.699, −0.052)	0.165	−0.096	−2.282	0.023
Salt intake[b]	−0.160 (−0.296, −0.024)	0.069	−0.105	−2.304	0.022
Light clothing	0.262 (0.127, 0.397)	0.069	0.172	−2.655	0.008
Company dormitory[c]	0.155 (0.019, 0.292)	0.070	0.095	2.233	0.026
Temporary housing[d]	1.191 (0.555, 1.826)	0.323	0.155	3.682	<0.001
Adequate sleep[e]	−0.210 (−0.366, −0.055)	0.079	−0.123	3.808	<0.001
Breakfast consumption[f]	0.227 (0.080, 0.375)	0.075	0.142	3.022	0.003

[a] Outdoor manual labor consists of working at the same company before radiation decontamination began, radiation decontamination, construction and agriculture, forestry and fisheries. [b] Intake of salt with water. [c] Living in company dormitory. [d] Living in temporary housing. [e] Adequate sleep before work. [f] Having breakfast every day.

age groups tending to engage in heavier workloads, whereas older age groups tend to engage in management work[24].

In our study, the most common symptom of heat illness was sweat (46.0%). Excessive sweating leads to water and electrolyte loss, the process of which may result in the onset of heat illness. Acclimatization to heat increases tolerance, changes sweating function (such as the threshold body temperature for sweating), causes excessive sweating and decreases sodium loss due to sweat[25, 26]. Our study showed that intake of salt with water is preferable to prevent heat illness rather than intake of water alone.

Past studies have indicated that acclimatization to heat is important in the prevention of heat illness and have recommended for workers to be acclimatized to heat[25, 27–29]. Our study did not show a significant relationship between working duration and heat illness. The mean working duration of the subjects was 7.6 months. We therefore think that working duration was not a significant index for acclimatization to heat for our study subjects.

Most company dormitories provided shared rooms and were not thought to provide a good living environment according to the responses of the questionnaires. In addition, some of the workers lived in temporary housing as a consequence of the evacuation due to the earthquake and nuclear power plant accident. Our study results showed that workers living in a company dormitory or temporary housing were at higher risk of heat illness, suggesting the importance of an adequate living environment for preventing heat illness. The present study also revealed that adequate sleep was a contributing factor in preventing heat illness. This coincides with several other studies, which have shown that inadequate sleep is associated with heat illness[24, 25, 29]. It is reasonably assumed that workers living in company dormitories or temporary housing have difficulties in obtaining adequate sleep, thereby increasing the risk of heat illness. Additionally, those decontamination workers who work in resident-prohibited areas have a long commute time. As a result, they tend to have less time to sleep and have difficulty engaging in health-related activities[30]. Because such employees may have difficulty managing a healthy lifestyle, employers should consider this in order to prevent heat illness.

Education on heat illness showed no significant relationship with heat illness occurrence in the multivariate regression analysis in the present study. However, in May 2013, the Fukushima Labor Association sent a letter of attention to the Ministry of Environment and the municipalities engaged in radiation decontamination urging the implementation of preventive measures against heat illness[16]. Furthermore, Bouchama and Knochel suggested that heat illness can be prevented with the appropriate knowledge[31]. Fortune *et al.* reported that those who have been engaged in manual or outdoor labor have a lower risk of heat illness[23]. We assume that this is because of their knowledge on the prevention of heat illness. As the decontamination work is still expanding and more workers are required, employment of inexperienced manual workers is expected to increase in the future. To prevent heat illness, it is recommended for employers to provide inexperienced manual workers with guidance on such things as management of their daily lives, work clothing and hydration.

In this study, 39.8% of the workers stated that "light clothing" aided heat illness prevention but also had an inverse effect. Direct sunlight is a risk factor for heat illness. Inaba and Mirbod showed that covering the face and neck is useful to avoid direct sunlight and prevent heat illness[32]. Radiation decontamination workers have to wear long-sleeved clothes to prevent radiation exposure. The workers who selected "light clothing" in the questionnaire possibly wore inadequate clothing to guard against both heat illness and radiation exposure, such as short sleeves and no helmet. In Japan, Miyake *et al.* reported that light clothing causes more heat illness than heavy clothing[22]. Pascoe also stated that adequate clothing is required to prevent heat illness[33]. Satsumoto indicated that the clothing material properties, such as water absorbency, rapidity of drying, water vapor absorption, etc., have effects on heat illness[34]. To prevent heat illness, workers should also wear adequate underclothes and cover their face and neck. Clean-up workers at the Fukushima Daiichi Nuclear Power Plant wear cool vests to prevent heat illness, which is an effective preventive factor that is consistent with the present study[12]. The number of workers wearing cool vests was rather small in our study, possibly due to lack of knowledge on heat illness and the small number of workers wearing a radiation protective suit (only 17 people). Thus, better awareness of preventive factors is necessary.

The present study showed that having breakfast was a risk factor of heat illness, which contradicts the Ministry of Environment, who recommend having breakfast to prevent heat illness[18]. Consuming breakfast seems to have an inverse result compared with that shown in the Health Care Manual for Heatstroke published by Ministry of Environment. We hypothesized that subjects who require medication, including drugs for chronic diseases such as hypertension, are more likely to have breakfast than those who do not. Such drugs are required to be taken with every meal.

The current study had some limitations. The questionnaire did not cover any questions regarding the medical history or drug use of the workers, even though they are reported to be risk factors associated with heat illness[21, 29, 31, 35]. Additionally, questions regarding working hours or duration of work were not included in the questionnaire. The clean-up workers at the Fukushima Daiichi Nuclear Power Plant rested between 14:00 and 17:00, which was thought to be a contributing factor in decreasing the risk of heat illness[15]. Questions concerning working place were also not included in the questionnaire. Environmental radiation dose rate and working procedures vary depending on the work site location, but this was not considered in this study. Despite these limitations, this is the first study to focus on occupational health management of radiation decontamination workers. We believe this study will help improve occupational management not only for the radiation decontamination workers but also for all outdoor manual workers.

In conclusion, we revealed risk and preventive factors for heat illness in radiation decontamination workers. Age and immediate previous experience of outdoor manual work decreased the risk of heat illness during decontamination work. Furthermore, salt intake, use of a cool vest and adequate clothing are important in preventing heat illness. In addition, type of housing and sleep time are strongly associated with heat illness. Employers of decontamination workers should consider not only the employees' working conditions but also their living conditions to prevent heat illness.

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Conflict of interest: The authors declare that there is no conflict of interest.

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