HIROSAKI UNIVERSITY

Radiation Emergency Medicine 2013 Vol. 2 No. 2 63-67

REM
Radiation Emergency Medicine

Regular Article

Healthcare of 18 Workers who Supported the Regulation of Radiological Contaminations at the Fukushima Daiichi Nuclear Power Plant

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Received 28 February 2013; revised 27 June 2013; accepted 3 July 2013

The Great East Japan Earthquake on March 11, 2011 generated large tsunami waves that struck the Fukushima Daiichi nuclear power plant (F1-NPP) of Tokyo Electric Power Company, Inc. (TEPCO). This disaster led to the enormous release of radioactive material into the surrounding environment. In order to support recovery efforts at the F1-NPP, a number of workers have been dispatched to the site. In this study, the peripheral blood samples from 18 workers dispatched to the F1-NPP from May to June 2011 to support the regulation of radiological contamination were collected before and after work, and hematology and blood biochemistry were analyzed for worker healthcare administration. The physical external radiation doses of workers were estimated in the range of 0.2–4.8 mSv, which do not pose a health risk. The results of hematological analysis did not identify health hazards related to work at the F1-NPP. Furthermore, C-reactive protein levels, which are used as a biomarker for estimating exposure dose, were within the normal range except for those of 1 worker, and no findings suggested hypothyroidism. As expected, no negative effects on health were observed due to the external exposure dose in workers who supported the recovery of the F1-NPP.

Key words: hematology, blood biochemistry, Fukushima Daiichi NPP, worker, radiation, healthcare

1. Introduction

The Great East Japan Earthquake occurred on March 11, 2011 and caused a large tsunami that struck the east coast of Japan that resulted in enormous damage including harm to the emergency diesel generator at the Fukushima Daiichi nuclear power plant (F1-NPP) site of Tokyo Electric Power Company, Inc. (TEPCO). The F1-NPP lost emergency power and reactor cooling function. A large amount of radioactive material was subsequently released into the surrounding area due to hydrogen explosions. Many staff contributed to suppressing the spread of contamination at the F1-NPP. Therefore, it is important to provide healthcare and manage the radiation exposure of workers after working at the F1-NPP. Hematological and biochemical biomarkers were

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Table 1. Hematological parameters of workers before and after support work at the F1-NPP

Parameters	Reference Value	Before Average ± SE	After Average ± SE	*P*-value
WBC	3500 9700/μL	5,129.44 ± 249.47	5,898.89 ± 478.05	0.081
RBC	438 577 × 100/μL	491.44 ± 8.86	495.39 ± 7.34	0.404
Hb	13.6 18.3 g/dL	15.52 ± 0.27	15.56 ± 0.22	0.747
Ht	40.4 51.9%	45.56 ± 0.74	46.41 ± 0.63	0.142
MCV	83 101 fL	94.00 ± 0.66	89.17 ± 4.76	0.188
MCH	26.2 34.7 pg	31.59 ± 0.21	31.41 ± 0.19	0.330
MCHC	31.8 36.4%	34.06 ± 0.17	33.51 ± 0.14	0.013*
PL	14.0-37.9 × 10/μL	23.53 ± 0.84	22.73 ± 0.69	0.145
Baso	0.0 2.0%	0.68 ± 0.14	0.64 ± 0.09	0.622
Eosino	0.0 7.0%	2.75 ± 0.61	3.24 ± 0.67	0.524
Neutro	42.0 74.0%	59.72 ± 2.24	61.13 ± 2.09	0.375
Lympho	18.0 50.0%	31.96 ± 2.07	30.31 ± 1.74	0.323
Mono	1.0 8.0%	5.08 ± 0.49	4.68 ± 0.28	0.940
Neu/Lyn (%)	ND**	210.71 ± 27.09	222.41 ± 22.72	0.298

$^*P < 0.05$, **ND, no data

Table 2. Blood biochemical parameters of workers before and after support work at the F1-NPP

Parameters	Reference Value	Before Average ± SE	After Average ± SE	*P*-value
T-Bil	0.3 1.2 mg/dL	0.63 ± 0.04	0.72 ± 0.05	0.117
AST	10 40 U/L	27.83 ± 1.84	29.24 ± 2.16	0.211
ALT	5 45 U/L	38.33 ± 4.89	38.06 ± 4.93	0.799
γ-GTP	<79.0 U/L	79.83 ± 20.64	82.83 ± 21.72	0.329
CK	50 230 U/L	125.67 ± 8.85	168.89 ± 28.73	0.459
BS	70 109 mg/dL	106.78 ± 5.76	100.94 ± 2.89	0.818
T-cho	150 219 mg/dL	207.61 ± 6.31	215.11 ± 7.02	0.154
TG	50 149 mg/dL	213.78 ± 44.06	191.39 ± 34.46	0.671
UA	3.6 7.0 mg/dL	6.66 ± 0.25	6.72 ± 0.35	0.669
UN	8.0 20.0 mg/dL	12.45 ± 0.63	12.58 ± 0.39	0.551
Crea	0.65 1.09 mg/dL	0.75 ± 0.02	0.76 ± 0.03	0.225
Na	135 145 mEq/L	141.00 ± 0.28	140.61 ± 0.41	0.487
K	3.5 5.0 mEq/L	4.18 ± 0.07	4.20 ± 0.11	0.818
Cl	98 108 mEq/L	103.83 ± 0.60	103.11 ± 0.55	0.191
CRP	< 0.30 mg/dL	0.10 ± 0.03	0.11 ± 0.03	0.922

useful indicators for medical and healthcare after the Chernobyl accident[1] as well as the JCO accident in Tokai-mura, Japan[2]. Decreases in peripheral blood lymphocytes and neutrophils as well as an increase in the ratio of neutrophils to lymphocytes are reported in acute radiation exposure[3]. In addition, C-reactive protein (CRP), known as an inflammation marker, is a biomarker for estimating the dose of acute radiation exposure. CRP levels appear to increase significantly with increasing radiation dose due to atomic bomb radiation[4]. Mal'tsev et al.[5] described the CRP concentrations in the blood of 147 victims of the Chernobyl accident. They determined that CRP levels in peripheral blood during primary reactions due to irradiation (1 or 2 days after irradiation) and in the latent period of the disease (3–9 days after irradiation) as well as the titer of a complement 3–9 days after irradiation can provide information about the prognosis and outcomes of a radiation injury with clinically significant doses in the hepatic tissue. Ossetrova et al.[6] reported that serum CRP levels exhibit a bimodal response after whole-body radiation in a non-human primate model.

The radioactivity released from the F1-NPP was predominantly volatile fission products including isotopes of the noble gases (xenon and krypton), iodine (^{131}I and ^{132}I), cesium (^{134}Cs, ^{136}Cs, and ^{137}Cs), and tellurium (^{132}Te)[7,8]. The Japanese Ministry of Economy, Trade, and Industry estimated that the Fukushima source term included approximately 160 PBq of ^{131}I and 15 PBq of ^{137}Cs released into the atmosphere. Radioactive iodine taken up by the body accumulates in the thyroid gland, where it may cause thyroid dysfunction and cancer[9]. Infants in Chernobyl suffered internal exposure due to the intake of milk contaminated with a high density of ^{133}I[10]. In general, levels of free thyroxine (FT-4), free triiodothyronine (FT-3), and thyrotropin hormone (TSH) in serum are measured to evaluate thyroid function. The

Table 3. Thyroid function analysis of workers before and after support work at the F1-NPP

Parameters	Reference Value	Before	After	*P*-value
		Average ± SE	Average ± SE	
FT-3	2.2 4.1 pg/mL	3.27 ± 0.07	3.32 ± 0.07	0.464
FT-4	0.8 1.9 ng/dL	1.34 ± 0.04	1.38 ± 0.04	0.583
TSH	0.4 4.0 μIU/mL	1.46 ± 0.19	1.56 ± 0.20	0.459

cross-sectional Ukrainian–American Cohort study (1998–2000)[11] revealed 719 cases of hypothyroidism (TSH > 4 mIU/L), including 14 with overt hypothyroidism. Furthermore, Boehm et al.[12] reported that serum FT-4 levels were within the normal range in all 74 cases in their study; 1 patient who suffered second-degree acute radiation syndrome had serum TSH levels slightly above the normal range and FT-4 levels close to the reference minimum. Pacini et al.[13] reported no major alterations of serum FT-4, FT-3, or TSH in children or adolescents from Belarus exposed to radioactive fallout from the Chernobyl accident.

In this study, the peripheral blood samples of 18 workers dispatched to the F1-NPP from May to June 2011 to support the regulation of radiological contamination were collected before and after work, and hematology and blood biochemistry were analyzed for worker healthcare administration.

2. Materials and methods

Workers and blood collection

The working terms of staff dispatched to the F1-NPP were approximately 2–3 weeks. Cumulative external radiation dose was estimated using a personal dosimeter. Radiation safety officers accompanied and managed their support work in the contaminated area. Peripheral blood was drawn from the 18 workers before and after their F1-NPP dispatch from May to June 2011. After informed consent was obtained from all workers, whole peripheral blood was collected. The informed consent form used was approved the Committee of Medical Ethics of Hirosaki University Graduate School of Medicine (Hirosaki, Japan). The mean worker age was 44.0 years, ranging from 36–61 years.

Hematology

After blood collection, the following hematological parameters were measured: white blood cell (WBC) count, red blood cell (RBC) count, hemoglobin level (Hb), hematocrit (Ht), mean corpuscular volume (MCV), mean corpuscular hemoglobin (MCH) level, mean corpuscular hemoglobin concentration (MCHC), platelet (PL) count, basophil (Baso) count, eosinophil (Eosino) count, neutrophil (Neutro) count, lymphocyte (Lympho) count, monocyte (Mono) count, and the ratio of neutrophils to lymphocytes (N/L).

Blood biochemistry

After blood collection, the concentrations of the following biochemical parameters were measured: total bilirubin (T-Bil), aspartate aminotransferase (AST), alanine aminotransferase (ALT), γ-glutamyl transpeptidase (γ-GTP), creatine kinase (CK), blood sugar (BS), total cholesterol (T-cho), triglyceride (TG), uric acid (UA), urea nitrogen (UN), creatinine (Crea), sodium (Na), potassium (K), chloride (Cl), CRP, FT-3, FT-4, and TSH.

Statistical analysis

The results represent the mean ± SE of 18 workers. Differences before and after work at the F1-NPP were assessed using the Wilcoxon signed-rank test. The level of significance was set at $P < 0.05$. All statistical analyses were performed using SigmaPlot ver. 12.0 (Systat Software Inc., USA)

3. Results and discussion

The peripheral blood samples from 18 workers was collected before and after F1-NPP dispatch, and hematology and blood biochemistry were analyzed for worker healthcare administration. In Japan, the effective dose limits for normal conditions are based on the ICRP recommendation[14]: 1 or 50 mSv/y (100 mSv/5 y) for public and radiation workers, respectively. The Japanese Government temporarily increased the effective dose limit to 250 mSv for radiation workers during an emergency period after the Fukushima accident. When carrying out emergency work, the employer may allow male radiation workers to be exposed to an effective dose not exceeding 100 mSv to protect them from health hazards[15]. The mean external radiation dose estimated in the present study was 1.74 mSv, ranging from 0.2–4.8 mSv. At the end of January 2012, there were 756 and 167 workers whose external exposure doses were 50–100 and >100 mSv, respectively, among approximately 20,000 workers. Although it was difficult to ascertain the external exposure dose of the workers engaged during that period, it is estimated that the radiation doses of the workers who were tested at that time were very low.

In this study, there were no significant changes in WBC or PL counts in hematological analysis in any worker except one. All test results were within the reference range, even in the workers who had the highest external radiation exposure (4.8 mSv) during support work at the F1-NPP. One worker exhibited a rise of WBC counts: 5,010 and 11,640 cells/μL before and after work, respectively. The Ht value of this worker slightly exceeded the reference value both before and after their work at the F1-NPP. Bone marrow and WBCs are the most radiation-sensitive tissues in humans[16]. Reduced WBC count in the peripheral blood is due to cell death of peripheral blood WBCs as well as degradation of the supply due to bone marrow injury after radiation exposure. In this study, peripheral blood lymphocyte and granulocyte counts remain within the normal ranges after low doses of radiation (degree 1)[17]. Blakely[3] reported that the N/L ratio is a useful biomarker for estimating the radiation dose in a non-human primate model. In that study, baseline N/L ratios ranged from 0.254–4.80 with a pooled cohort value of 1.074 ± 0.262. No workers in the present study deviated from the baseline range of the N/L ratio reported by Blakely after performing support work at the F1-NPP. In this study, there were no remarkable changes in RBC count, Hb concentration, or Ht values before and after work. In addition, there were no changes in MCH, MCHC, or MCV calculated on the basis of these results. However, the MCHC values differed significantly before and after work (P = 0.013). However, it was determined that this poses no problems, because MCHC values remained within the reference range.

Blood biochemical analysis did not reveal any significant changes in liver function or electrolytes before and after work in this study. In addition, no significant changes were observed in CRP levels, which are used as a biomarker of acute radiation exposure. CRP increases significantly after irradiation, and elevated CRP levels beyond 14 days post-radiation are correlated with prognosis[3]. The CRP level of 1 worker in whom values exceeded the reference value before work decrease to within the reference range after work at the F1-NPP. However, the CRP levels in the blood of the other worker in whom the number of the lymphocytes increased after work exceeded the reference range after working (0.50 mg/dL); the CRP level of this worker increased after work, and the external radiation exposure dose was 0.9 mSv. The increases in CRP level and WBC count, particularly the increase in neutrophils from 51.5% to 78.4%, are thought to be due to inflammation. However, there were no clear symptoms suggesting a history of inflammatory upon medical examination by a physician; thus, the reasons for the inflammation are unclear. All workers were followed up by the attending physician to determine their health status, and no health problems relevant to radiation exposure were observed between blood collecting intervals and until the end of 2011.

A major concern of accidents involving the release of radioactive iodine is their effects on the thyroid. The average age of the workers in the present study was 44.4 years. FT-4, FT-3, and TSH values were within their respective references ranges both before and after work. There were no significant differences between the 4 workers under the age of 40 (external radiation exposure dose: 1.18 ± 0.60 mSv) and the 14 workers over the age of 40 (external radiation exposure dose: 1.90 ± 1.51 mSv) with respect to FT-4, FT-3, or TSH values before and after work at the F1-NPP. A study on a cohort of workers strongly exposed to radiation in the Chernobyl accident showed surprisingly little impact on the thyroid[12]. Therefore, further studies on the significance of examining thyroidal-related hormones for analyzing the influence of radiation exposure on the thyroid gland may be required.

Imaizumi[18] reported that the lifetime risk of thyroid cancer did not change if the age of Hiroshima and Nagasaki atomic bomb survivors at radiation exposure was more than 40 years. Furthermore, the authors estimated that approximately 28% of all solid nodules, 37% of malignant tumors, 31% of benign nodules, and 25% of cysts are associated with radiation exposure at mean and median thyroid radiation doses of 0.449 and 0.087 Sv, respectively. In the present study, it was difficult to determine the internal exposure doses and thyroid equivalent doses of workers. The Japanese Ministry of Economy, Trade, and Industry disclosed the estimates of radioactive material released from the F1-NPP into the atmosphere in June 2011. The quantity of ^{131}I emitted into the atmosphere from the F1-NPP was 160 PBq, which is approximately 2.5 times that released by the Hiroshima atomic bomb (63 PBq). Moreover, the deposition of ^{131}I on land mostly stemmed from release into the atmosphere from March 15 to 16, 2011[19, 20]. However, the workers analyzed in the present study started their support work at the F1-NPP from the middle of May 2011. By then, it was estimated that the radioactivity of ^{131}I had decreased to 1/64th of its original level. Therefore, concerns about the present workers having thyroidal functional disorders after their work are small.

The results suggest that the age selection of workers dispatched to the F1-NPP, i.e., not dispatching workers in their 20s, and work management based on external radiation dose were suitable. It should be noted that this is the first report involving hematological and blood biochemical analyses before and after work at the F1-NPP. As expected, the medical examinations of workers after dispatch to the F1-NPP for support work did not reveal any clinical symptoms or health impairments related to external radiation exposure.

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