

BMJ Open Whole body counter assessment of internal radiocontamination in patients with end-stage renal disease living in areas affected by the Fukushima Daiichi nuclear power plant disaster: a retrospective observational study

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ABSTRACT

Objective: To assess internal radiocontamination of patients with end-stage renal disease (ESRD) who were regularly taking haemodialysis (HD) and living in areas affected by the crippled Fukushima Daiichi nuclear power plant after the Great East Japan earthquake on 11 March 2011.

Methods: Internal radiocontamination in 111 patients with ESRD regularly taking HD at Jyoban Hospital in Iwaki city, Fukushima from July 2012 to November 2012 was assessed with a whole body counter (WBC). The maximum annual effective dose was calculated from the detected Cs-137 levels. Interviews concerning patient dietary preferences and outdoor activities were also conducted.

Results: Among the 111 patients tested, internal radiocontamination with Cs-137 was detected in two participants, but the levels were marginal and just exceeded the detection limit (250 Bq/body). The tentatively calculated maximum annual effective dose ranged from 0.008 to 0.009 mSv/year, which is far below the 1 mSv/year limit set by the government of Japan. Relative to 238 non-ESRD participants, patients with ESRD had significantly more opportunities to consume locally grown produce that was not distributed to the market ($p < 0.01$). However, the percentage of patients with ESRD with detectable Cs (1.8%) was lower than that for non-ESRD participants (3.8%), although this difference was not significant ($p = 0.51$).

Conclusions: These findings suggest that internal radiocontamination levels and the calculated annual additional effective doses were negligible for patients with ESRD taking HD in areas affected by the crippled Fukushima nuclear plant. Although HD is suggested to promote Cs-137 excretion, continuous inspection of locally grown produce together with WBC screening for radiocontamination should be continued for patients with ESRD regularly taking HD.

Strengths and limitations of this study

- An unprecedented observation of whole body counter (WBC) assessments of internal radiocontamination for patients with end-stage renal disease on haemodialysis living in areas affected by the Fukushima Daiichi nuclear power plant disaster.
- A less number of participants, limiting the generalisability of these findings to patients in other affected areas around the crippled nuclear plant.
- A delayed period between the disaster and the beginning of this study (1 year), due to a lack of systematic measurements during this time.

INTRODUCTION

The aftermath of the Great East Japan earthquake that occurred on 11 March 2011 brought diverse health threats and impaired medical care services for residents living in the affected areas during different periods.^{1–4} Residents of the radiocontaminated areas surrounding the Fukushima Daiichi nuclear power plant that was crippled by the earthquake and tsunami were forced to consider possible health threats, mainly from radiation exposure.^{5–6} To reduce health threats and avoid undesirable radiation exposure, accurate assessment of radiation exposure of residents living in the radiocontaminated areas was necessary. Monitoring of the ambient air doses provided a basis for establishing safe residential regions in the affected areas.⁷ Moreover, inspection of produce grown in affected areas and whole body counter (WBC) measurement of internal radiocontamination of residents living in affected areas

were performed to ensure that their annual effective dose from internal radiation exposure was below governmental limits.⁸

Our series of studies revealed that internal radiation exposure was marginal in the aftermath of the nuclear incident and that for nearly all examinees the doses from internal radiation exposure were far below the government-allowed limit (1 mSv/year).^{9–12} However, a small percentage (1–2%) of the examinees did show detectable internal radiocesium (Cs; Cs-134 and Cs-137) contamination within 1 year of the incident, and even beyond 1 year Cs-137 could still be detected in a few individuals.^{13 14} This radiocontamination could presumably be attributed to the intake of contaminated, locally grown produce that did not undergo radiation inspection. The findings from these studies clearly suggest that internal radiation exposure is manageable for residents living in radiocontaminated areas, but continuous WBC screening and food inspection is mandatory at the present time.

Although systematic WBC screening has been performed for voluntary hospital visitors and schoolchildren younger than 16 years of age, no specific screening has been done for hospital patients. In this regard, patients with end-stage renal disease (ESRD) undergoing haemodialysis (HD) could represent a patient population among affected residents, since Cs tends to be eliminated via the urine, and urine production may be compromised in patients with ESRD due to severely impaired kidney function. In addition, HD requires large amounts of tap water that could have been contaminated with radionuclides dispersed from the crippled nuclear plant, including radioiodine (I-131) as well as Cs.^{15 16} However, this possibility seems unlikely except for the period immediately after the disaster, since the I-131 half-life is short (8 days) and Cs is presumably trapped during common water purification processes (eg, coagulation–flocculation–sedimentation) used for drinking water in Japan.¹⁷

Measurement of internal radiocontamination in patients with ESRD living in the affected areas is an unprecedented clinical opportunity to assess previous reports indicating that HD is more effective in eliminating Cs in patients with ESRD relative to non-ESRD participants.^{18–20} The present study was thus conducted to assess internal Cs contamination in 111 patients with ESRD from July 2012 to November 2012.

METHODS

Patients

An internal radiation exposure-screening programme was conducted between 1 April 2012 and 31 December 2014 to assess internal radiocontamination among all residents in affected areas that were south of the Fukushima nuclear plant. There were no costs to the residents to participate in the programme.

The participants of this study were patients with ESRD undergoing HD who were among the voluntary visitors to Jyoban Hospital. The study participants were examined after obtaining informed consent to collect data on age, sex and results of the internal radiation exposure-screening programme during the study period.

Assessment of internal radiation exposure by WBC

Internal radiocontamination was assessed by WBC measurements at the Jyoban Hospital between July 2012 and November 2012. The recorded major variables for the patients were age, sex and the total body burden of radioactive Cs (Cs-134 and Cs-137). The patients changed into a hospital gown before WBC measurement to exclude any radiocontamination that may have been present on their clothing.

Measurement procedure

The WBC device used was a stereoscopic apparatus with two 3×5×16 inch NaI scintillation detectors (Fastscan Model 2251; Canberra, Inc, Meriden, Connecticut, USA). The Cs detection limits in a 2 min scan were 220 and 250 Bq/body for Cs-134 and Cs-137, respectively.

Calculation of effective dose from detected Cs-137 internal contamination

Calculation of annual effective doses based on observed levels of internal Cs-137 contamination was performed using effective dose coefficients derived from the International Commission on Radiological Protection, Publication 67, where the amount of Cs activity detected by WBC examinations is assumed to be in an equilibrium state between consecutive ingestions and excretions over the course of 1 year.²¹ Since there is no available information to calculate the annual effective doses that reflect the observed levels of internal Cs-137 contamination in patients with renal disease, we tentatively calculated the annual effective doses of the present participants with respect to healthy subjects who had normal renal function.

Questionnaire regarding dietary preference

In addition to the WBC measurements, a self-report exposure risk assessment questionnaire that was used in previous studies was administered to and completed by the screening participants.^{12 13 22} This questionnaire included items regarding food and water consumption. Questions concerning food asked whether the respondent selected certain produce on the basis of the origin listed at the supermarket (Fukushima vs non-Fukushima), or it was simply purchased from local farms. Beginning on 1 April 2012, a maximum allowed limit of 100 Bq/kg of Cs was set for general foods; thus, commercially available foods were considered to have been monitored regardless of their origins (ie, Fukushima or non-Fukushima).²³ Questions concerning water asked whether the respondents avoided drinking tap water. The patients were also asked about how much

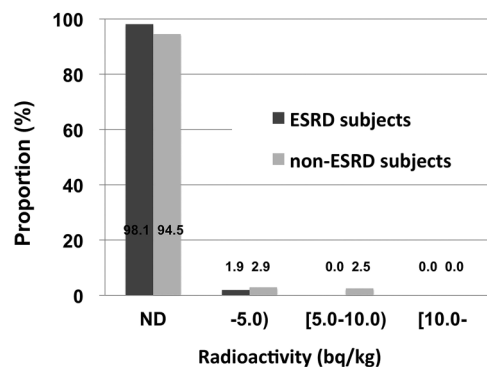


Figure 1 Levels of Cs-137 internal contamination among patients with end-stage renal disease.

time they spent outdoors. All study participants provided written documentation for informed consent.

Statistical analysis

All statistical analyses were conducted using R V.3.2.0.

RESULTS

A whole body counter (WBC) radiation exposure screening of 111 patients with ESRD regularly taking HD was conducted in Jyoban Hospital between July 2012 and November 2012. Among the 111 patients, 26 (23.4%) were women, and their ages ranged from 25 to 83 years, with a median age of 61 years.

Internal radiocontamination with Cs was detected for 2 of the 111 participants (figure 1). Of a total of 2503 voluntary hospital visitors who did not have kidney disease and underwent WBC screening during the same period, 238 individuals in the same age range as the study subjects (patients with ESRD) were selected as the control group, which is hereafter referred to as non-ESRD participants with a median age of 53.5 years and 45.0% females (table 1). The percentage of patients with ESRD with detectable Cs (1.8%) was lower than that of non-ESRD participants (3.8%), although this difference was not statistically significant ($p=0.51$, determined by Fisher's exact test). Moreover, among the putative radiocesium released from the crippled Fukushima nuclear plant, only Cs-137 was detected

while Cs-134 levels were below the detection limit (220 Bq/body). The detected Cs-137 levels for the two patients were 257 (for a 75-year-old man) and 279 Bq/body (for a 73-year-old man), which were just over the detection limit (250 Bq/body). The annual effective radiation dose from Cs-137 could be virtually calculated for the two patients to be 0.008 and 0.009 mSv/year, respectively, which are both far below the dose limit for radiation exposure (1 mSv/year) that was set by the government.

The nutrition interview results showed that some participants consumed locally grown rice (42 patients; 37.8%) and vegetables (31 patients; 27.9%) that were not distributed to the market, while meat, fish, mushrooms and milk were more likely to have been commercially obtained (table 2). Relative to non-ESRD participants, the patients with ESRD had significantly more opportunities to consume locally grown produce that was not distributed to the market ($p<0.01$; determined by Pearson's χ^2 test). Even though the patients with ESRD spent less time outdoors, they were presumed to maintain, at least to a certain extent, a similar lifestyle after the incident in terms of harvesting and collection of food. While the nutrition interview results from 1 of the 2 detected participants were available, this participant regularly consumed undistributed locally grown rice and vegetables.

DISCUSSION

Two of the 111 (1.8%) patients in the study exhibited detectable but marginal levels of internal Cs-137 contamination, but not Cs-134. The committed effective doses for the two patients were calculated to be 0.008–0.009 mSv/year, which is far below the government-allowed limit of 1 Sv/year. These findings suggest that the internal Cs contamination in patients with ESRD living in areas affected by the nuclear incident was marginal and that programmes to encourage avoiding intake of uninspected potentially contaminated local foods were successful in preventing undesirable radiocontamination. However, detection of internal radiocontamination levels ended during September 2012, or 18 months after the incident. The detection of

Table 1 Results of WBC screenings

Month, year	Non-ESRD examinees			ESRD examinees		
	N	Number of Cs-137 detected individuals	Per cent	n	Number of Cs-137 detected individuals	Per cent
July, 2012	79	7	8.9	47	1	2.1
August, 2012	41	2	4.9	49	0	0.0
September, 2012	33	0	0.0	13	1	7.7
October, 2012	40	0	0.0	0	0	NA
November, 2012	45	0	0.0	2	0	0.0
Total	238	9	3.8	111	2	1.8

Cs, ESRD, end-stage renal disease; NA, not applicable; WBC, whole body counter.

Table 2 Number of examinees who regularly eat locally grown produce which was not distributed to the market

	Non-ESRD examinees (n=238)		ESRD examinees (n=111)	
	Number of examinees	Per cent	Number of examinees	Per cent
Rice	50	21.0	42	37.8
Vegetables	37	15.6	31	27.9
Mushrooms	4	1.7	5	4.5
Beans	2	0.8	5	4.5
Fruits	4	1.7	2	1.8
Milk	0	0.0	2	1.8
Meat	1	0.4	1	0.9
Fish	3	1.7	1	0.9
Total	66	27.7	47	42.3

ESRD, end-stage renal disease.

Cs-137 radiocontamination long after the incident supported results from other studies of areas affected by the nuclear plant accident that showed that a very less number of study subjects had detectable levels of internal Cs-137 contamination even 2 years after the incident.

We assume that the detected Cs-137 was derived from contaminated locally grown produce that in particular was consumed soon after the accident, when the supplies of commercially available and uncontaminated food were severely compromised owing to the several month-long evacuations of employees of commercial food distribution companies located within a 50 km radius of the crippled nuclear plant. During this period, some residents within this 30–50 km radius were forced to consume locally grown produce that had not undergone inspections for radiocontamination. Alternatively, the detected internal Cs-137 contamination could have been derived from a continuous intake of uninspected contaminated produce grown in the study subjects' gardens and fields, as was suggested in a previous study.¹³ In fact, interviews that assessed the dietary preferences of study subjects (table 2), and particularly one of two participants who showed Cs-137 contamination, suggested that they did indeed consume locally grown produce, presumably from their own garden. In this regard, visitors to the hospital who were seeking medical care also require continuous assessment of internal Cs-137 radiocontamination in addition to the voluntary visitors who underwent WBC screenings.

Earlier reports showing that tap water was radiocontaminated with radioactive substances (I-131, Cs-134, and Cs-137) immediately after the nuclear plant incident suggest that patients with ESRD could have been radiocontaminated during HD that used contaminated tap water for the dialysates.¹⁵ However, dialysates can be successfully purified and decontaminated using reverse osmosis equipment such that radionuclides are present at undetectable levels. Even immediately after the

disaster, Cs appeared to be effectively trapped within muds in riverbeds and areas affected by the tsunami, and was generally undetectable in drinking water in the affected areas. However, monitoring of potential I-131 contamination of tap water immediately after the disaster was most likely to be far more important than internal radiocontamination measurements in patients undergoing HD since I-131 cannot be removed by coagulation–flocculation–sedimentation purification processes, but instead must be removed by special purification measures, including activated charcoal treatment and separation with reverse osmosis membranes. In our HD facility, all tap water used for the dialysates is purified by reverse osmosis and activated charcoal treatment according to standard procedures, which would reduce the likelihood that the radionuclides detected in the patients accumulated after HD treatment. This assumption is further supported by this study where only a few patients with ESRD showed internal radiocontamination. These findings again imply that the detected Cs-137 was most likely derived from contaminated food.

Previous reports of patients with ESRD who experienced radiocontamination from the Chernobyl incident showed that HD was two times more effective at eliminating whole body 137-Cs that remained in patients with ESRD as compared to the healthy examinees, and even for those patients with ESRD who had impaired renal-dependent radiocesium excretion.^{19 20} During HD, radiocesium, along with electrolytes and waste products, can be removed by diffusion through a membrane. Since patients with ESRD generally need to undergo several hours of dialysis three times a week, presumably HD should function to excrete Cs-137 as well as or better than normal renal function. From the findings of this study, we assumed that most of the tested patients with ESRD had undetectable levels of internal radiocontamination because they were regularly undergoing dialysis and the WBC screening was performed over 15 months after the incident.

More unexpectedly, the percentage of patients with ESRD who had detectable levels of radiocontamination (2/111=1.8%) did not statistically differ from those seen for voluntary hospital visitors during the same period (9/238=3.8%, table 1). The reasons behind this similar detection rate between patients with ESRD and healthy patients are unclear at this stage due to the less number of participants included in the study. However, from information gathered from interviewing study participants to determine their dietary preferences, relative to non-ESRD participants, the patients with ESRD had significantly more opportunities to consume locally grown produce that was not distributed to the market ($p<0.01$). To reduce the long-term health risks of radiation for patients with ESRD, long-term measures, including continuous monitoring of internal contamination by WBCs, in addition to assessment of agricultural product contamination and public education efforts, are essential to prevent radiocontamination in the future.

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Contributors HS, JM and TT carried out clinical examinations that were supervised by HK and MT. JA conducted WBC screening. KA and SS technically supervised to establish the WBC screening. MT, SK, SN and JA prepared the figures. HS designed the study. MT, SN and SK analysed the data. MT and SK wrote the manuscript. All the authors read and approved the final manuscript.

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Competing interests None declared.

Patient consent Obtained.

Ethics approval The ethical review committee of the Jyoban Hospital institutional review board approved the study.

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Data sharing statement All data underlying the findings in our study will be made freely available to other researchers on request; please contact HS at shimmura@tokiwa.or.jp

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REFERENCES

1. Tsubokura M, Takita M, Matsumura T, *et al.* Changes in metabolic profiles after the Great East Japan Earthquake: a retrospective observational study. *BMC Public Health* 2013;13:267.
2. Harasawa K, Tanimoto T, Kami M, *et al.* Health problems in the temporary housing in Fukushima. *Lancet* 2012;379:2240–1.
3. Nomura S, Gilmour S, Tsubokura M, *et al.* Mortality risk amongst nursing home residents evacuated after the Fukushima nuclear accident: a retrospective cohort study. *PLoS ONE* 2013;8:e60192.
4. Tsubokura M, Horie S, Komatsu H, *et al.* The impact of the Great Tohoku Earthquake on the dialysis practice in the disaster-stricken area. *Hemodial Int* 2012;16:320–1.
5. Sugimoto A, Nomura S, Tsubokura M, *et al.* The relationship between media consumption and health-related anxieties after the Fukushima Daiichi nuclear disaster. *PLoS ONE* 2013;8:e65331.
6. Sugimoto T, Shinozaki T, Naruse T, *et al.* Who was concerned about radiation, food safety, and natural disasters after the great East Japan earthquake and Fukushima catastrophe? A nationwide cross-sectional survey in 2012. *PLoS ONE* 2014;9:e106377.
7. Yasumura S, Hosoya M, Yamashita S, *et al.* Study protocol for the Fukushima Health Management Survey. *J Epidemiol* 2012;22:375–83.
8. Nagataki S, Takamura N, Kamiya K, *et al.* Measurements of individual radiation doses in residents living around the Fukushima nuclear power plant. *Radiat Res* 2013;80:439–47.
9. Tsubokura M, Gilmour S, Takahashi K, *et al.* Internal radiation exposure after the Fukushima nuclear power plant disaster. *JAMA* 2012;308:669–70.
10. Tsubokura M, Shibuya K, Kato S, *et al.* Acute intake of radionuclides immediately after the incident as the main contributor of the internal radiation exposure after Fukushima Daiichi nuclear disaster. *JAMA Pediatr* 2013;167:1169–70.
11. Tsubokura M, Kato S, Nihei M, *et al.* Limited internal radiation exposure associated with resettlements to a radiation-contaminated homeland after the Fukushima Daiichi nuclear disaster. *PLoS ONE* 2013;8:e81909.
12. Tsubokura M, Kato S, Nomura S, *et al.* Absence of internal radiation contamination by radioactive cesium among children affected by the Fukushima Daiichi nuclear power plant disaster. *Health Phys* 2015;108:39–43.
13. Tsubokura M, Kato S, Nomura S, *et al.* Reduction of high levels of internal radio-contamination by dietary intervention in residents of areas affected by the Fukushima Daiichi nuclear plant disaster: a case series. *PLoS ONE* 2014;9:e100302–00.
14. Hayano RS, Tsubokura M, Miyazaki M, *et al.* Internal radiocesium contamination of adults and children in Fukushima 7 to 20 months after the Fukushima NPP accident as measured by extensive whole-body-counter surveys. *Proc Jpn Acad Ser B Phys Biol Sci* 2013;89:157–63.
15. Kamei D, Kuno T, Sato S, *et al.* Impact of the Fukushima Daiichi Nuclear Power Plant accident on hemodialysis facilities: an evaluation of radioactive contaminants in water used for hemodialysis. *Ther Apher Dial* 2012;16:87–90.
16. Hamada N, Ogino H, Fujimichi Y. Safety regulations of food and water implemented in the first year following the Fukushima nuclear accident. *J Radiat Res* 2012;53:641–71.
17. Kosaka K, Asami M, Kobashigawa N, *et al.* Removal of radioactive iodine and cesium in water purification processes after an explosion at a nuclear power plant due to the Great East Japan Earthquake. *Water Res* 2012;46:4397–404.
18. Josefsson D, Hegbrant J, Holm E, *et al.* The effect of dialysis on radiocaesium in man. *Sci Total Environ* 1995;173–174:407–11.
19. Verzijl JM, Wierckx FC, Hennen LA, *et al.* The influence of extracorporeal clearance techniques on elimination of radiocesium after internal contamination. *Health Phys* 1995;69:521–9.
20. Verzijl JM, Wierckx FC, van Dijk A, *et al.* Hemodialysis as a potential method for the decontamination of persons exposed to radiocesium. *Health Phys* 1995;69:543–8.
21. International Commission on Radiological Protection. Age-dependent Doses to Members of the Public from Intake of Radionuclides—Part 2 Ingestion Dose Coefficients. ICRP Publication 67. Secondary Age-dependent Doses to Members of the Public from Intake of Radionuclides—Part 2 Ingestion Dose Coefficients. ICRP Publication 67 Ann. ICRP 22, 1992. <http://www.icrp.org/publications.asp>
22. Sugimoto A, Gilmour S, Tsubokura M, *et al.* Assessment of the risk of medium-term internal contamination in Minamisoma City, Fukushima, Japan, after the Fukushima Dai-ichi nuclear accident. *Environ Health Perspect* 2014;122:587–93.
23. Merz S, Shozugawa K, Steinhäuser G. Analysis of Japanese radionuclide monitoring data of food before and after the Fukushima nuclear accident. *Environ Sci Technol* 2015;49:2875–85.