



Estimates of Radiation Doses and Cancer Risk from Food Intake in Korea

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The aim of this study was to estimate internal radiation doses and lifetime cancer risk from food ingestion. Radiation doses from food intake were calculated using the Korea National Health and Nutrition Examination Survey and the measured radioactivity of ¹³⁴Cs, ¹³⁷Cs, and ¹³¹I from the Ministry of Food and Drug Safety in Korea. Total number of measured data was 8,496 (3,643 for agricultural products, 644 for livestock products, 43 for milk products, 3,193 for marine products, and 973 for processed food). Cancer risk was calculated by multiplying the estimated committed effective dose and the detriment adjusted nominal risk coefficients recommended by the International Commission on Radiation Protection. The lifetime committed effective doses from the daily diet are ranged 2.957–3.710 mSv. Excess lifetime cancer risks are 14.4–18.1, 0.4–0.5, and 1.8–2.3 per 100,000 for all solid cancers combined, thyroid cancer, and leukemia, respectively.

Keywords: Diet; Neoplasm; Nuclear Power Plants; Radioactivity; Radionuclide; Risk Assessment

INTRODUCTION

After the Fukushima Daiichi nuclear power plant accident, a widespread public concern for radiation exposure through the contamination of domestic or imported food has continued worldwide. The internal exposure from contaminated food is an important consideration for human health effects because radioactive materials can contact directly with human tissues and they may accumulate over a long period of time. Some studies for estimating radiation doses and cancer risk from the Fukushima nuclear accident have been conducted in several countries such as Japan (1-3), the US (4), UK (5), and Ireland (6).

Although it has been reported that the accident did not significantly affect environmental radioactivity levels in Korea (7), potential contamination of radionuclides in domestic food and imported marine products from Japan have aroused public attention and fear of radiation. However, to the best of our knowledge, no studies on radiation doses and cancer risk from food intake have been reported.

The aim of the study, therefore, was to estimate internal radia-

tion dose and lifetime cancer risk from food ingestion in the Korean population.

MATERIALS AND METHODS

Study design

We conducted a health risk assessment of internal radiation exposure with the following steps. First, we selected three radionuclides (cesium 134 [¹³⁴Cs], cesium 137 [¹³⁷Cs], and iodine 131 [¹³¹I]) to study because these radionuclides are important for practical purposes with regards to internal radiation doses during the first few weeks after the accident (i.e., radioiodine) and after about one month (i.e., radiocesiums) (8). Second, we conducted radiation dose assessment from food intake using the Korea National Health and Nutrition Examination Survey (KNHANES), measured radioactivity concentration data from the Ministry of Food and Drug Safety (MFDS) in Korea, and the age-dependent committed effective dose coefficients from the International Commission on Radiation Protection (ICRP). Third, we used the detriment adjusted nominal cancer risk co-

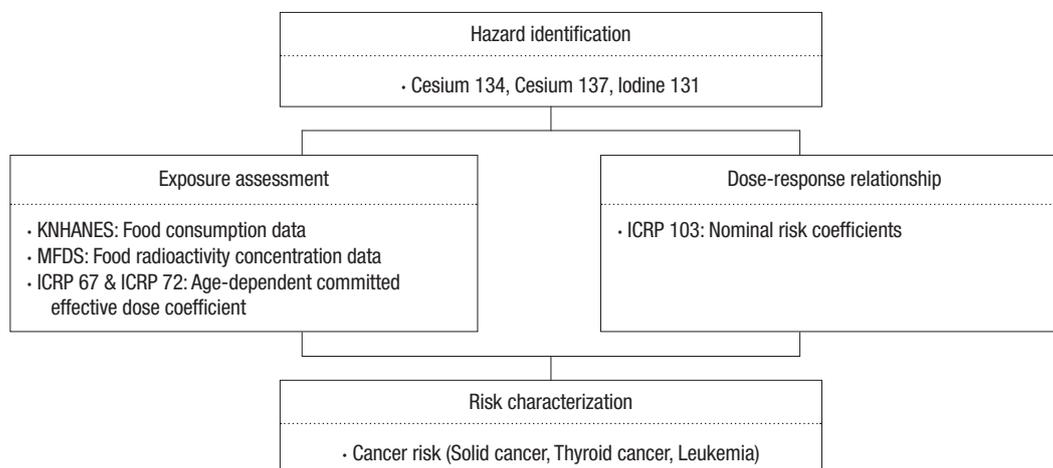


Fig. 1. Study framework. KNHANES, Korea National Health and Nutrition Examination Survey; MFDS, Ministry of Food and Drug Safety; ICRP, International Commission on Radiation Protection.

efficients that were recommended by the ICRP for the dose-response relationship. Finally, cancer risks for all solid cancers, thyroid cancer, and leukemia were calculated by multiplying the lifetime committed effective doses and the detriment adjusted nominal risk coefficients. The framework of this study is given in Fig. 1.

Intake of radionuclides

The amount of food intake was obtained from daily consumption data provided by the KNHANES in 2008-2010. The KNHANES has been carried out annually to assess the surveillance system in Korea that assesses the health and nutritional status of the Korean population (9). For infants, the information of measured formula milk powder was obtained from MFDS (10). The individual food items were grouped into five categories by the Food Code used in KNHANES (i.e., agricultural products, livestock products, milk products, marine products, and processed food). The food consumption rate was estimated according to age group: under 1 yr, 1 yr (covering 1-2 yr of age), 5 yr (3-7 yr of age), 10 yr (8-12 yr of age), 15 yr (13-17 yr of age), and adults (≥ 18 yr of age). These are the same groupings for the committed effective dose coefficients (11,12).

To assess the internal radiation dose to radionuclides in food, we used the radioactivity concentration data of food contaminated by ^{134}Cs , ^{137}Cs , and ^{131}I measured by the MFDS between 2012 and 2013. Total number of measured data was 8,496 (i.e., 3,643 for agricultural products, 644 for livestock products, 43 for milk products, 3,193 for marine products, and 973 for processed food). The measured concentration levels of radionuclide in individual food items were averaged and assumed to be the concentration level of radionuclide of each food category. The data values below the minimum detectable activity (MDA) were assumed to be 0.5 Bq/kg. The amount of intake of all food groups was calculated by adding the amounts of each food group con-

sumed in the annual diet for a person (kg/yr). To conservatively estimate the annual intakes of radionuclide, we used the 95th percentile level of food consumption amounts and average radioactivity concentration for each food category.

Dose estimation

The annual committed effective dose (CED) (mSv/yr) from ingestion of the three radionuclides was calculated using the following formula:

$$\text{CED} = \sum_j \{M(A) \times C_j \times e_{j,\text{ing}}(A)\}$$

$M(A)$ is the food consumption per year for age and food group (kg/yr). C_j is the radioactivity concentration of radionuclide j in food group (Bq/kg) and $e_{j,\text{ing}}(A)$ is the age-dependent committed effective dose coefficient from ingestion of radionuclide j (mSv/Bq) represented in ICRP 67 (11) and ICRP 72 (12). The intakes of radionuclide were converted into internal radiation doses using age-dependent ingestion dose coefficients of ^{134}Cs , ^{137}Cs , and ^{131}I according to organ sites in ICRP 67 (11) and ICRP 72 (12).

Cancer risk estimation

All solid cancers, thyroid cancer, and leukemia were selected because of their radiosensitivity. For lifetime nominal risk assessment, lifetime doses were estimated by applying the annual committed effective dose from the age of first exposure until 89 yr of age for conservative estimation even though the actual life expectancy was 81 yr for Korean population in 2013 (13). Excess lifetime fatal cancer risk was estimated by multiplying the lifetime committed effective dose and the detriment adjusted nominal risk coefficient of 4.871%/Sv for all solid cancers, 0.127%/Sv for thyroid cancer, and 0.615%/Sv for leukemia in ICRP 103 (14).

RESULTS

The annual amounts of food consumption (kg/yr) by age groups and average of radioactivity concentration for the five food categories are shown in Table 1. Annual consumption rates of all food increased with increasing age, with the exception of milk products. Agricultural products had the highest annual consumption and marine products had the lowest among all food categories. The concentration of ^{134}Cs was below the MDA in all food products, whereas the concentrations of ^{137}Cs were 0.5011 Bq/kg in agricultural products, 0.5011 Bq/kg in marine products, and 0.5082 Bq/kg in processed food. The concentration of ^{131}I was below the MDA in all food products except marine products.

Table 2 shows the annual committed effective and equivalent doses, lifetime dose, and excess lifetime cancer risk by age group. The highest annual committed effective dose and thyroid equivalent dose were observed in the 1-yr age group, whereas the highest red marrow equivalent dose was observed in adults. The lifetime doses from the daily diet were 2.957-3.710 mSv for the committed effective dose, 25.213-36.133 mSv for the thyroid equivalent dose, and 1.704-1.912 mSv for the red marrow equivalent

Table 1. Annual food intake and measured radionuclide concentrations by food category

Food category	Agricultural products	Livestock products	Milk products	Marine products	Processed food
95th percentile annual intake (kg/yr)*					
Age group (yr)					
< 1	-	-	68.4	-	-
1 (1-2)	280.0	36.8	249.9	29.5	177.2
5 (3-7)	318.3	65.4	224.0	39.8	190.8
10 (8-12)	412.6	93.7	212.8	56.4	291.2
15 (13-17)	435.4	130.8	232.1	67.8	372.1
Adults (≥ 18)	526.6	130.7	149.5	98.4	612.4
Average radionuclide concentration (Bq/kg)					
^{134}Cs	0.5 [†]	0.5 [†]	0.5 [†]	0.5 [†]	0.5 [†]
^{137}Cs	0.5011	0.5 [†]	0.5 [†]	0.5011	0.5082
^{131}I	0.5 [†]	0.5 [†]	0.5 [†]	0.5072	0.5 [†]

*Food intake was calculated using the Korea National Health and Nutrition Examination Survey in 2008-2010; [†]Minimum detectable activity (MDA) was assumed to be 0.5 Bq/kg.

Table 2. Annual committed effective and equivalent doses, lifetime dose, and excess lifetime cancer risk from dietary intake by age

Age group (yr)	Annual committed effective and equivalent dose (mSv/yr)			Lifetime dose (mSv)*			Excess lifetime cancer risk (case per 100,000) [†]		
	Committed effective dose	Thyroid	Red marrow	Committed effective dose	Thyroid	Red marrow	Solid cancer	Thyroid cancer	Leukemia
< 1	0.008	0.128	0.001	3.710	36.133	1.912	18.1	0.5	2.3
1	0.081	1.4	0.009	3.702	36.005	1.911	18.0	0.5	2.3
5	0.051	0.89	0.008	3.467	31.932	1.877	16.9	0.4	2.1
10	0.041	0.546	0.012	3.242	28.512	1.825	15.8	0.4	2.0
15	0.041	0.441	0.019	3.039	26.096	1.743	14.8	0.4	1.9
Adults	0.041	0.35	0.024	2.957	25.213	1.704	14.4	0.4	1.8

*Lifetime doses were estimated by applying the annual committed effective dose from the age of first exposure until 89 yr of age; [†]Excess lifetime cancer risk was estimated by multiplying the lifetime committed effective dose and the detriment adjusted nominal risk coefficient of 4.871%/Sv for all solid cancers, 0.127%/Sv for thyroid cancer, and 0.615%/Sv for leukemia in ICRP 103.

dose. The lifetime nominal risks for all solid cancers combined, leukemia, and thyroid cancer were decreased with increasing age with ranges of 14.4-18.1, 1.8-2.3, and 0.4-0.5 per 100,000, respectively.

DISCUSSION

This is the first study to estimate the internal radiation exposure through food ingestion and lifetime cancer risk in Korea. Our results showed that the lifetime radiation doses and corresponding cancer risk were low among the Korean population. Compared with the population attributable fraction of well-known cancer risk factors in Korea (15), the potential contribution of cancer risk from internal radiation exposure through food consumption would be very small. However, the limitations of the ICRP nominal risk coefficient, which was applied to radiation-induced lifetime risk as an average by sex and age of the whole population, require careful interpretation for populations susceptible to radiation.

The internal exposure level of radiation through food intake is expected to be lower than our estimates, which were calculated using conservative assumptions. First, the detection rate for ^{134}Cs , ^{137}Cs , and ^{131}I concentration in food was only 0.2% and the value of 0.5 Bq/kg was assigned for the below MDA. Second, this study used the 95th percentile of food consumption and the average concentration of radionuclides as part of our conservative approach. Third, the radioactivity concentration of the radionuclides for any single food item was assumed to be the concentration level of radionuclide for each food category.

On the other hand, the risks might be an underestimate. First the analysis of radionuclides was restricted to radiocesium and radioiodine and the other radioactive elements of strontium (Sr), plutonium (Pu), zirconium (Zr), and ruthenium (Ru) were not included in this analysis although the effective doses of strontium-90 were about 1/500 to 1/50 of that from radioactive cesium from the monitoring of fishery products in Japan (16). Second, the food intake pattern may change over decades and more extreme situations of food consumption could be possible.

Previous studies of the Fukushima accident reported very low levels of radiation exposure or health risks among the population in Japan (1-3), the US (4), UK (5), Ireland (6), and worldwide (17). Although a direct comparison with these studies is difficult because of the different methods of evaluation such as including other radioactive materials and using cancer incidence data, the different assumptions for the estimation of ingestion dose and applying Monte-Carlo simulation, and radiation exposure pathways including water drinking as well, our findings were consistent with others in that the Fukushima accident did not notably contribute to increased internal radiation dose or health risk to other countries.

Our findings suggest no discernible increase in radiation doses or excess fatal cancer risk from food ingestion at this stage in Korea, and provide scientific evidence of the risk communication with general public associated with low-dose radiation exposure. However, the results were based on current monitoring situation and have considerable uncertainties in estimating the dose and risk, therefore, continuous food monitoring and strict regulation on food safety at the government level should be emphasized to prevent any additional health hazards from food contamination.

DISCLOSURE

The authors have no conflicts of interest to disclose.

AUTHOR CONTRIBUTION

Conception and coordination of the study: Lee WJ, Jin YW, Yoon HJ. Acquisition of data: Kim HS, Hwang MS, Choi H. Analyzed the data: Moon EK, Ha WH, Seo SW, Choi H. Data review: Lee WJ, Jin YW, Yoon HJ, Jeong KH, Hwang MS, Kim HS, Ha WH, Seo SW, Choi H, Moon EK. Manuscript preparation: Moon EK, Lee WJ. Manuscript approval: all authors.

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