Radiocesium concentrations in wild boars captured within 20 km of the Fukushima Daiichi Nuclear Power Plant

Limeng Cui1,2, Makiko Orita1✉, Yasuyuki Taira1 & Noboru Takamura1

The Fukushima Daiichi Nuclear Power Plant (FDNPP) accident in 2011 released large amounts of artificial radioactive substances into the environment. In this study, we measured the concentration of radiocesium ($^{134}$Cs + $^{137}$Cs) in 213 muscle samples from wild boars (Sus scrofa) captured in Tomioka town, which is located within 20 km of the FDNPP. The results showed that 210 (98.6%) muscle samples still exceeded the regulatory radiocesium limit (100 Bq/kg) for general foods. Radiocesium ($^{134}$Cs + $^{137}$Cs) levels ranged from 87.1–8,120 Bq/kg fresh mass (FM), with a median concentration of 450 Bq/kg FM. The median committed effective dose was estimated to be 0.070–0.26 μSv/day for females and 0.062–0.30 μSv/day for males. The committed effective dose for one-time ingestion of wild boar meat could be considered extremely low for residents in Tomioka. The relatively high levels of radioactivity found in this study suggest that the high variability of food sources may have led to the large accumulation of radioactive substances. These results suggest that comprehensive long-term monitoring is needed to identify risk factors affecting recovery from a nuclear disaster.
Results

Radioactivity concentration. Among the 213 wild boar (Sus scrofa) samples collected, 3 (1.4%), 110 (51.6%), 55 (25.8%), and 45 (21.2%) had radiocesium (\(^{134}\text{Cs} + ^{137}\text{Cs}\)) levels of <100, 100–500, 501–1,000, and >1,000 Bq/kg fresh mass (FM), respectively (Fig. 1). The minimum and maximum radiocesium concentrations were 87.1 Bq/kg FM and 8,120 Bq/kg FM, respectively, with a median concentration of 450 Bq/kg FM (Table 1).

No significant correlation was found between radiocesium concentration and males and females (Mann–Whitney Test, \(p = 0.516\)) or between radiocesium concentration and the weight of the wild boars (Spearman correlation coefficient, \(p = 0.376\)). The average \(^{134}\text{Cs}/^{137}\text{Cs}\) activity ratios in all samples were 0.08 in January 2019 and 0.06 in December 2019.

The distribution of radiocesium concentrations in the muscle tissue of wild boars for each month is shown in Fig. 2. Radioactivity concentrations varied significantly with month (Jonckheere–Terpstra test, \(p < 0.05\)).

Committed effective dose. Among 213 samples collected that contained radiocesium, the median committed effective dose ranged from 0.070 to 0.26 μSv for females and from 0.062 to 0.30 μSv for males, considering one-time ingestion of wild boar meat as the meat source (Table 2).
of 40,200 Bq/kg FM14. The Fukushima Prefecture government also published data on the radioactivity of wild
to be one of the causes of radioactive accumulation8,21. In 2019, the local government of Tomioka town published the results of an assessment of radioce-
concentrations from 2011 and 2019 were 5,720 in 2011, 61,000 in 2012, 20,000 in 2013, 30,000 in 2014, 30,000
in other food types, such as vegetables, potatoes, oranges, and plums, were mostly

| Age (y) | Female Median (Minimum-Maximum) | Male Median (Minimum-Maximum) |
|---------|----------------------------------|-------------------------------|
| 1–6     | 0.069 (0.012–1.3)               | 0.072 (0.012–1.4)             |
| 7–14    | 0.18 (0.030–3.7)                | 0.19 (0.031–3.8)              |
| 15–19   | 0.26 (0.049–4.6)                | 0.30 (0.058–5.4)              |
| 20–29   | 0.17 (0.032–3.0)                | 0.18 (0.035–3.3)              |
| 30–39   | 0.15 (0.029–2.7)                | 0.21 (0.040–3.7)              |
| 40–49   | 0.16 (0.030–2.8)                | 0.24 (0.046–4.3)              |
| 50–59   | 0.12 (0.023–2.2)                | 0.18 (0.035–3.3)              |
| 60–69   | 0.070 (0.013–1.2)               | 0.12 (0.024–2.2)              |
| 70+     | NA*                             | 0.062 (0.012–1.1)             |

Table 2. Committed effective doses for one-time ingestion of wild boar meat from Tomioka town (μSv/day). NA*: not available. Median pork consumption was 0g among women aged >70 years in Japan in 2016.

Discussion
After the FDNPP accident, Nemoto et al. reported that the 137Cs concentration of wild boar meat in Fukushima
Prefecture from 2011 to 2016 was 900 ± 2,740 Bq/kg FM (mean ± standard deviation [SD]), with a maximum
of 40,200 Bq/kg FM14. The Fukushima Prefecture government also published data on the radioactivity of wild
boars that were captured in the Sousou area of Fukushima (1,737 km2), and reported that the highest 134Cs + 137Cs
concentrations from 2011 and 2019 were 5,720 in 2011, 61,000 in 2012, 20,000 in 2013, 30,000 in 2014, 30,000
in 2015, 3,100 in 2016, 14,000 in 2017, 460 in 2018 and 5000 Bq/kg in 2019, respectively15. Our results showed a
mean ± SD radioiodine concentration of 866 ± 1,270 Bq/kg FM, with a maximum of 8,120 Bq/kg FM. Despite
the 134Cs/137Cs activity ratios in this study agreed with those predicted from physical decay because the aver-
age 134Cs/137Cs activity ratios in all samples were 0.08 in January 2019 and 0.06 in December 2019, our results
showed that the wild boar contamination level is still relatively high, even though 8–9 years had passed since the
Fukushima accident.

Previous studies in Europe and Japan have reported that about 90% of the diet of wild boars consisted of
plants, small animals, insects, and earthworms, based on the season and availability16–20, and dietary habits are
typically considered an important factor affecting radioactivity levels in wild boars21,22. At the same time, the
ingestion of soil and deer truffles in winter has also been reported to be one of the causes of radioactive accu-
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pieces of wild boar meat were collected from January to December 2019 (males: 116, females: 97; weight range: 1.1–103 kg).

Samples of fresh wild boar meat (14–108 g) were minced and then enclosed in 100 mL plastic containers made of polypropylene for the radionuclide measurements. All samples were measured fresh and analyzed with a high-purity germanium detector (ORTEC, GMX30–70, ORTEC INTERNATIONAL Inc., Oak Ridge, TN, USA) coupled with a multi-channel analyzer (MCA7600, SEIKO EG&G Co., Ltd., Chiba, Japan). Integration times were 3,600 s for the wild boar samples. The measuring time was set to detect the objective radionuclide, and the gamma-ray peaks used for the measurements were 604.66 keV for $^{134}$Cs and 661.64 keV for $^{137}$Cs. Decay corrections were made based on the sampling date, and detector efficiency calibration was performed for different measurement geometries using mixed-activity standard volume sources (Japan Radioisotope Association, Tokyo, Japan). The relative efficiency was 31%, and energy resolution of the spectrometer was 1.85 keV for $^{60}$Co. The correction factor of the sum-peak effect of $^{134}$Cs and $^{137}$Cs were almost 1, respectively. Activity concentrations of radioisocium were automatically adjusted based on the date of collection, and the data were defined as the activity concentrations at the collection date. The counting errors were ±2.9 Bq/kg for $^{134}$Cs (median) and ±9.5 Bq/kg for $^{137}$Cs (median), respectively. The $^{134}$Cs concentrations in 7 samples were lower than the detection limits, which were in the range of 4.1–9.6 Bq/kg. Sample collection, processing, and analysis were executed in accordance with standard methods of radioactivity measurement authorized by the Ministry of Education, Culture, Sports, Science, and Technology, Japan.

**Effective dose.** The committed effective doses from the wild boar samples were estimated from the radioactive concentration of the fresh samples using Eq. (1):

$$ H_{int} = C \cdot D_{int} \cdot e $$  

where $C$ is the activity concentration of the detected artificial radioesium (Bq/kg FM). Here, $D_{int}$ represents the age-dependent dose conversion coefficients for $^{134}$Cs (age 1 year, 1.6E-08 Sv/Bq; age 5 years, 1.3E-08 Sv/Bq; age 10 years 1.4E-08 Sv/Bq and age 15–70 years, 1.9E-08 Sv/Bq) and $^{137}$Cs (age 1 year, 1.2E-08 Sv/Bq; age 5 years, 9.6E-09, age 10 years, 1.0E-08 Sv/Bq; and age 15–70 years, 1.3E-08 Sv/Bq) used in the assessments, which were provided by ICRP Publication 7226, and $e$ is quoted from the mean value of daily intake for age and sex. Because wild boar is not a conventional food in Japan, the government and research institutes have not published data on the amount of wild boar consumed. Consequently, wild boar meat consumption was estimated based on the median pork consumption in Japan published by the Ministry of Health, Labour, and Welfare in 2016 (males: 10–49.5 g/day; females: 0–42 g/day).  

**Statistical methods.** Data are expressed as medians, minimums, and maximums. Normality was checked using the Kolmogorov–Smirnov test. Because the variables were not normally distributed, non-parametric statistical tests were used. Differences in the concentrations of radioesium in wild boars at each sampling month were evaluated using the Jonckheere–Terpstra test. Relationships between body weight and the radioesium concentration in muscle tissue were evaluated using Spearman’s rank correlation analysis. Differences in the concentrations of radioesium between male and female wild boars were evaluated using the Mann–Whitney U test. P values < 0.05 were considered statistically significant. All statistical analyses were performed using SPSS Statistics 25.0 (IBM Corp., Armonk, NY, USA).

**Data availability** All relevant data are within the paper.

Received: 3 March 2020; Accepted: 20 May 2020;
Published online: 09 June 2020

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Acknowledgements

We would like to thank all the study participants and the staff of Tomioka town office for their cooperation. This work was supported by the Fukushima Innovation Coast Promotion Project (Revitalization Knowledge Project) and a Japan China Sasakawa Medical Fellowship.

Author contributions

Conceived and designed the observations: N.T., M.O.; performed the observations: M.O., L.C. and Y.T.; analyzed the data: L.C. and M.O.; wrote the paper: L.C. and M.O. All authors have approved the final version of the manuscript.

Competing interests

The authors declare no competing interests.

Additional information

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