

Communication

## Radiocesium Distribution in the Tissues of Japanese Black Beef Heifers Fed Fallout-Contaminated Roughage Due to the Fukushima Daiichi Nuclear Power Station Accident

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**This study examined the accumulation and tissue distribution of radioactive cesium nuclides in Japanese Black beef heifers raised on roughage contaminated with radioactive fallout due to the accident at the Fukushima Daiichi Nuclear Power Station on March 2011. Radiocesium feeding increased both <sup>134</sup>Cs and <sup>137</sup>Cs levels in all tissues tested. The kidney had the highest level and subcutaneous adipose had the lowest of radioactive cesium in the tissues. Different radioactive cesium levels were not found among parts of the muscles. These results indicate that radiocesium accumulated highly in the kidney and homogeneously in the skeletal muscles in the heifers.**

**Key words:** beef; cattle; radiocesium; muscle; tissue distribution

Radioactive isotopes were widely distributed in the northeastern region of Japan by fallout from the accident at the Fukushima Daiichi Nuclear Power Station (FDNPS) following the 2011 Tohoku Earthquake off the Pacific coast. Pasture plants contaminated with radioactive fallout containing <sup>134</sup>Cs and <sup>137</sup>Cs<sup>1)</sup> were identified around the power station. The transfer of radionuclides from contaminated grass plants to animal products should be of concern, particularly as to muscle foods, since orally ingested radiocesium is easily taken up by skeletal muscles.<sup>2,3)</sup> In fact, it has been reported that beef containing ~2000 Bq/kg of radiocesium were observed after the accident.<sup>4)</sup> Hence it is important to investigate the transfer and tissue distribution of radionuclides derived from contaminated fodder to maintain meat safety.

It has been reported that radionuclides were transferred from feed to muscles,<sup>5)</sup> and radionuclide transfer factors have been estimated for cattle.<sup>6–8)</sup> Varying accumulation of radioisotopes among tissues in experimental and domestic animals has been found.<sup>9–15)</sup> However, differences in radiocesium accumulation due to the nuclear accident among tissues in Japanese Black beef cattle have not been investigated under experimental control of feeding. This is the first study to demonstrate the distribution of radiocesium in tissues, including muscles of beef cattle fed roughage contami-

nated with radioactive fallout from the FDNPS accident by feeding experiment using roughage containing radiocesium at known concentrations.

Six Japanese Black heifers maintained at the Miyota Experimental Station of the National Institute of Livestock and Grassland Science (NILGS) (Miyota, Japan, 36°20'N, 138°29'E), a distance approximately 250 km from FDNPS, were divided into 3 groups of two cattle each: a control group, a low-radiocesium group, and a high-radiocesium group (Table 1). All animal experimental procedures were carried out in accordance with the guidelines of the Animal Care and Use Committee of NILGS.

Italian ryegrass, which was seeded on October 5, 2010, contaminated with fallout from the FDNPS accident was harvested from the Nasu Research Station of NILGS (Nasu-Shiobara, Japan, 36°55'N, 139°55'E) in May 2011. Total mixed rations (TMR) were prepared with corn, soybean meal, beet pulp, a vitamin mix, and the contaminated roughage, according to the Japanese Feeding Standard for Beef Cattle<sup>16)</sup> (Table 2) to satisfy the recommended nutrient content of diets for growing and finishing beef heifers. Milk secretion and urinary excretion of <sup>134</sup>Cs in lactating cows orally administered <sup>134</sup>Cs increased until 210 h after the feeding experiments were started,<sup>17)</sup> hence we had fed beef heifers radiocesium-contaminated fodder for at least 2 weeks. Consequently the TMR were provided to animals for 2 and 6 weeks for the low-radiocesium group and for 2 and 3 weeks for the high-radiocesium group. The control animals were not fed any contaminated roughage. The heifers were sacrificed by the usual protocol at a slaughterhouse of NILGS (Tsukuba, Japan) after contaminated TMR feeding was finished without any additional feeding treatment.

To examine the accumulation and tissue distribution of radiocesium, the liver, heart, kidney, subcutaneous adipose tissue, and muscles including the so-called neck part, longissimus, biceps femoris, and triceps brachii were harvested from the carcasses immediately after sacrifice. The neck part consists mainly of the longus capitis and sternocephalic muscles. The samples were vacuum-packed and stored at –20°C. The <sup>134</sup>Cs and <sup>137</sup>Cs levels in the tissue samples and the roughage were

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**Table 1.** Age and Body Weights of Heifers in This Experiment  
Values are expressed as least squares means ± SEM (n = 2).

Group	Age (months)	Body weight (kg)	
		initial	at slaughter
Control	56.3 ± 13.5	423.0 ± 52.2	390.0 ± 59.9
Low-radiocesium	82.6 ± 13.5	449.0 ± 52.2	417.5 ± 59.9
High-radiocesium	47.1 ± 13.5	439.5 ± 52.2	413.5 ± 59.9

**Table 2.** Nutrient and Radiocesium Concentrations of Total Mixed Rations

Nutrients	Group	
	low-radiocesium	high-radiocesium
Crude protein (% of DM)	18.95	18.66
Crude fiber (% of DM)	15.66	17.22
Acid detergent fiber (% of DM)	20.48	21.97
Neutral detergent fiber (% of DM)	38.25	40.15
TDN (% of DM)	78.60	77.42
Daily DM intake (kg/d/cattle)	5.01	5.24
<sup>134</sup> Cs + <sup>137</sup> Cs (Bq/d/cattle)	5676.4	13093.6

**Table 3.** Effects of Cesium Treatments and Tissues on <sup>134</sup>Cs and <sup>137</sup>Cs Levels in the Heifers

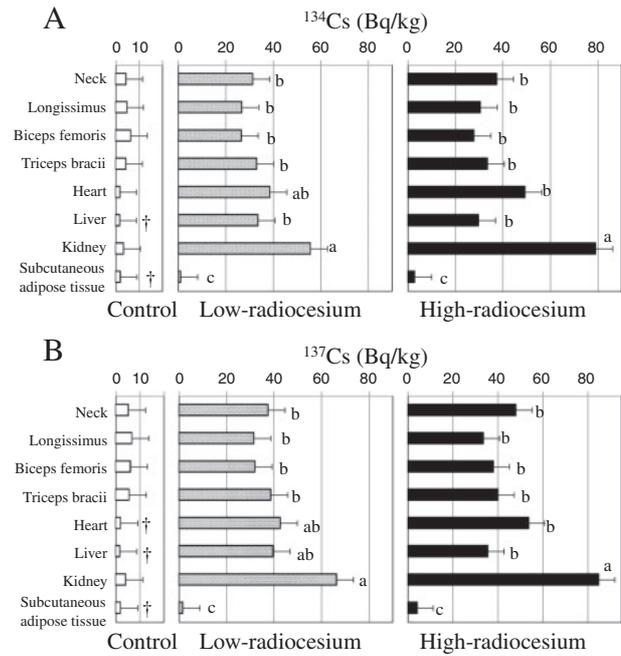
Values are least squares means and are expressed as Bq/kg wet tissue and standard errors of means (SEM). Values with different superscripts within each effect and nuclide mean a significant difference (*p* < 0.05). Feeding conditions and statistical analysis are described in main text.

Effects	Nuclide	
	<sup>134</sup> Cs	<sup>137</sup> Cs
Treatment	<i>p</i> < 0.01	<i>p</i> < 0.01
control	3.7 <sup>b</sup>	4.3 <sup>b</sup>
low-radiocesium	30.9 <sup>a</sup>	36.4 <sup>a</sup>
high-radiocesium	36.3 <sup>a</sup>	42.3 <sup>a</sup>
SEM	6.1	7.5
Tissue	<i>p</i> < 0.001	<i>p</i> < 0.001
neck	24.4 <sup>b</sup>	30.3 <sup>b</sup>
longissimus	20.8 <sup>b</sup>	24.0 <sup>b</sup>
biceps femoris	20.4 <sup>b</sup>	25.5 <sup>b</sup>
triceps brachii	23.7 <sup>b</sup>	28.2 <sup>b</sup>
heart	30.0 <sup>b</sup>	32.9 <sup>b</sup>
liver	21.8 <sup>b</sup>	25.7 <sup>b</sup>
kidney	46.1 <sup>a</sup>	51.9 <sup>a</sup>
subcutaneous adipose tissue	2.1 <sup>c</sup>	2.7 <sup>c</sup>
SEM	4.0	5.0
Treatment × Tissue	<i>p</i> < 0.001	<i>p</i> < 0.001

determined with a germanium semiconductor detector at the Japan Chemical Analysis Center (Chiba, Japan) or at Isotope Research Institute (Yokohama, Japan).

Radiocesium levels were analyzed by mixed model analysis of variance (ANOVA) using the MIXED procedure of the SAS (version 9.12, SAS Institute, Cary, NC). Treatment and tissue were used for the fixed effects and individual heifers were used for the random effect. Multiple comparisons were conducted by Tukey-Kramer test by the SAS system. Limit values of quantitation were applied to the statistical analysis for samples containing radiocesium at undetectable levels (1.6–2.3 Bq/kg).

As for the results, <sup>134</sup>Cs and <sup>137</sup>Cs contents were 30.9 and 36.4 Bq/kg in low-radiocesium group and 36.3 and



**Fig. 1.** <sup>134</sup>Cs and <sup>137</sup>Cs Contents of Tissues, Including Muscles, in Control, Low-Radiocesium Fed, and High-Radiocesium Fed Japanese Black Beef Heifers.

Experimental conditions are described in the text. Values are expressed as least squares means ± standard errors of means: a, b, c *p* < 0.05; †Including undetectable level samples. Minimum limits of determination were 1.8 and 2.1 Bq/kg for <sup>134</sup>Cs for the liver and subcutaneous adipose tissues, and 1.6, 1.9, and 2.3 Bq/kg for <sup>137</sup>Cs for the heart, liver, and subcutaneous adipose tissues respectively.

42.3 Bq/kg in high-radiocesium group, significantly higher than the control group, 3.7 and 4.3 Bq/kg for <sup>134</sup>Cs and <sup>137</sup>Cs (*p* < 0.01; Table 3). Radiocesium levels differed among tissues (*p* < 0.001). In particular, the <sup>134</sup>Cs and <sup>137</sup>Cs levels in the kidney were 46.1 and 51.9 Bq/kg respectively, highest in all the tissues (*p* < 0.05). In contrast, these levels in the subcutaneous adipose tissue, 2.1 and 2.7 Bq/kg for <sup>134</sup>Cs and <sup>137</sup>Cs, were lowest in all the tissues tested (*p* < 0.05), but the <sup>134</sup>Cs and <sup>137</sup>Cs levels in the skeletal muscles did not differ statistically.

Statistical interactions between treatments and tissues for the <sup>134</sup>Cs and <sup>137</sup>Cs levels were also observed (*p* < 0.001, Table 3). The highest accumulation of <sup>134</sup>Cs and <sup>137</sup>Cs was detected in the kidneys of the heifers in the low-radiocesium group, at 55.7 and 66.4 Bq/kg, respectively, as well as the high-radiocesium group, at 79.2 and 85.0 Bq/kg, respectively (Fig. 1). The <sup>134</sup>Cs and <sup>137</sup>Cs levels in the subcutaneous adipose tissue were 1.12 and 1.76 Bq/kg in low-radiocesium group and 2.99 and 4.22 Bq/kg in high-radiocesium group respectively, lower than in all the other tissues tested in these groups (*p* < 0.05). In the hearts and livers, both radioactive cesium nuclides showed levels similar to those in the skeletal muscles in both of the radiocesium-treated groups. In contrast, there were no significant differences among tissues in <sup>134</sup>Cs and <sup>137</sup>Cs contents in the control group (*p* > 0.05), although the radiocesium levels in the tissues in the low- and high-radiocesium groups were different from each other. Moreover, no intermuscular differences in radiocesium levels were observed in the three treatment groups.

Metabolism and the accumulation of cesium have been investigated in various experimental and farm animals. Some reports state that the kidney and/or skeletal muscles accumulated high radiocesium.<sup>9–13,18–20</sup> These differences in cesium concentrations across tissues are considered to be attributable to differences in Na,K-ATPase activity.<sup>12</sup> In addition, a kinetic model of Cs flow in human body has been proposed,<sup>21</sup> in which plasma Cs accumulates in highly distributes into the kidneys and muscle. Our result that the radiocesium level in the kidney was the highest of all tissues confirms previous studies of ruminants and the kinetics model of humans, although other studies have found that radiocesium was distributed homogeneously in the soft tissues.<sup>3,14</sup> It is likely that the tissue distribution of radionuclides is affected by experimental conditions such as resources, dosage, dosing period, and route of administration of radionuclides. Tissue distribution of radiocesium in beef cattle under various feeding conditions should be clarified for the sake of the management of radionuclide contamination in muscle foods.

Our results regarding the intermuscular distribution of radiocesium are in good agreement with previous studies of beef cattle<sup>15,20</sup> and reindeer.<sup>18,19</sup> In contrast, it has been reported that tongue, masseter, and diaphragm muscles showed higher radiocesium levels than other skeletal muscles in goats 30 min after <sup>134</sup>Cs administration.<sup>12</sup> Short-term distribution of radiocesium is different from the long-term distribution found in previous studies. The neck is generally used in radionuclide inspection of beef carcasses since the FDNPS accident in Japan. The sampling procedure in carcass inspection has high validity according to earlier and contemporary reports. The effects of dosing period on distribution of radionuclides in parts of the muscles should be investigated for validation of current method of carcass inspection.

Intramuscular radiocesium distribution is also important. We compared radiocesium concentrations as between thoracic and lumbar parts within longissimus muscles in the low- and high-radiocesium groups, and found no statistical differences in radiocesium level between them (data not shown). Our results suggested that radiocesium distribution is homogeneous within individual muscles, although it has been reported that <sup>137</sup>Cs accumulation differs between ribs in cows.<sup>22</sup> Intramuscular distribution of radionuclides within homogeneous and non-homogeneous muscles should be investigated in detail in further studies.

Transfer of radioactive nuclides from fodder to meat can be estimated using the transfer coefficient ( $F_f$ ). This factor is defined as the equilibrium ratio between the radionuclide activity concentration of meat and the daily dietary intake of radionuclide;<sup>23</sup> this value is stated in units of  $\text{day}\cdot\text{kg}^{-1}$ . The International Atomic Energy Agency (IAEA) has estimated the  $F_f$  values for radiocesium in beef cattle. However, in the  $F_f$  estimation for beef cattle in the IAEA report, data from experiments less than 60 d in duration were not used.<sup>24</sup> Our results are quite limited because the experimental duration was 2–6 weeks, less than the 60 d used in  $F_f$  estimation by IAEA, and dosing period was not uniform. Consequently, our results do not provide  $F_f$  values. Moreover, previous report on reindeer meat indicate that  $F_f$  for

fallout radiocesium was lower than that for fodder sprayed with <sup>134</sup>CsCl.<sup>19</sup> In further studies, prolonged feeding experiments using contaminated fodder and various source of radiocesium are needed for Japanese Black Beef cattle under controlled conditions in order to estimate  $F_f$ .

In conclusion, we investigated radiocesium distribution in tissues, including muscles, in Japanese Black beef heifers administrated radiocesium for the first time. Feeding of a ration containing radiocesium increased radiocesium contents in cattle tissues. Radiocesium levels in the kidney and subcutaneous adipose tissue were the highest and the lowest respectively among the tissues we tested. No differences in radiocesium contents among muscles were observed. We concluded that radiocesium derived from roughage contaminated with fallout from the FDNPS accident accumulated homogeneously in skeletal muscles of Japanese Black beef heifers. These results should be useful in maintaining meat safety against radionuclides from nuclear accidents.

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