

Fat tissue is not a reservoir for radiocesium in wild boars

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Received: 16 March 2017 / Published online: 25 April 2017
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Abstract Meat of wild boars is not only known for high ¹³⁷Cs activity concentrations but also for the remarkable constancy of these levels. Even decades after the Chernobyl accident, the ¹³⁷Cs levels in wild boar meat in Central Europe have not declined but even partly increased. In the present study, we investigated an unusual hypothesis for this very unusual phenomenon: may the boars' fat tissue act as a reservoir for radiocesium? We investigated fat and muscle tissues of four wild boars in Western Germany and found that the ¹³⁷Cs concentrations in fat were in the range of 10–30% of the respective activities in muscle tissue. Hence, the hypothesis was refuted.

Keywords Wild boar (*Sus scrofa*) · ¹³⁷Cs · Fat tissue · Muscle tissue · Central nervous system · Hypothesis

Introduction

Releases of volatile radionuclides, above all radiocesium, into the environment triggers concern for the environmental and human health as well as for food safety. Ingestion of contaminated food is the main pathway for internal exposure with anthropogenic radionuclides [1–4].

Wild boars (*Sus scrofa*) are well-known accumulators of radiocesium in their soft tissues [5–13]. This makes them a sensitive meat source, especially in contaminated areas in Europe and Japan, as a result of the Chernobyl and Fukushima nuclear accidents [14], respectively. They feed on cesium-rich fodder, including mushrooms, lichens, worms and snails, which explains why they exhibit higher ¹³⁷Cs activity concentrations in their tissues than grazing animals such as cattle. Nevertheless, the activity levels in their bodies seem not to correlate with the levels in their abiotic environment. It was often observed that the radiocesium levels in wild boars remain constant over longer periods of time or—even more puzzling—tend to increase over time, while the radiocesium levels in their abiotic environment (above all: soil) as well as in plants [15] and other animals decrease considerably over time [6, 9, 11, 13, 16]. Radiocesium levels in soil decrease with an effective half-life (T_{eff}) that is typically shorter than the physical half-life ($T_{1/2} = 30.08$ y), because of the combination of physical (T_{phys} or $T_{1/2}$) and ecological half-life (T_{eco}) (see Eq. 1).

$$\frac{1}{T_{\text{eff}}} = \frac{1}{T_{\text{eco}}} + \frac{1}{T_{\text{phys}}} \quad (1)$$

The ecological half-life takes into account losses due to washout, uptake by plants/animals/other biota etc. [17], and hence the effective half-life of radiocesium in soil may be as short as one third of the physical half-life [18]. Only on very few occasions, an increase of a radionuclide's concentration in the environment is deemed possible, such as in case of the deposition of resuspended materials [19–22]. Therefore the question arises, how wild boars remain a source of constant high or even increasing level of activity while the levels in their surrounding are ever decreasing. Several hypotheses were presented and discussed by the

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nuclear and veterinary medical communities. One argument that could be heard was that the overpopulation of wild boars induces food stress and forces them to dig out their food from deeper underground. However, such food stress usually does not occur within the European wild boar populations, and it would cause temporary infertility within the distressed communities. Such temporary infertility would exhibit a certain degree of self-regulation for the overpopulated communities. Other hypotheses focus on the wild boars' feed. It was often observed that mushrooms may exhibit a key role in the internal contamination levels of wild boars. Accordingly, the hypothesis says that it has taken years for radiocesium to migrate down to soil horizons where they can be taken up by fungi of the genus *Elaphomyces* with a variety of 25 truffle-like species. These fungi have been shown to be potent cesium accumulators [23], and it has been suggested that these fungi are responsible for the persistent radiocesium levels in wild boars [13, 24]. However, since the "Cs horizon" does not migrate linearly through the soil horizon, there are some questions how mushrooms can compensate the losses of Cs in their environment through radioactive decay as well as washout and migration processes.

In the present study, we investigated a different hypothesis for the peculiar phenomenon of constant radiocesium in boars: Could there be any reservoir within the wild boars' organism that supplies the muscle tissue, which is of entire interest for humans, with a constant level of radiocesium? As an alkali metal, the physiological behavior of the Cs⁺ ion is generally associated with the behavior of essential K⁺. The monovalent alkali ions are only expected to accumulate in aqueous media. However, with its low charge density, could it be that Cs⁺ may exhibit a more lipophilic characteristics inside the body than one might have anticipated? Would it be possible that radiocesium is hence accumulated preferentially in the wild boars' fat tissue and went unnoticed in the organ screenings that naturally focused primarily on muscle tissue (i.e., the human food source)? For example, in the extensive study by Tanoi et al., several organs and tissue types of wild boars were investigated for their contamination levels, however, no primary fat tissue has been objective in their study [5]. Fielutz even reported that fat was removed prior to the radiometric measurement of muscle tissue [13]. Literature did not provide further insight into the accumulation characteristics of radiocesium in fat tissue and hence warranted for a further investigation in this study.

Materials and methods

Four wild boars were used for this study. They were hunted down in Western Germany between February and April 2016 (Table 1).

Several samples of skeletal muscles and fat tissue were taken per wild boar. Additionally, no. 1 was sampled for tongue, brain, and omentum, no. 2 for brown adipose tissue, spinal marrow, tongue, and heart, no. 3 for spinal marrow, and tongue, and no. 4 for omentum, spinal marrow, heart, and tongue. The general idea behind sampling was covering all three types of interesting tissue types for the testing of the study's hypothesis: skeletal muscle tissue, specialized and/or well-perfused muscle tissue/organs (heart and tongue), and various types of fat tissue or fat-enriched organs (white fat tissue, brown adipose tissue, greater omentum, as well as the central nervous system, i.e., brain or spinal marrow).

The tissue samples were weighed in fresh state into petri dishes of suitable diameter, sealed into air-tight polyethylene bags in order to minimize mass fluctuations due to the evaporation of moisture and deep frozen at -18°C for storage. Gamma-ray spectrometry was conducted at a Canberra GR2818 131 cm³ HPGe gamma detector with 28% relative efficiency at the IRS in Hannover. The deep-frozen samples were positioned on top of the gamma detector and measured for approximately 24 h each (or less, if a counting uncertainty of <10% could be reached within a shorter time-span). The efficiency of each geometry was determined via a QCY48 multinuclide reference material with certified activities. Only the characteristic 662 keV line of ¹³⁷Cs was used for the evaluation of the spectra. Uncertainties are mainly due to counting statistics in this setup.

Results and discussion

The results of the study are tabulated in Table 2. Activity levels in this study's wild boars were rather moderate compared with what has been reported in German wild boars previously [6, 13].

The data show that fat tissue does contain some radiocesium, however, not comparable to the contamination levels of skeletal muscle tissue. The (¹³⁷Cs activity concentration in white fat tissue)/(¹³⁷Cs activity concentration in skeletal muscle tissue) ratio ranges between 10 and 30%. The same trend could be observed with other types of fat tissues, as shown in Fig. 1. This figure illustrates the ratio of activity in skeletal muscle tissue (tissue category A) versus fat tissue (tissue category C). It shows that activity concentrations in muscle tissue are generally higher than in fat tissues, with only one possible exception: spinal marrow in boar #3. However, this outlier is not significant when the uncertainties of the gamma measurement are taken into account. All other samples exhibited a ratio of (¹³⁷Cs activity concentration in fat tissue)/(¹³⁷Cs activity concentration in skeletal muscle tissue) < 1. Fat tissue hence is not a reservoir for radiocesium. Remarkably, however,

Table 1 Wild boars included

	Date of shooting	Approx. age	Mass (kg)	Sex	Location
Boar #1	27.02.2016	14 months	42	Female	Bad Dürkheim
Boar #2	28.02.2016	5 months	28	Male	Bad Dürkheim
Boar #3	21.03.2016	2–3 years	44	Female	Bad Dürkheim
Boar #4	06.04.2016	4 months	23	Male	Wendenberg

Table 2 Results of the gamma-spectrometric measurement in various tissue types in wild boars

Boar no.	Tissue type	Tissue category	¹³⁷ Cs activity concentration Bq/kg (f.w.)	Uncertainty (%)
1	Muscle tissue	A	16	6.7
1	Tongue	B	13	11
1	Brain	C	8.5	6.5
1	Omentum	C	7.9	9.0
1	White fat tissue	C	1.6	43
2	Muscle tissue	A	80	2.5
2	Heart	B	47	3.3
2	Tongue	B	59	2.5
2	Brown adipose tissue	C	9.1	14
2	Spinal marrow	C	38	23
2	White fat tissue	C	16	7.5
3	Muscle tissue	A	9.6	9.0
3	Tongue	B	3.2	36
3	Spinal marrow	C	12	20
3	White fat tissue	C	2.2	30
4	Muscle tissue	A	63	4.7
4	Heart	B	38	9.9
4	Tongue	B	40	5.0
4	Omentum	C	10	9.1
4	Spinal marrow	C	28	6.6
4	White fat tissue	C	19	11

A skeletal muscle tissue, B specialized muscle tissue, C various types of fat tissue, f.w. fresh weight

¹³⁷Cs accumulated in the central nervous system (CNS) and thus links the CNS to the skeletal muscle tissue with respect to high radiocesium activity levels.

A second, interesting insight comes from the comparison of skeletal muscle tissue (tissue category A) versus specialized muscle tissue (tissue category B). Specialized muscle tissues, i.e. heart and tongue, seem to exhibit similar activities as skeletal muscle tissues, but always at a slightly lower degree, as shown in Fig. 2. This phenomenon has been reported previously by Tanoi et al. [5], who also observed a depletion of ¹³⁷Cs activity concentrations in tongue and heart tissue, respectively, compared with skeletal muscle tissue. One may argue that this may be a consequence of hunting, when most blood supply is driven to skeletal muscles. However, Tanoi et al. [5] already showed that blood itself is severely depleted in radiocesium, at least compared with skeletal muscle tissue.

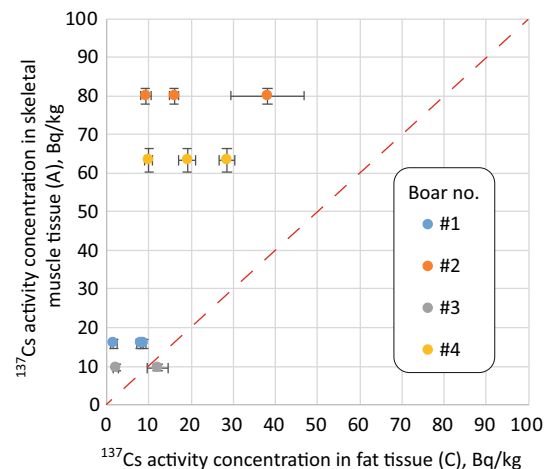


Fig. 1 Comparison of ¹³⁷Cs activity concentrations in fat tissue versus skeletal muscle tissue of the boars

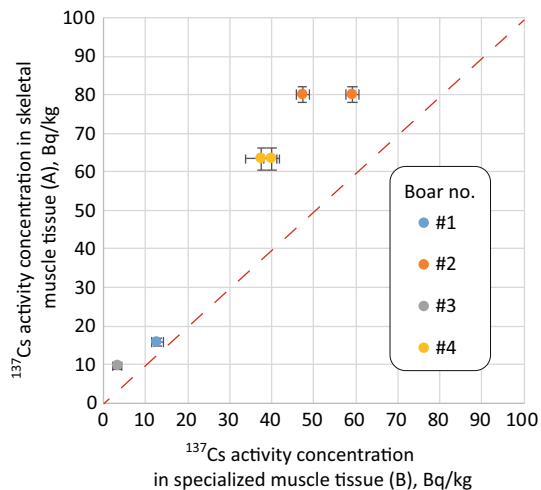


Fig. 2 Comparison of ^{137}Cs activity concentrations in specialized muscle tissue versus skeletal muscle tissue of the boars

Blood perfusion alone, hence cannot explain higher radiocesium levels in skeletal muscles. The ratios of activity concentrations in various tissue types compare quite well (but not exactly) between Tanoi et al. [5] and this study. The ratio of the ^{137}Cs distribution between brain/skeletal muscle was found to be about 0.25 (Tanoi et al.) but was slightly higher in animal no. 1 of this study with about 0.5. However, there is decent agreement in the ratios of ^{137}Cs activity concentrations of heart/skeletal muscle tissue of approximately 0.53 (Tanoi et al.) and 0.59 (this study). The ratio of ^{137}Cs in tongue/skeletal muscle tissue was about 0.7 (Tanoi et al.) and ranged between 0.34 and 0.81 in this study.

Tanoi et al. [5] already showed that other types of tissue, such as bone or liver, only exhibit low or intermediate contamination levels. Our study, however, was the first that focused on various types of fat tissue that had not been in the focus of research so far.

Table 2 also shows that the two lighter male animals exhibited higher contamination levels than the heavier female animals. This is a rather unusual observation as the biological half-life tends to increase with increasing weight of the organism. It is very unlikely that such phenomenon is due to sex-specific differences, because such drastic differences do not usually occur in trace element distributions between male and female members of a mammal species. It is possible that the differences are due to differences in the specific diet of the animals, but also that the organisms of intensely growing individuals have a different trace element demand and hence a different radiocesium accumulation behavior. In any case, the number of animals investigated is not great enough to substantiate any hypotheses for this phenomenon by statistical means.

Conclusions

Although considerable radiocesium activities were found in various fat tissues of German wild boars, fat tissue does not act as a reservoir of ^{137}Cs for muscle tissue and other organs of the wild boar. Our study's working hypothesis, therefore, cannot explain the peculiar phenomenon of constant (or even increasing) radiocesium levels in wild boars' meat that have been observed for many years or even decades. Taken our results together, high (and constant) radiocesium levels in wild boars are more likely caused by contaminated feed uptake, as primarily well perfused tissues are affected. The main culprit for the anomalous behavior of ^{137}Cs in wild boars is probably an anomalous cesium accumulator within the wild boars' food chain (possibly a mushroom such as *Elaphomyces*). In agreement with present knowledge, wild boars apparently resorb radiocesium intestinally and spread it via the blood stream to the periphery, but, as our study shows, without forming depots in fatty compartments. One exception is the CNS that accumulates radiocesium to a higher degree than white fat tissue. Small molecules (and ions, including radionuclides) pass the blood-brain barrier, where these can accumulate. However, in Western countries, CNS tissues do not enter the human food chain and therefore this aspect may not be of further significance with respect to human health. Monitoring of muscle tissue for radiocesium will remain advisable in Europe (and possibly also Japan) for many years to come, as muscle tissue is the main accumulator of ^{137}Cs .

Acknowledgements The authors would like to thank Prof. Alfred Moser for establishing the contact and initiating this collaboration.

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