Metabolism of Radiocarbon and Tritium in the Human Body

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Abstract

In the radiation safety review for nuclear facilities including the first commercial spent nuclear fuel reprocessing plant in Rokkasho, Japan, the internal doses of the pubic due to radiocarbon (^{14}C) and ^{3}H have been estimated using the dose conversion factors based on the ICRP metabolic models of carbon and those of hydrogen in the human body, respectively. The models are simple and are believed to be conservative leading to overestimation of radiation dose. The carbon model has one compartment of total carbon with biological half-life of 40 d, and the hydrogen model comprises a free water tritium (FWT) compartment and an organically bound tritium (OBT) compartment having biological half-lives of 10 and 40 d, respectively.

Although the biological half-life of tritium water (HTO) in the human body was examined in many cases such as accidental intakes or experimental administrations, actual data on the metabolism of organic ^{14}C and OBT are quite limited. The objectives of this research program are to establish experimentally the metabolisms of organic ^{14}C and OBT in the human body for more realistic dose estimations. The metabolism model of ^{14}C is also to be utilized for OBT, because a significant part of the hydrogen atoms in OBT covalently bonds to carbon and is hard to remove from the carbon excluding decomposition to inorganic forms of the elements: CO_2 and H_2O.

We have tried to establish a more realistic metabolic model of ingested ^{14}C through the metabolism experiments of volunteers who ingested one or two ^{13}C-labeled chemicals each of which were representative of carbohydrates, proteins or lipids. The metabolic models constructed by the results of experiments well simulated the metabolism of ^{13}C -labeled rice, but failed in the case of ^{13}C-labeled bean. This failure suggests that each nutrition group cannot be represented by only one or two chemicals, and the metabolism of more chemicals representing each nutrition group is necessary for developing the realistic metabolic model of ^{14}C and ^{3}H in diet. We have launched a further project to study the metabolism of additional ^{13}C-labeled compounds during FY 2015-2019.

All processes of the experiment were approved by the IES Review Board for Human Subject Experiments, and written informed consents were obtained from all volunteers. After oral administration of ^{13}C-labeled compounds, breath samples are collected at pre-determined times as representative of inorganic carbon excretion. Hair samples are also collected on the final day of the experiment as representative of organic carbon excretion such as via hair, nail, skin cells, mucus, and other secretions. For estimating growth rate of each hair sample, a small dose of ^{13}C-labeled compounds was administered 7-10 days before collecting the sample. In FY 2015, ^{13}C-labeled linoleic acid and glutamic acid with dose rates of 14 and 21 mg kg^{-1} d^{-1} ^{13}C, respectively, were administered to volunteers as part of lunches consumed on four successive days. Breath samples were collected until 154-170 d after the first administration and hair samples were collected at the end of the experimental period. Concentrations of ^{13}C in breath samples were measured in FY2015, while hair samples are to be analyzed in FY2016.

A five-compartment metabolic model was developed for organic carbon ingestion; it consisted of a

digestive tract C_{DT}, fast and slow compartments excreting carbon as an inorganic form (C_{Bf} and C_{Bs}) and fast and slow compartments excreting carbon as an organic form (C_{Of} and C_{Os}),. Some parameter values in the model were estimated by a least square fitting method using the measured data for breath, while all parameters are to be estimated in FY2016 by using the additional data for hair. Mean distribution factor to carbon excretion via an inorganic form of linoleic acid (0.62±0.14) was lower than that for the palmitic acid group (0.97±0.05) studied previously, suggesting that there is less utilization of linoleic acid for energy production than palmitic acid. The mean distribution factor of the glutamic acid group (0.84±0.08) was larger than that of the leucine group (0.69±0.14) though the differences were not statistically significant.

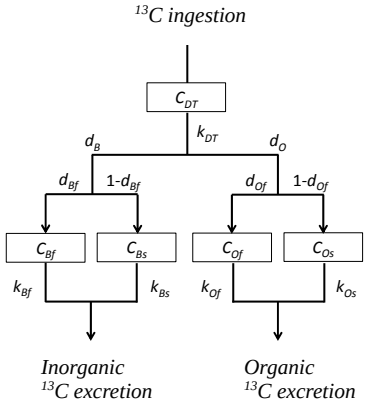

Fig. 1 Structure of the metabolic model for ingested ^{13}C. C_{DT} is a digestive tract compartment. C_{Bf} and C_{Bs},are fast and slow compartment excreted as an inorganic form, and C_{Of} *and* C_{Os} are those excreted as an organic form. *d* and *k* denote distribution factor and elimination rate constant, respectively.

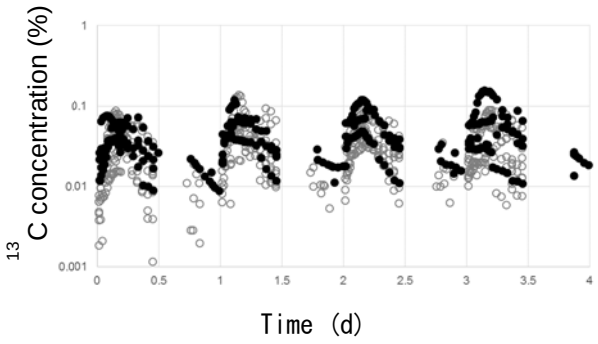

Fig. 2 Time course of the elevation of ^{13}C concentration from the mean pre-control concentration in breath samples during the ^{13}C labeled fatty acid administration period of four days. Solid circles, linoleic acid. Open circles, palmitic acid.

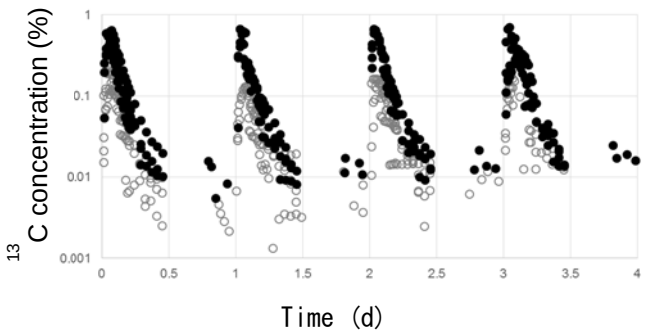

Fig. 3 Time course of the elevation of ^{13}C concentration from the mean pre-control concentration in breath samples during the ^{13}C labeled amino acid administration period of four days. Solid circles, glutamic acid. Open circles, leucine.

Table 1 Estimated parameters for ^{13}C in fatty acids*.

Parameters	Linoleic acid		Palmitic acid**	
k_{DT} (d^{-1})	26±19		2.7	0.1
d_B	0.62	0.14	0.97	0.05
d_{Bf}	0.50	0.16	0.54	0.19
k_{Bf} (d^{-1})	3.6	3.7	2.7	0.1
k_{Bs} (d^{-1})	0.061	0.019	0.073	0.069

* Mean value with a standard deviation for 3 volunteers.

** Institute for Environmental Sciences, 2010.

Table 2 Estimated parameters for ^{13}C in amino acids*

Parameters	Glutamic acid		Leucine**	
	Mean	Standard deviation	Mean	Standard deviation
k_{DT}	32	28	19	6
d_B	0.84	0.08	0.69	0.14
d_{Bf}	0.74	0.04	0.50	0.11
k_{Bf}	26	24	5.4	1.1
k_{Bs}	0.19	0.07	0.061	0.029

* Mean value with a standard deviation for 3 volunteers.

** Institute for Environmental Sciences, 2009.