Metabolism of Radiocarbon and Tritium in the Human Body

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Abstract

In the radiation safety assessment for nuclear facilities including the first commercial spent nuclear fuel reprocessing plant in Rokkasho, Japan, the internal doses of the public due to ingested ^{14}C and tritium have been estimated using the dose conversion factors based on the simple ICRP metabolic models in the human body. Although the biological half-life of tritium water (HTO) in the human body was examined in several cases, actual data on the metabolism of organic ^{14}C and organically bound tritium (OBT) in the diet are quite limited. The objective of this research program is to establish experimentally the metabolic models of organic ^{14}C and OBT in the human body for more realistic dose estimation. To obtain metabolic parameter values of ^{14}C, which are also utilized for OBT, we used the stable isotope of ^{13}C to label organic molecules on orally administration experiments as a substitute for ^{14}C.

Until FY 2014, ^{13}C-labeled glucose, palmitic acid, and leucine were administered to volunteers, followed by measuring the ^{13}C concentration in their breath, urine, feces, and hair. In FY2015, ^{13}C-labeled linoleic acid and glutamic acid were administered, followed by collecting breath and hair samples as representative of carbon excretion via inorganic form and organic form, respectively. Following the measurement of ^{13}C concentration in breath samples in FY2015, hair samples were measured in FY2016. In 2016, ^{13}C-labeled oleic acid and glycine were also administered to volunteers, followed by collecting breath and hair samples. The breath samples were measured for ^{13}C, and the hair samples will be analyzed in FY2017. 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.

A model was developed, having five compartments consisting of a compartment for ^{13}C in the digestive tract (C_{DT}), and two compartments each for ^{13}C excreted inorganically (C_{Bf} and C_{Bs}) and organically (C_{Of} and C_{Os}), and parameter values in the model were determined by using excretion data of ^{13}C. Mean distribution ratios to the inorganically excreted route of ^{13}C in palmitic acid and glutamic acid were higher than those in linoleic acid and leucine, respectively, suggesting that the former two are preferentially utilized for energy production. However, un-recovered ^{13}C was obtained in the model calculation for each substance, with an especially large proportion of 0.38 ± 0.16 for linoleic acid. We simulated carbon retention in the body after ingestion of the diet with nutrition compositions according to the Dietary Reference Intakes for Japanese (2015). The metabolic models for palmitic acid, linoleic acid, glutamic acid, leucine, and glucose was applied to the nutrition components in the diet, while the components for which models have not yet been constructed were represented by one of the substances mentioned above. We also assumed that the un-recovered ^{13}C was directly transferred to a total carbon compartment of 16 kg C. The 50-year cumulative body burden for ^{13}C, as an index of the committed dose of the radioisotope ^{14}C, was found to be 51 g d, which is comparable with 58 g d by the ICRP metabolic model. Further accumulation of model parameters of different substances is required to obtain the value that is more realistic.

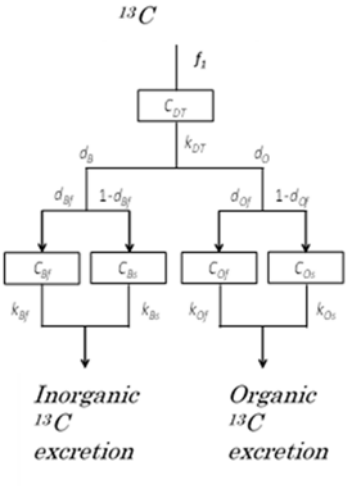

Fig.1 Structure of the metabolic model for ingested ^{13}C. Compartment of ^{13}C: C_{DT}, digestive tract; C_{Bf} and C_{Bs}, fast and slow compartments for inorganic excretion, respectively; C_{Of} and C_{Os}, fast and slow compartments for organic excretion, respectively. d is distribution factor, and k is elimination rate constant.

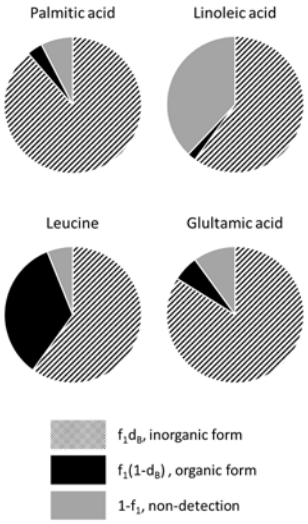

Fig.2 Transition rate by carbon excretion pathway
$f_1 d_B$, excretion via inorganic form path.
$f_1(1-d_B)$, excretion via organic form path.
$1-f_1$, excretion not detected experimentally.