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FAST NEUTRON ABSORPTION DOSE ESTIMATED FROM THE ELEMENTAL CONSTITUTION OF BONE MARROW OF SMALL ANIMALS

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元素組成から算定される小動物骨髓の速中性子吸収線量

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哺乳動物の一つであるラットを用い、骨髓およびその他の種々の軟組織の化学元素の割合を乾湿重量差および乾燥組織の元素分析の結果から求めた。この割合から14.1MeV 中性子についての吸収線量の計算が試みられた。元素組成ないしは

その算定吸収線量に骨髓と他軟組織との間に殆んど異りを認めなかつた。したがって含有水素量に関しては吸収線量低下の原因とは考えられず、他面からの考察が必要である。

Introduction

A number of studies has been made on the biological effects of various ionizing radiations on mammals. It has been observed that the time of death of mice irradiated with ionizing radiations falls into two types; that is, deaths occurring from about 3 to 5 days following whole body irradiation and deaths occurring from about 10 to 15 days. It is reported that early deaths are associated with damage to the gastrointestinal tract while the latter with damage to the bone marrow¹⁻⁵).

Each kind of radiation produces in fact a specific effect which may be manifested by type of death. In the case of neutron irradiation in contrast with X-ray and gamma-ray irradiations, the effect was characterized by injury to the intestinal tract which gives rise to death²⁾⁶⁻⁹). On the contrary, X-ray and gamma-ray irradiations chiefly brought about injury to the bone marrow causing later death⁶⁻¹²), but in the case of high doses intestinal injury was induced. These observations are also consistent with the minimum values in the body weight curves¹¹⁾¹³⁾¹⁴) after irradiation of lower doses.

Why should these irradiations produce such difference in effect? It is impossible to account for such differences merely by difference in LET. One explanation⁵) is given for

the difference in effects. That is, such difference is related to the difference in radiation energy or ionization density in the tissue surrounded by bone having a smaller content of hydrogen when compared with the other soft tissues.

However, if the hydrogen content of bone marrow is smaller than that of the other soft tissues, it would be possible to explain the decrease in marrow dose from neutron. In order to ascertain whether the hydrogen content of the bone marrow, a soft tissue, is smaller than that of the other soft tissues and whether it is possible to decrease the absorption energy from neutron which can change the type of death, the elemental constitution on a various of organs of rats and the estimated dose absorbed by such constitution from 14.1MeV neutron will be reported in this paper. The results will be discussed together with other considerations.

Experiments

1. The difference in weight between the wet soft tissue and dried soft tissue.

Rats (age: 8 weeks, strain: Donryū, sex: female, mean weight: 25.0 g) were used in this experiment. About 0.5 gs of soft tissue were removed from various organs of the rats. They heated and dried on watch glasses for 3 hours by infra-red lamp at a distance of 30 cm. The tissues, powdered in a onyx mortar, were placed in a desiccator (10 mmHg) for one day. Moreover, a heat vacuum drier was used. After the heating for 5 hours at 110° and 1 mmHg, the tissue powder of each organ was immediately enclosed in glass tubes and sent to Tokyō for elemental analysis. In the preliminary experiments it was ascertained that the weights of dried tissues became constant.

To obtain about 0.5 gs of soft tissue of each organ except the bone marrow, two rats made up one experimental unit. For the bone marrow ten rats made up one experimental unit because only a small quantity of marrow could be obtained. The weight differences between wet tissue and dried tissue are shown in percent to the weight of the wet in Table 1.

2. Elemental analysis of powdered tissues.

From the experimental units of each organ, three ampouls of the dried powdered tissues were selected at random and analyzed. This elemental analysis was performed at

Table 1. The weight difference between wet tissue and dried tissue (percentage to the weight of the wet).

Experimental unit Tissue	I	II	II	IV	V	Mean
Muscle	76.2	75.9	76.7	77.1	77.1	76.6±0.2
Liver	74.0	76.1	75.8	77.3	76.2	75.9±0.5
Kidney	77.5	78.3	77.5	77.8	78.2	77.9±0.2
Spleen	78.1	78.0	78.2	78.3	78.6	78.2±0.1
Small intestine	76.2	73.8	76.3	76.5	76.6	75.9±0.5
Large intestine	78.6	77.3	79.8	78.0	78.0	78.3±0.4
Fat	26.5	17.0	28.1	16.2	19.3	21.4±2.2
Bone marrow	71.8	74.4	72.1	—	—	72.8±0.5

Table 2. The elemental analysis of powdered rat tissues (percentage in weight).

Tissue	Analytical element	H (SE $< \pm 0.1$)	C (SE $< \pm 0.3$)	N (SE $< \pm 0.4$)
Muscle		7.0	49.9	13.9
Liver		6.9	51.1	12.0
Kidney		7.2	51.4	12.6
Spleen		6.8	48.6	13.5
Small intestine		7.2	51.1	12.1
Large intestine		7.0	49.6	13.2
Fat		11.7	76.6	0
Bone marrow		6.6	47.2	12.9

(The trace of ash was recognized in each tissue except fat)

Rikagaku-Kenkyūsho in Tokyō. The result of elemental analysis of each organ is shown in Table 2, in which the values are the means of three samples in weight percent.

Results and Discussion

The elemental constitution of the tissues by the weight difference between the wet and the dried, and the elemental analysis of powdered tissues was as shown in Table 3. Difference of weight between the wet and the dried was arbitrarily considered to be water. All elements except carbon, hydrogen and nitrogen which are shown in Table 2 were presumed to be oxygen. The elemental constitution of the wet tissue¹⁵⁾ and the standard man¹⁶⁾ in the literature were added to the table for comparisons.

Table 3. The elemental constitution of rat tissues (percentage in weight).

Tissue	Constitutional element	C	H	O	N
Muscle		11.7	10.0	75.0	3.3
Liver		12.3	10.0	74.8	2.9
Kidney		11.4	10.2	75.6	2.8
Spleen		10.6	10.1	76.4	2.9
Small intestine		12.3	10.0	74.8	2.9
Large intestine		10.8	10.2	76.1	2.9
Fat		60.2	11.5	28.3	0
Bone marrow		12.8	9.8	73.9	3.5
cf. Wet tissue ¹⁵⁾		12	10	73	4
cf. Standard man ¹⁶⁾		18	10	65	3

The method of estimating the neutron absorbed doses will be described. Using the principles of conservation of energy and momentum from classical mechanics, the recoil energy E_r of a nucleus with mass number M after scattering a neutron of initial energy E_0 can be given by

$$E_r = \frac{2ME_0}{(M+1)^2} \left[1 - \frac{(M+1)E^*}{2ME_0} - \sqrt{1 - \frac{(M+1)E^*}{ME_0} \cos \theta} \right]$$

where E^* is the excitation energy of the nucleus after collision, and θ is the neutron scattering angle in center-of-mass coordinates.

For isotropic scattering or scattering symmetric about θ equal to 90° , the equation is reduced to the first two terms. If the incident neutron energy exceeds 20 MeV, the simple billiard-ball type of collision becomes modified in such a way as to yield a stronger and narrower forward projection of protons¹⁷⁾. When the nuclear force in the collision begins to be affected by angular momentum and the distribution of the particles after collision no longer has spherical symmetry in the center-of-mass reference frame, the third terms of equation becomes necessary.

In the case of 14.1 MeV neutron energy, the scattering is isotropic or symmetric. Besides, when only elastic scattering occurs in absence of inelastic scattering, the excitation energy E^* is zero. Therefore, E_r for only the elastic scattering can be described with only the first term of equation.

Using this equation, Randolph¹⁸⁾ gave the average energy dissipation per unit flux, d , for the four common elements in the tissue,—hydrogen, carbon, nitrogen and oxygen—using all available data on cross sections and energy transfer. The cross section and the energy dissipation d which he presented are shown in Table 4.

Table 4. Total cross section and total d value given by Randolph¹⁸⁾ for 14.1 MeV neutron.

Constitutional element	Total cross section (barn)	Total d value (MeV-barn)
H	0.689	4.86
C	1.350	2.99
O	1.590	3.73
N	1.600	3.42

Using these values, absorbed dose per unit flux of each soft tissue irradiated with 14.1 MeV neutron was estimated in rad unit with consideration given to atomic density (atoms/g). The result is shown in Table 5. In Table 3 and Table 5 on difference in the elemental constitution, specially the proportion of hydrogen contained, or the absorbed doses estimated between the bone marrow and the other soft tissues except fat can be noted. For this experimental data, it is impossible to conclude that a decrease in absorbed dose by reason of the smaller content of hydrogen in the bone marrow brings about a decrease in bone marrow injury.

Table 5. The estimated absorption dose of rat tissues.

Tissue	Estimated absorption dose (rads/neutron)	Tissue	Estimated absorption dose (rads/neutron)
Muscle	6.70×10^{-9}	Small intestine	6.69×10^{-9}
Liver	6.69×10^{-9}	Large intestine	6.78×10^{-9}
Kidney	6.78×10^{-9}	Fat	7.42×10^{-9}
Spleen	6.74×10^{-9}	Bone marrow	6.61×10^{-9}

Another reason, therefore, must be pursued in view of the emanation of recoil protons which differ with electrons in the case of X-ray or gamma-ray. As a lead to the solution,

the geometrical features of bone appear challenging. The subject of geometrical features of various bones will be discussed in detail in other papers.

Summary

Rats were used as the mammal for the experiment. The proportion of chemical elements in the bone marrow and the other soft tissues were given from the weight difference between wet tissue and dried tissue together with the elemental analysis of the dried tissues. From these proportions, the absorbed dose estimation for 14.1 MeV neutron was attempted. No difference of elemental constitution or the estimated absorbed doses between the bone marrow and the other tissues could be recognized. As the decrease in absorbed dose in the bone marrow cannot be considered to be due to the smaller content of hydrogen in the bone marrow, a different approach should be considered.

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