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RADIATION BIOLOGY OF THE FETAL AND JUVENILE MAMMAL

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FETAL RADIATION DOSE FROM MATERNALLY ADMINISTERED ^{59}Fe AND ^{131}I

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ABSTRACT

Of all the segments in the population exposed to ionizing radiation, the most sensitive age group is the developing embryo. Occasionally, pregnant women are given diagnostic or therapeutic amounts of radionuclides, deliberately or, more usually, inadvertently. To correctly assess hazards from the exposure to ionizing radiation, the radiation absorbed dose to the fetus must be known.

Calculations of the radiation dose to the fetus and the critical fetal organ have been made for the radioisotopes ^{131}I and ^{59}Fe. The critical fetal organ and the other necessary fetal parameters for the dose calculations were determined, and dose measurements were made in nine fetuses. The self-dose from the isotope in the fetus or critical fetal organ plus the penetrating-radiation dose from the mother were considered in the dose calculations.

Over a gestational stage from 9 to 22 weeks, the total fetal dose from ^{59}Fe is about 35 rads/mCi. The critical fetal organ for ^{59}Fe is the liver, which receives a radiation dose of from 331 to 536 rads/mCi. For ^{131}I the total fetal dose varies from 0.796 to 3.00 rads/mCi over the same gestational age. The critical organ for ^{131}I is the fetal thyroid, which receives a radiation dose of from 715 to 5900 rads/mCi. The amount of radioisotope quoted is that amount administered to the maternal unit. The formulations and considerations needed for the fetal dose calculations are presented.

Of all the segments of the population exposed to ionizing radiation, the most sensitive age group is the developing embryo. This study was undertaken to augment the limited information available on doses of ^{59}Fe and ^{131}I absorbed by the human fetus. Iron-metabolism studies were performed by Hahn and co-workers[1] at Vanderbilt University during the late 1940's to evaluate nutritional requirements for iron in approximately 800 pregnant women. An epidemiologic follow-up study of the children resulting from these and control pregnancies has just been completed.[2] The epidemiologic study was designed to detect biological damage if it occurred and to determine whether damage could be attributed to radiation from the ^{59}Fe. Absorbed-dose estimates are being obtained from studies we are now conducting in women receiving therapeutic abortions.[3] These estimates will be used to determine the magnitude of the potential hazard to the fetus from these exposures. Because of extensive medical use of ^{131}I, we are accumulating information on fetal radiation exposures from this nuclide in the same subjects in whom we are studying maternal–fetal transport of ^{59}Fe.

METHODS

The absorbed-dose calculations considered the self-dose from the isotope in the fetus or fetal organ plus the penetrating radiation dose to the fetus from the mother. The absorbed-fraction technique, as described in the MIRD Committee report,[4] was utilized for the dose calculations along with factors from Hine and Brownell[5] for situations not catalogued in the MIRD Committee report.

Before the dose to the fetus and fetal organs for the two radioisotopes is considered, the dosimetry equations and their general application to the present studies will be reviewed briefly. Equation 1 is the general expression for the dose delivered by ionizing radiation:

$$\text{Dose} = \int_{\text{time}} \Delta\phi \ C \ dt \qquad (1)$$

where C is the time-dependent concentration of the radioisotope within the organ or biological system and has units of microcuries per gram. The expression for C is shown in Eq. 2:

$$C = C_0 e^{-\lambda t}/m(t) \qquad (2)$$

where C_0 is the activity at time zero and λ is the effective decay constant for the radioisotope. Unlike the more usual case for dose calculations where the mass of the biological system does not change over the relevant time period, the mass of the fetus and its organs is rapidly changing, and hence the mass must be considered as a function of time, i.e., m(t) is the time-dependent mass of the fetus or fetal organs. The term Δ is a function of the physical decay scheme of the radioisotope and has units of gram-rads per microcurie-hour. The absorbed fraction, ϕ, is the fraction of the energy emitted by the source region which is absorbed in the organ or region of interest. For nonpenetrating radiation (beta or beta like), the absorbed fraction is usually considered to be unity. However, for very small organs this is not strictly correct. As the organ becomes small with respect to the range of the beta particle and the ratio of surface area to volume becomes large, is determined by neutron activation analysis of maternal and fetal blood samples taken postpartum. Should any of those pregnancies result in stillbirths or neonatal deaths, a comparison of circulating and fixed ^{58}Fe concentrations will be made to determine the validity of circulating levels as an index of transport. The radioiodine transport studies have confirmed information previously available on distribution and fetal exposure. We plan to extend these studies to obtain data on the effect of blocking doses of stable iodine on maternal thyroid uptake, transport to the fetus, and fetal-thyroid uptake. This has importance with respect to the way in which we cope with the planned and unplanned exposures of pregnant women to radioiodine.

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