A Brochure for Physicians

PRENATAL RADIATION EXPOSURE

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Most of the ways a pregnant woman may be exposed to radiation will not expose the fetus to levels likely to cause health effects. This is true for radiation exposure from most diagnostic medical exams as well as from occupational radiation exposures that fall within regulatory limits. However, instances may arise where an expectant mother and her physician may have some concern. This brochure provides physicians with background information about prenatal radiation exposure as an aid in counseling these patients.

Although radiation doses to a fetus tend to be lower than the dose to the mother, due to protection from the uterus and surrounding tissues, the human embryo and fetus[1] are sensitive to ionizing radiation at doses greater than 0.1 gray (Gy). Depending on the stage of fetal development, the health consequences of exposure at doses greater than 0.5 Gy can be severe, even if such a dose is too low to cause an immediate effect for the mother. The health consequences can include growth restriction, malformations, impaired brain function, and cancer.

It is important to understand that the purpose of this brochure is only to provide technical background information to the clinician recognizing that health care providers will use their clinical judgement when assessing and discussing the risk/benefit of radiation exposure to the expectant mother. Although these discussions may begin with risk or balancing risk and benefit, the counseling generally includes identifying all influences that could increase the likelihood of adverse maternal and fetal health outcomes. How to best communicate with the expectant mother about any type of risk depends upon many factors. First consideration is the educational background of the patient and linguistic and cultural barriers. But generally, one must also take into account the level of stress in the expectant mother and other potential psychological influences.

The CDC recognizes that providing information and advice to expectant mothers falls into the broader context of preventive healthcare counseling during prenatal care. In this setting, the purpose of the communication is always to promote health and long-term quality of life for the mother and child.

[1]During the first nine weeks postconception, the developing fetus is referred to as an embryo.

ESTIMATING THE RADIATION DOSE TO THE EMBRYO OR FETUS

Because fetal sensitivity to radiation exposure depends largely on the radiation dose to the fetus, the dose needs to be estimated before potential health effects can be assessed.

Estimating the radiation dose to the fetus requires consideration of all sources external and internal to the mother's body. For this document, the fetal radiation dose from sources external to the mother's body can be estimated by determining the dose to the mother's abdomen. Estimating the dose from sources internal to the mother's body is more complex.

If a pregnant woman ingests or inhales a radioactive substance that subsequently is absorbed in her bloodstream (or enters her bloodstream through a contaminated wound), the radioactive substance may pass through the placenta to the fetus. Even though for some substances the placenta acts as a barrier to the fetal blood, most substances that reach the mother's blood can be detected in the fetus' blood, with concentrations that depend on the specific substance and the stage of fetal development.
A few substances needed for fetal growth and development (such as iodine) can concentrate more in the fetus than in corresponding maternal tissue. In addition, radioactive substances that may concentrate in the maternal tissues surrounding the uterus including the mother's urinary bladder can irradiate the fetus.
For substances that can localize in specific organs and tissues in the fetus, such as iodine-131 in the thyroid or iron-59 in the liver, consideration of the dose to specific fetal organs may be prudent.

CONSULTING EXPERTS IN RADIATION DOSIMETRY ABOUT FETAL DOSE ESTIMATION

Medical physicists, health physicists, nuclear medicine teams and other radiation professionals at hospitals are good resources for expertise in radiation dose estimation. Physicians can first consult these in-hospital radiation professionals when seeking assistance in estimating fetal radiation dose. The National Council on Radiation Protection and Measurements (NCRP) Report No. 174,

"Preconception and Prenatal Radiation Exposure: Health Effects and Protective Guidance," [NCRP2013] provides strategies to effectively manage dose in diagnostic imaging of the pregnant or possibly pregnant individual. NCRP Report 128, "Radionuclide Exposure of the Embryo/Fetus," [NCRP1998] provides detailed information for assessing fetal doses from internal uptake of radionuclides.

Fetal dose estimations from medical exposures to pregnant women can also be found in "Publication 84: Pregnancy and Medical Radiation" from the International Commission on Radiological Protection (ICRP) [ICRP2000]. In addition, the Conference of Radiation Control Program Directors, Inc. (https://www.crcpd.org/) maintains a list of state Radiation Control/Radiation Protection contact information and the Health Physics Society (http://hps.org) maintains a list of active certified Health Physicists.

Once the fetal radiation dose is estimated, the potential health effects can be assessed. The possible effects associated with prenatal radiation exposure include early effects (such as fetal death or malformations) or increased risk for cancer later in life.

POTENTIAL HEALTH EFFECTS (Other Than Cancer)

The potential noncancer health risks of concern are summarized in Table 1. This table is intended only to help physicians advise pregnant women who may have been exposed to radiation, not as a definitive recommendation. The indicated doses and times postconception are approximations. Often in this context the term gestational age is used rather than time postconception. The gestational age refers to the duration since the first day of the last menstrual period before pregnancy. Postconception time is generally approximated as the gestational age minus two weeks.

Postconception (or gestational) age and radiation dose are important determinants of potential noncancer health effects. The following points are of particular note:

Before about 2 weeks postconception, the health effect of concern from an exposure > 0.1 gray (Gy) or 10 rads is the death of the embryo. If the embryo survives, however, radiation-induced noncancer health effects are unlikely, no matter what the radiation dose. Because the embryo is made up of only a few cells, damage to one cell, the progenitor of many other cells, can cause the death of the embryo, and the blastocyst will fail to implant in the uterus. Embryos that survive, however, will likely have no significant noncancer health effects.

- In all postconception stages, radiation-induced noncancer health effects are not detectable for doses to the embryo or fetus below about 0.1 Gy (10 rads).

From 8 to 15 weeks postconception, radiation exposure may significantly affect brain development, especially at doses > 0.5 Gy (50 rads). Severe intellectual disability is possible during this period for doses > 0.5 Gy (50 rads).

From 14 weeks postconception to birth, radiation-induced noncancer health effects are unlikely below about 0.5 Gy (50 rads). However, between 0.1 and 0.5 Gy (10-50 rads), growth restriction is possible. Atomic bomb survivor data show a permanent restriction of physical growth with increasing dose, particularly above 0.5 Gy (50 rads). This growth restriction is most pronounced when the exposure occurs during 3 to 13 weeks postconception.

From 24 weeks postconception to term, miscarriage and neonatal death may occur at doses > 0.5 Gy (50 rads).

POTENTIAL CARCINOGENIC EFFECTS OF PRENATAL RADIATION EXPOSURE

Radiation exposure to an embryo or fetus may increase the risk of cancer in the offspring, especially at radiation doses > 0.1 Gy (10 rads), which are well above typical doses received in diagnostic radiology. However, attempting to quantify cancer risks from prenatal radiation exposure presents many challenges. These challenges include the following:

The primary data for the risk of developing cancer from prenatal exposure to radiation come from the lifespan study of the Japanese atomic bomb (A-bomb) survivors [Preston et al.2008]. The analysis of that cohort includes cancer incidence data only up to the age of 50 years. This precludes making lifespan risk estimates as a result of prenatal radiation exposure.

  - » Using numerical risk coefficients determined by the Preston et al. analyses, a theoretical chance of developing an adult-onset cancer through the age of 50 from fetal radiation exposure can be estimated. For example, for a dose of 0.01 Gy (1 rad), which is a typical dose delivered during a CT scan of the abdomen and pelvis, the excess risk to an embryo/fetus of adult-onset cancer is likely less than 1 in 1,000.

- From the Japanese lifespan study [Preston et al.2008], it can be concluded that for those exposed in early childhood (birth to age 5 years), the theoretical risk of an adult-onset cancer by age 50 is approximately ten-fold greater than the risk for those who received prenatal exposure. Therefore, the risk following prenatal exposure may be considerably lower than for radiation exposure in early childhood [NCRP2013].
- No reliable epidemiological data are available from studies to determine which stage of pregnancy is the most sensitive for radiation-induced cancer in the offspring [NCRP2013].

The lifespan study of the Japanese A-bomb survivors is continuing as the cohort ages. Future analyses of the accumulating data can provide a better understanding of the lifetime risk of cancer from prenatal and early childhood radiation exposure.

CONCLUSION

Fetal sensitivity to radiation-induced health effects is highly dependent on fetal dose, and the mother's abdomen provides some protection from external sources of ionizing radiation. In addition, noncancer health effects depend on when the radiation exposure occurs relative to the time postconception or the gestational age. Finally, radiation exposure to an embryo or fetus may increase the risk of cancer in the offspring, especially at radiation doses > 0.1 Gy (10 rads), which are well above typical doses received in diagnostic radiology.

REFERENCES

[ICRP2000] International Commission on Radiological Protection, editors. Annals of the ICRP, Publication 84: Pregnancy and Medical Radiation 30 (1). Tarrytown, New York: Pergamon, Elsevier Science, Inc.; 2000.

[NCRP1998] National Council on Radiation Protection and Measurements. NCRP Report No. 128: Radionuclide Exposure of the Embryo/Fetus. Bethesda, Maryland: NCRP; 1998.

[NCRP2013] National Council on Radiation Protection and Measurements (NCRP). Preconception and Prenatal Radiation Exposure: Health Effects and Protective Guidance. NCRP Report No. 174. Bethesda (MD): NCRP; 2013.

[Preston, et.al.2008] Preston DL, Cullings H, Suyama A, Funamoto S, Nishi N, Soda M, Mabuchi K, Kodama K, Kasagi F, Shore RE. 2008. Solid cancer incidence in atomic bomb survivors exposed in utero or as young children. J Natl Cancer Inst 100(6):428-436.

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Table 1:
Potential Health Effects (Other Than Cancer) of Prenatal Radiation Exposure

ACUTE RADIATION DOSE* TO THE EMBRYO/FETUS	TIME PRECONCEPTION (UP TO 2ND WEEK)	TIME POSTCONCEPTION (3RD TO 5TH WEEK)	TIME POSTCONCEPTION (6TH to 13TH WEEK)	TIME POSTCONCEPTION (14TH TO 23RD WEEK)	TIME POSTCONCEPTION (24th WEEK TO TERM)
< 0.1 Gy (10 rads)†	**Noncancer HEALTH EFFECTS NOT DETECTABLE**				
0.1-0.5 Gy (10-50 rads)	Failure to implant may increase slightly, but surviving embryos will probably have no significant (noncancer) health effects.	Growth restriction possible	Growth restriction possible	Noncancer health effects unlikely	
> 0.5 Gy (50 rads) The expectant mother may be experiencing acute radiation syndrome in this range, depending on her whole-body dose.	Failure to implant will likely be high, depending on dose, but surviving embryos will probably have no significant (noncancer) health effects.	• Probability of miscarriage may increase, depending on dose. • Probability of major malformations, such as neurological and motor deficiencies, increases. • Growth restriction is likely.	• Probability of miscarriage may increase, depending on dose. • Growth restriction is likely.	• Probability of miscarriage may increase, depending on dose. • Growth restriction is possible, depending on dose. (Less likely than during the 6th to 13th weeks postconception) • Probability of major malformations may increase.	Miscarriage and neonatal death may occur, depending on dose. §

8th to 25th Weeks Postconception:
The most vulnerable period for intellectual disability is 8th to 15th weeks postconception.
Severe intellectual disability is possible during this period at doses > 0.5 Gy.
Prevalence of intellectual disability (IQ<70) is 40% after an exposure of 1 Gy from 8th to 15th week.
Prevalence of intellectual disability (IQ<70) is 15% after an exposure of 1 Gy from 16th to 25th week.

Note: This table is intended only as a guide. The indicated doses and times post conception are approximations

* Acute dose: dose delivered in a short time (usually minutes). Fractionated or chronic doses: doses delivered over time. For fractionated or chronic doses, the health effects to the fetus may differ from what is depicted here.
† Both the gray (Gy) and the rad are units of absorbed dose and reflect the amount of energy deposited into a mass of tissue (1 Gy = 100 rads). In this document, the absorbed dose is that dose received by the entire fetus (whole-body fetal dose). The referenced absorbed dose levels in this document are assumed to be from beta, gamma, or x-radiation.
§ For adults, the LD50/60 (the dose necessary to kill 50% of the exposed population in 60 days) is about 3-5 Gy (300-500 rads) and the LD100 (the dose necessary to kill 100% of the exposed population) is around 10 Gy (1000 rads).

Table adapted from Table 1.1 of the National Council on Radiation Protection and Measurements Report No. 174, “Preconception and Prenatal Radiation Exposure: Health Effects and Protective Guidance” [NCRP2013].

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