

# Radiological Imaging of Pregnant Women: Frequently Asked Questions Concerning Radiation and Contrast Media

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## Abstract

Ionizing radiation delivered and contrast media used during diagnostic imaging of pregnant women are major dilemmi for gynecologists and radiologists. As the overall risk of abnormality is negligible at doses received during diagnostic radiological examinations, the radiologic examination can be performed cautiously if the mother is at risk and appropriate indications for an imaging examination exist. Termination of pregnancy is rarely justified because of the risk to the conceptus from a radiological study. In this article, the frequently asked questions concerning radiation dose and its potential risks to the conceptus (embryo or fetus) associated with different radiological imaging modalities were reviewed.

**Keywords:** pregnancy, radiation, diagnostic imaging, fetal dose

## Özet

### Gebelikte Radyolojik İnceleme: Radyasyon ve Kontrast Maddeleri Hakkında Sıkça Sorulan Sorular

Gebelikte yapılan tanısal radyolojik tetkikler sırasında alınan iyonizan radyasyon ve kullanılan kontrast maddeleri kadın doğum ve radyoloji hekimleri için ikilem oluşturmaktadır. Bununla birlikte, tanısal radyolojide kullanılan radyasyon dozlarında fetal anomali riski ihmal edilebilir düzeydedir. Eğer annenin sağlığı risk altında ve görüntüleme için uygun endikasyon varsa, radyolojik tetkikler dikkatli şekilde yapılabilir. Fetüsün radyolojik tetkik esnasında maruz kaldığı radyasyon riskine bağlı gebelik terminasyonu nadiren gerekir. Bu yazıda, farklı radyolojik tetkikler esnasında maruz kalınan radyasyon dozunun embriyo ve fetüse olan potansiyel etkileri hakkında sıkça sorulan sorular gözden geçirilmiştir.

**Anahtar sözcükler:** gebelik, radyasyon, tanısal görüntüleme, fetal doz

## Introduction

With the wide availability and expanding clinical applications of diagnostic imaging, more pregnant or possibly pregnant patients are referred to evaluation by radiological imaging. Ionizing radiation delivered and contrast media used during diagnostic imaging of pregnant women are major concerns for gynecologists and radiologists. That's why radiological examinations involving the use of ionizing radiation require a balance between the risks and benefits.

The aim of this study is to review the frequently asked questions concerning radiation dose and its potential risks to

the conceptus (embryo or fetus) associated with different imaging modalities. The article primarily focuses on radiological imaging in pregnant women. Ionizing radiation from nuclear medicine studies and non-ionizing radiation are beyond the scope of this review.

### What is ionizing radiation and what kind of imaging tools deliver it?

Ionizing radiation is a function of the individual particles (e.g.  $\alpha$  and  $\beta$  particles, neutrons) or waves (e.g. X-rays,  $\gamma$  rays), that have enough energy to remove electrons from atoms or molecules when it passes through or collides with some material giving rise to positively charged atom or molecule (ion). Radiological imaging tools involving ionizing radiation are plain radiographs, intravenous urography, mammography, fluoroscopic examinations, angiography, and computerized tomography (CT). These

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equipments produce diagnostic X-rays which ionize the molecule or the atom. Nuclear medicine studies also involve ionizing radiation. Other diagnostic tools such as ultrasonography, Doppler examination and magnetic resonance imaging do not deliver ionizing radiation.

### **What units are used for measuring radiation exposure, and radiation dose?**

*Exposure* describes the ability of X-rays to ionize air. It is measured with an ionization chamber and an electrometer, in units of roentgens (R):  $1R=2.58 \times 10^{-4}$  C/kg air (1). It only measures how much ionization is present in air, not in tissue, and therefore it does not quantify how much energy has been absorbed by the irradiated tissue. *Absorbed radiation dose* describes the amount of energy absorbed per unit mass at a specific point. It is measured in grays (1 Gy=1 joule/kg) or rads (1 rad=100 erg/gr): 1 Gy=100 rad (radiation absorbed dose). Absorbed dose does not take into account the type and quality of radiation or relative radiosensitivity of the tissues being irradiated (1). *Equivalent dose* is defined as the product of the absorbed dose and the radiation weighing factor (1 for X-rays and  $\gamma$  rays, 20 for  $\alpha$  particles). It is measured in sieverts or rems: 1 Sv=100 rem (roentgen equivalent men). For X-rays used in diagnostic radiology, exposure (R)=absorbed dose (rad) = equivalent dose (rem) (2).

*Effective dose* takes into account where the radiation dose is absorbed in addition to type of radiation, and reflects the equivalent whole body dose (the sum of weighted average of all organs or tissues doses) (1,3,4). According to the International Commission on Radiological Protection (ICRP) Publication 103 of 2007 (5) the highest tissue weighing factors are those of breasts, colon, stomach, lungs, red marrow (each 0.12), followed by gonads (0.08). Effective dose is measured in sieverts or rems. In the remainder of this paper we will use sieverts as a unit of radiation dose.

### **What are the biological effects of radiation exposure on a fetus?**

Biological effects of ionizing radiation can be classified as deterministic or stochastic. Deterministic effects such as skin injuries, cataract formation, alopecia and sterility occur predictably when radiation dose exceeds a certain threshold, whereas stochastic effects such as teratogenesis and carcinogenesis occur with a probability that increases with dose. Exposure from radiological examinations is limited and has only stochastic effects if ever. Biologic effects are created by physical and chemical processes resulting in cell death, morphological or DNA changes leading to carcinogenesis and genetic mutations (6).

Main source of human data describing effects of ionizing radiation are based on the studies of the 1945 atomic bomb survivors of Hiroshima and Nagasaki. Approximately 2800 pregnant women were affected and 500 of them received a

fetal dose of more than 10 mSv (6,7). Prenatal death, intrauterine growth retardation, mental retardation, organ malformation and childhood cancers are potential effects of ionizing radiation depending on dose and time of exposure during pregnancy (6-8). It is estimated that the increased risk of a childhood cancer produced by doses on the order of 10 mSv with an excess risk of approximately 6% per Sv (9). The ICRP published (10) that the overall risk of childhood cancer for a fetus receiving 30 mSv (the fetal dose for an abdominopelvic CT) is doubled, reaching 2 in 600, compared to 1 in 600 in the general population. The relative risk of carcinogenesis secondary to ionizing radiation decreases later in pregnancy (11). The excess relative risk of developing childhood cancer estimated for 1.0 mSv is approximately 0.28 in the first trimester; 0.03 in the third trimester, and 0.037 overall during pregnancy (10).

Radiation is a dose-dependent teratogen, up to certain limits effects are similar between the exposed and the control population who have received only background radiation. Background radiation is radiation originating from cosmic rays, soil or air. Embryos are exposed to less than 1 mSv (100 mrem) of background radiation during 9 months of gestation (12).

### **What are the determinants of fetal radiation dose?**

The time and duration of the radiation, the type of radiologic examination (i.e. plain radiographs, fluoroscopy, or CT), the energy (peak kilovolt=kVp) and amount (milliamperes=mA) of the photons used, the thickness of the patient and the depth of the fetus from the skin surface are the major determinants of fetal exposure. The closer the conceptus to the source, the higher the radiation it absorbs. Exposure is minimal when the uterus is positioned out of the field of view. Examinations of body parts above the diaphragm or below the hips (e.g. extremities, head, neck, and chest) do not expose the fetus directly, but by scattered radiation. Therefore, the fetus receives virtually no radiation from these examinations particularly when lead shielding is employed.

### **Is sensitivity of conceptus the same during developmental stages?**

No, the sensitivity of a developing fetus to radiation can vary with the stage of development, hence gestational age at time of exposure is one of the most important factors along with the magnitude of the dose, and the length of time of the total exposure (Table 1). The gestational time can be divided into three stages; preimplantation or blastogenesis (0-2 weeks), major organogenesis (3-8 weeks), and fetal development (9 weeks to birth).

In the pre-implantation phase, radiation exposure either causes failure of implantation and death of the conceptus (spontaneous abortion), or no effect at all. This is called as "all or nothing effect". During the phase of major organogenesis (3-8 weeks), irradiation up to 100 mSv

(10 rem) does not increase the risk of anomalies. However, the probability of malformation increases when the dose is more than 100 mSv (2,6-8,13).

During the fetal development stage, the sensitivity of fetus decreases, with central nervous system being the most sensitive to ionizing radiation between weeks 8 and 25; it is most radiosensitive from weeks 8 to 15, less sensitive during weeks 16 to 25, and relatively radioresistant after week 25. Potential abnormalities of the CNS include impaired mental development, behavior disorders, and diminished IQ. If fetal exposure exceeds 150 mSv (15 rem), there is a 15% risk of microcephaly, 6% risk of mental retardation, and 3% chance of childhood cancers, particularly leukemia (2,9,14). After the 26<sup>th</sup> week of pregnancy, the radiation sensitivity of the unborn baby is similar to that of a newborn, therefore birth defects are not likely to occur, and only a slight increase in the risk of having cancer later in life is expected.

### Which exams carry lower dose compared to others?

Low dose exams are those that expose the fetus to less than 1 mSv (0.1 rem), such as plain films of extremities and chest. Moderate dose studies include plain films of abdomen and lumbar spine, chest CT and most of the nuclear medicine exams, and expose the fetus 10 mSv (1 rem) or less. High dose exams are those exposing fetus more than 10 mSv (1 rem) and include abdominopelvic CT, fluoroscopy and most interventional procedures. In general, fetal dose is calculated as that of ovarian or uterine dose. Radiation absorbed by the fetus is approximately 40% of the dose delivered to the mother's abdomen or pelvis (2). Table 2 summarizes the conceptus doses from various radiodiagnostic examinations.

### Is CT examination justified in pregnant women?

CT has become the primary imaging tool in the emergency setting, particularly after the introduction of multidetector

CT. It is associated with higher levels of radiation exposure being responsible for 40% of the annual collective dose from all medical procedures (15). Therefore, the CT examination should be used cautiously after assessing the potential risks and benefits. CT examinations of head, neck, chest and extremities can be performed safely during pregnancy because the fetus is out of the field of view. Therefore, CT can be chosen as an imaging tool in the setting of pulmonary embolism, trauma, and cancer staging (7,8,14,16,17). On the other hand, the fetus is within the field of view in CT of the abdomen and pelvis. The estimated fetal radiation dose depends on the technical parameters, anatomic coverage, and scanner type, typically being in the range of 8-40 mSv (16-18). When imaging of the abdominopelvic organs is necessary, alternative imaging modalities not involving ionizing radiation such as ultrasonography or magnetic resonance imaging (MRI) should be preferred. If they are not feasible or the results are inconclusive, CT scan should not be cancelled if the mother is at risk and appropriate indications for an imaging examination exist, because the well being of the conceptus primarily depends on the well being of the mother. A recent survey showed that academic radiologists prefer CT to MRI for imaging abdominal complaints in pregnant women particularly in the second and third trimesters (17). Evaluation of abdominal trauma, renal calculus, appendicitis, cancer staging, intestinal obstruction and abscess are major indications for abdominal CT. Hurwitz et al. (16) estimated the fetal radiation doses during early pregnancy for renal stones and appendicitis too low to induce fetal neurologic deficits. But they concluded that dose fetus exposed during maternal imaging for appendicitis may double fetal risk of childhood cancer (16). When abdominal CT study is justified, the scanning parameters should be optimized (reducing milliamper-second values, z-axis modulation, increasing scan pitch) in order to keep radiation dose to the fetus as low as reasonably achievable. In a recent survey among academic centers in Turkey, 57% of radiologists reported that they optimize CT parameters, and 9% reported that they do not work with pregnant patients

**Table 1.** Fetal effects of radiation dose in different gestational stages\*

Gestational period	Radiation dose	Effect
Blastogenesis (0-2 weeks)	50-100 mSv (5-10 rem)	Death of embryo or no consequence (all or none)
Organogenesis (3-8 weeks)	<100 mSv (10 rem)	No significant increase in anomalies
	>100 mSv (10 rem)	Risk of anomalies (skeleton, eyes, genitals) increases 1% per 100 mSv Growth retardation Therapeutic abortion may be considered
9-15 weeks	<100 mSv (10 rem)	No significant risk of anomaly
	>150 mSv (15 rem)	15% risk of microcephaly, 6% chance of mental retardation (25 IQ point loss per 100 rem), 3% chance of cancer
16-25 weeks	>10 mSv (1 rem)	Increase in childhood cancers and leukemia
	>250 mSv (25 rem)	Severe mental retardation (low risk)

\*Source: References 6-9,14.

**Table 2.** Conceptus doses from various radiodiagnostic examinations\*

Examination	Conceptus dose (mSv)	Comments
<b>Plain radiography</b>		
Cervical spine (AP, Lat)	<0.001	Dose increases with patient body thickness in abdominopelvic studies
Extremities	<0.001	
Chest (PA, Lat)	0.002	
Thoracic spine (AP, Lat)	0.003	
Abdomen ( AP)	1-5	
Lumbar spine (AP, Lat)	1-7	
Limited IVU (4 image)	6	
<b>Fluoroscopic examinations</b>		
Small bowel study	7-10	<b>Dose varies with fluoroscopy time and number of spot images</b> Fluoroscopy fetal dose = 0.15 x entrance skin dose
Barium enema	7-10	
<b>CT studies</b>		
Head CT	0	<b>Doses vary greatly with scanning parameters</b>
Chest CT	0.2	
CT pulmonary angiography	0.25-0.65	
Abdominopelvic CT (standard)	15-35	
Abdominopelvic CT (stone protocol)	4-12	
CT angiography of aorta (chest, abdomen and pelvis)	34	
mSv=millisievert=100 millirem (roentgen equivalent men).		
*Source: References 6-8,12,14,16.		

because of concerns about either radiation dose or use of contrast material (18).

### Should I obtain informed consent?

Informed consent should be obtained for the rare occasion in which the estimated fetal radiation exposure reaching or above 50 mSv (5 rem). These include interventional procedures with long fluoroscopy times and multiphasic abdominopelvic CT scans. Informed consent can also be obtained to the preference of the practitioner for those procedures exposing the fetus between 10-50 mSv (1-5 rem). These include abdominal radiography, lumbosacral spine examination, limited excretory urography, barium enema, CT of the abdomen and pelvis, and fluoroscopy.

The patient should be counseled about the risks (e.g. childhood cancer, congenital abnormality, mental retardation and small head size, miscarriage) and benefits of the diagnostic test or interventional procedure. The referring physician and the radiologist should document the circumstances and medical justification for the diagnostic study or interventional procedure in the patient's medical record. Previous exposures to radiation must also be considered before new procedures are initiated, because health risks associated with radiation to the conceptus are cumulative (2,14). In a recent survey, 68% of academic radiologists reported that they obtain written informed consent before abdominal CT examination in pregnant women (17). The consent form is not required for diagnostic

procedures when the fetus is not in the X-ray beam (e.g. plain radiographs or CT examination of body parts above the diaphragm and below the hips).

### What is the risk of pregnant health care providers?

A pregnant women working in the radiology department are usually exposed only to scattered radiation, that is much less than direct exposure. Therefore, the radiation dose incurred by the fetus of working mother is small. Film badges (dosimeters) worn by workers measure doses and fetus exposed lower than that level. In a study of Royal College of Radiologist and British Institute of Radiology, the badge dose is recorded as zero in 93% of diagnostic workers, and only in 0.3% dose greater than 2 mSv in a year (19). Brachytherapy nurses received an annual dose of 4.8 mSv and radiotherapy nurses 14.1 mSv (20).

National Council on Radiation Protection and Measurements (NCRP) recommends that fetuses of laboratory workers not receive more than a cumulative dose of 5 mSv (0.5 rem) during the whole gestation period (21). In addition, once a pregnancy becomes known, the rate of dose accumulation is restricted to 0.5 mSv (50 mrem) per month. This occupational exposure guideline is one tenth of the safe dose limit applied to general population and should not be confused with the teratogenic threshold dose. Although most exposed workers receive negligible radiation, few workers exposing greater doses should declare their pregnancy as

early as possible to arrange their pattern of work as to reduce exposure.

### **What is the critical dose for the fetus and what should be the policy for therapeutic abortion?**

According to guidelines published by professional and radiation protection societies, fetal radiation exposure is usually less than 50 mSv (5 rem) in most of the radiologic studies, and risk of abnormality is negligible at diagnostic doses (2,7,8,13,14,16,22,23). The International Commission on Radiological Protection (13) stated that, prenatal doses from most properly done diagnostic procedures present no measurably increased risk of prenatal death, malformation, or impairment of mental development over the background incidence of these entities. The commission also established that fetal doses below 100 mSv should not be considered a reason for terminating a pregnancy. According to the policy established by the American College of Radiology (22) concerning the use of therapeutic abortion, the interruption of pregnancy is rarely justified because of radiation risk to the embryo or fetus from a radiologic examination. The American College of Obstetricians and Gynecologists (23) has also issued the following policy statement: Women should be counseled that X-ray exposure from a single diagnostic procedure does not result in harmful fetal effects. Specifically, exposure to less than 50 mSv (5 rem) has not been associated with an increase in fetal anomalies or pregnancy loss. Based on these statements, it is clear that the risk is negligible at doses of less than 50 mSv, and it is comparable with the spontaneous risk of unexposed fetuses which includes 15% chance of spontaneous abortion, 3% risk of major malformations and 4% risk of intrauterine growth retardation, and 1% risk of mental retardation (8,9,24). With regard to doses of more than 50 mSv, with double that dose (i.e., 100 mSv), the increase over combined background incidence for organ malformation and the development of childhood cancer is only about 1% (7).

### **How can a physician avoid a medical malpractice lawsuit?**

Radiation exposure to pregnant or possibly pregnant women represents a potential clinical hazard to the conceptus and a medical-legal hazard to the radiologist. Malpractice lawsuits alleging that an abortion or fetal anomaly was caused by exposure to diagnostic radiation are relatively common in the 1980s but have become less common in the 1990s (25,26). Risk management in the gynecology and radiology practice can reduce the likelihood of incurring a medical malpractice lawsuit and increase chances for a successful defense if a litigation is filed while enhancing good patient care. Informed consent can be obtained before any radiologic examination to the preference of physicians, however it should be obtained regularly when the fetus is in the field of view (e.g. abdominopelvic examinations), and when the estimated fetal radiation exposure reaching or above 50 mSv (5 rem). Gynecologists and radiologists should possess

references that list radiation doses given during radiographic, fluoroscopic and CT examinations. Gynecologists with radiologists or radiation physicists should discuss with pregnant patients about the risks of radiation exposure, the risks of delaying or cancelling the radiologic examination, alternative diagnostic imaging methods, and ways of modifying the radiologic examination to reduce radiation (e.g. decreasing the number of radiographic views, shortening fluoroscopic time, and using low dose during CT examination). The patient should be counseled about the risks (e.g. childhood cancer, congenital abnormality, mental retardation and small head size, miscarriage) and benefits of the radiologic examination or interventional procedure. The referring physician and the radiologist should document the medical justification for the radiologic study and discussions with the pregnant woman in the patient's medical record and radiologic reports (26,27).

### **What is the effect of iodinated contrast agents during pregnancy?**

Iodinated contrast media are commonly indicated for CT examinations in cases where differentiation of vascular structures, and neoplastic or inflammatory processes is required. They are small molecules and rapidly distributed throughout the extracellular fluid. They readily cross placenta and breast milk and are classified as category B drugs. Although, there is no evidence of teratogenicity in animal studies, no controlled studies in pregnant women exist. In a recent survey, the administration of iodinated contrast material varied among respondents, but only 18% of 84 responding medical centers indicated that they never use iodinated contrast material in pregnant women (17).

The theoretical risk of iodinated contrast agents in pregnancy and breast feeding period is the depression of fetal or newborn thyroid function due to free iodide. Therefore American College of Radiology consensus advised not to use iodinated contrast media in pregnancy and during breast feeding period to discard breast milk for 12 hours after contrast media injection (28,29). If the mother was administered iodinated contrast media after assessment of potential risk-benefit ratio, the thyroid function of the newborn should be checked in the first week after delivery (30).

### **Key points**

1. Radiation exposure to pregnant or possibly pregnant women may cause potential risks to the conceptus. The risks and benefits of the procedure must be determined before ordering radiological examinations involving the use of ionizing radiation. If possible, alternative imaging modalities not involving ionizing radiation such as ultrasonography or magnetic resonance imaging should be preferred.
2. Because the risk of abnormality is generally negligible at doses received during diagnostic radiological examinations, the radiological examination should not be

cancelled if the mother is at risk and appropriate indications for an imaging examination exist. Radiological examinations of body parts can be performed safely when the fetus is out of the field of view (e.g. plain radiographs or CT examination of body parts above the diaphragm and below the hips). Informed consent should be obtained when the fetus is in the direction of X-ray beam (abdominopelvic examinations), and attention should be paid to keep the radiation dose as low as reasonably achievable.

3. The gestational age of the fetus at the time of exposure and the radiation dose received are two major determinants for radiation induced abnormalities. Conceptuses are considerably more sensitive to adverse radiation effects between 2 and 15 weeks' gestation while abnormalities are extremely unlikely in fetuses who are less than 2 weeks' gestation or more than 15 weeks' gestation.
4. Termination of pregnancy is rarely justified because of the risk to the conceptus from a radiologic study. Pregnant women exposed to less than 50 mSv (5 rem) should be reassured and counseled accordingly reminding that each healthy woman begins pregnancy with a 3% risk of birth defects and a 15% risk of miscarriage in the absence of radiation exposure.

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