Diagnostic imaging procedures during pregnancy

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INTRODUCTION — Preconceptional ovarian exposure to diagnostic levels of ionizing radiation has no measurable effect on future pregnancies. Therefore, the ideal time to schedule radiologic procedures in women of reproductive age is during the first 10 days of the menstrual cycle, if possible. At the time of the radiologic examination, all women of childbearing potential should be asked if they could be pregnant [1]. If any doubt exists, the results of a pregnancy test should be obtained before proceeding.

Sometimes diagnostic imaging is necessary during pregnancy, and utilization rates appear to be increasing [2]. Sonographic examination of the uterus and its contents is a common occurrence in pregnant women, but other types of radiological evaluation may also be required. Although the safety of radiation exposure during pregnancy is a common concern, a missed or delayed diagnosis can pose a greater risk to the woman and her pregnancy than any hazard associated with ionizing radiation [3]. In many cases, the perception of fetal risk is higher than the actual risk [4,5]. For the woman herself, the effects of ionizing radiation are the same whether or not she is pregnant, and will not be dealt with in this topic.

GUIDELINES — Multiple national and international organizations have written guidelines on imaging the pregnant patient. A comprehensive resource including the names of 17 of these organizations and their 33 reports was published in 2011 [6]. The following discussion includes information derived from several of these reports.

RADIATION BASICS — Any discussion of the effects of radiation requires background knowledge of radiation nomenclature and dosimetry. The absorbed dose of radiation is the amount of energy deposited per kilogram of tissue and is measured in "rads." One rad is the energy transfer of 100 ergs per gram of any absorbing material. The following relationships apply to diagnostic X-rays in soft tissue:

- 1 rad = 0.01 gray (Gy) = 0.01 sievert (Sv) = 1 rem (roentgen-equivalent man)

In the United States, the average person is exposed to an effective radiation dose equivalent of approximately 3.1 mSv (310 mrem) whole-body exposure per year from natural sources [7]. The US Nuclear Regulatory Commission (10 CFR 20) recommends that occupational radiation exposure of pregnant women not exceed 5 mSv (500 mrem) to the embryo/fetus during the entire pregnancy [8].

(See "Biology and clinical features of radiation injury in adults", section on 'Examples of radiation exposures'.)

EFFECTS OF IONIZING RADIATION ON THE FETUS

Overview — There are no studies in humans from which to derive data on risks of ionizing radiation; most of our information is based upon case reports and extrapolation of data from investigations of survivors of the atomic bomb in Japan and the Chernobyl accident [9-15]. Based on these data, the potential deleterious consequences of ionizing radiation can be divided into four categories [16,17]:

- Pregnancy loss (miscarriage, stillbirth)
- Malformation
- Disturbances of growth or development
- Mutagenic and carcinogenic effects

The occurrence of each effect depends upon the gestational age at the time of radiation exposure, the dose of radiation absorbed by the fetus, and fetal cellular repair mechanisms. Cellular damage caused by low levels of radiation exposure is usually repaired by a number of physiologic processes. In contrast, high level exposure can interrupt important events in cell development and maturation, which may cause permanent injury or death.

The effects of radiation can be considered as either deterministic (exposure affects severity of outcome) or stochastic (exposure affects probability of outcome). The deterministic effects are dose-related and occur when many cells are affected by radiation; a large number of affected cells results in more significant clinical problems. If injury to these cells occurs during a critical stage of organogenesis (primarily but not exclusively days 15 to 50 after conception), impairment, agenesis, or deformity of the developing organ can occur (figure 1). As an example, microcephaly develops if a large number of differentiating central nervous system cells are injured.

Stochastic effects are monoclonal, resulting in changes to the cell genome and altered differentiation and function of the affected cells. The probability, but not the severity, of the effect increases with the radiation dose. As an example, the increased risk of thyroid cancer as a result of in utero exposure to radiation after the Chernobyl accident is a stochastic effect [9].

Exposure less than 0.05 Gy (5 rads) — Diagnostic imaging procedures typically expose the fetus to less than 0.05 Gy (5 rads) (table 1). There is **no** evidence of an increased risk of fetal anomalies, intellectual disability, growth restriction, or pregnancy loss from ionizing radiation at doses less than 0.05 Gy [18,19]. The margin of safety is augmented by the fact that most human exposures from diagnostic imaging will be fractionated over a period of time; this type of exposure is less harmful than acute exposure [18].

Carcinogenesis — Animal data suggest that carcinogenic effects are most pronounced during late fetal development [19]. Low levels (eg, 0.01 to 0.02 Gy [1 to 2 rad]) of in utero radiation exposure may increase the risk of childhood cancer, particularly leukemia, by a factor of 1.5 to 2 over the baseline incidence [18,20]. However, the carcinogenic potential of low level radiation is controversial since nonirradiated siblings of these children also have a higher incidence of leukemia. Furthermore, children exposed in utero at the bombing of Hiroshima and Nagasaki have not developed a significantly increased rate of cancer [21].

An estimate of the risk of childhood leukemia in various populations is shown in the table (table 2). Although an increased risk of radiation-induced carcinogenesis in children exposed in utero cannot be excluded, 10 to 20 mGy fetal exposure is estimated to increase the risk of leukemia by 1.5–2.0 over a background rate of about 1 in 3000 [22].

Solid cancer incidence rates have been examined among survivors of the atomic bombings of Hiroshima and Nagasaki who were in utero (n = 2452) or younger than 6 years (n = 15388) at the time of the bombings [23]. Both the in utero and early childhood groups exhibited statistically significant dose-related increases in incidence rates of solid cancers, but the lifetime risks following in utero exposure were much lower than for early childhood exposure. At age 50, the estimated excess absolute rate per 10,000 person-years per Gy was 6.8 (95% CI <0 to

49) for those exposed in utero and 56 (95% CI 36 to 79) for those exposed as young children. There was NO increase in oncogenic risk for exposures less than 0.2 Gy.

Exposure 0.05 to 0.50 Gy (5 to 50 rads) — The threshold at which an increased risk of congenital malformations is observed in radiation exposed embryos/fetuses has not been definitively determined. The evidence suggests the risk of malformations is increased at doses above 0.10 Gy, whereas the risk between 0.05 and 0.10 Gy is less clear [24]. It is important to note that even those diagnostic imaging procedures associated with high fetal radiation exposure (eg, abdominal or pelvic CT, barium enema, cystourethrogram) almost never expose the fetus to this level of radiation (table 1).

First 14 days after conception — The developing human is most sensitive to the lethal effects of ionizing radiation during the first 14 days after conception. During this period, the radiation-exposed "embryo" either survives undamaged or is resorbed (termed the "all or none" phenomenon) [25]. Radiation-induced teratogenesis, growth restriction, or carcinogenesis are **not** observed during this stage of development [18], presumably because of the pluripotent nature of each cell of the very early embryo.

For human exposure, a conservative estimate of the threshold for death at this stage is more than 0.1 Gy rads (10 rads) [19]. A fetal dose of 1 Gy (100 rads) will likely kill 50 percent of embryos; the dose necessary to kill 100 percent of human embryos or fetuses before 18 weeks of gestation is about 5 Gy (500 rads).

After the first 14 days — During the period of organogenesis (approximately 2 to 8 weeks after fertilization or 4 to 10 weeks after the last menstrual period), the embryo may be damaged as a result of radiation-induced cell death, disturbances in cell migration and proliferation, or mitotic delay [26]. Lethality is rare.

The major sequelae of radiation damage at this stage are fetal growth restriction and congenital malformations, particularly of the central nervous system (eg, microcephaly, intellectual disability, gross eye abnormalities). Microcephaly is the most frequently cited manifestation of radiation injury in utero [27]. In the absence of any of these findings, the presence of other types of malformations in humans should not be attributed to radiation exposure [18].

After approximately 20 to 25 weeks of gestation, the fetus is relatively resistant to teratogenic effects of ionizing radiation [28].

- Malformations – For the developing fetus under 16 weeks of gestation, the threshold for possible prenatal radiation effects is approximately 0.10 to 0.20 Gy (10 to 20 rads) [19]. After 16 weeks of gestation, the consensus of most researchers is that this threshold is much higher, at least 0.50 to 0.70 Gy (50 to 70 rads).

- Mental retardation – Studies in survivors of the Hiroshima atomic bomb demonstrated that the risk of mental retardation and microcephaly was highest for radiation exposures at 8 to 15 weeks after conception [10]. The abnormalities were attributed to alterations in neuronal development. No cases of severe intellectual disability were identified in the children of atomic bomb survivors who were exposed prior to 8 weeks or after 25 weeks following conception. The risk appeared to be a linear function of dose, with a threshold of 0.12 Gy (12 rads) at 8 to 15 weeks, and 0.21 Gy (21 rads) at 16 to 25 weeks [11-14].

  In addition, at 8 to 15 weeks, the average IQ loss was approximately 25 to 31 points per Gy (per 100 rads) above 0.1 Gy (10 rads), and the risk for severe intellectual disability was approximately 40 percent per Gy (per 100 rads) above 0.1 Gy (10 rads). By comparison, at 16 to 25 weeks, the average IQ loss was approximately 13 to 21 points per Gy at doses above 0.7 Gy, and the risk of severe intellectual disability was approximately 9 percent per Gy above 0.7 Gy.

- Growth restriction – Atomic bomb survivor data showed a permanent restriction of physical growth with increasing radiation dose, particularly above 1 Gy [19]. This was most pronounced when the exposure

occurred in the first trimester. A 3 to 4 percent reduction in height at age 18 occurred when the dose was greater than 1 Gy.

Genetic effects — Radiation may increase the frequency of naturally occurring mutations; it does not induce mutations unique to this source. Small increases in the rate of genomic mutation are difficult to detect because the background rate of spontaneous mutation is already high (about 10 percent), recessive mutations take several generations to become apparent, and autosomal dominant mutations are rare [12]. There is currently no way to distinguish radiation-induced genetic mutations from similar conditions arising from other environmental exposures. Studies attempting to estimate the incidence of radiation mutagenesis have been based largely upon animal and plant experiments. Very few human data are available, apart from observations in the offspring of Japanese atomic bomb survivors. An increased risk of genetic disorders induced by ionizing radiation has not been demonstrated in any human population at any radiation dose [12,29].

FETAL EXPOSURE FROM COMMON PROCEDURES — There are no known significant fetal effects from exposure to diagnostic ultrasound or magnetic resonance (MR) imaging involving a magnetic field at 1.5 Tesla or lower. (See 'Ultrasound' below and 'Magnetic resonance imaging' below.)

The estimated fetal exposures for some common imaging procedures involving ionizing radiation are listed in the table (table 1) [26,30,31]. Although several such tables are available, dosimetry calculations vary widely.

When counseling a pregnant woman about the radiation risks associated with a diagnostic procedure, the estimated dose for the specific patient should be calculated by a radiologist familiar with dosimetry. Factors to be considered include the number and type of projections, exposure time, distance, x-ray output, and use of digital acquisition systems designed to limit dosage.

ISSUES BY TYPE OF DIAGNOSTIC IMAGING PROCEDURE — Diagnostic imaging during pregnancy can involve ionizing radiation (eg, plain x-rays, fluoroscopy and angiography, computed tomography [CT], nuclear medicine) or nonionizing techniques (eg, ultrasound, magnetic resonance [MR] imaging). In addition, various contrast agents may be administered to enhance diagnostic sensitivity.

Procedures using ionizing radiation — Diagnostic x-rays of the head, neck, chest, and limbs produce almost no scatter to the embryo; any radiation received would not result in a measurably increased risk. Nevertheless, the patient should wear a lead apron to minimize fetal exposure from radiation scatter whenever non-abdominopelvic sites are being imaged. A fast film/screen combination or digital radiography can also be used to reduce total radiation exposure.

Plain films — Several techniques can be used to minimize fetal radiation exposure during abdominopelvic x-ray procedures:

- A posterior-anterior (PA) exposure lowers the radiation dose by 0.02 to 0.04 mGy (2 to 4 mrad) compared with the traditional anterior-posterior (AP) exposure because the uterus is located in an anterior pelvic position,
- Shutters can be employed to collimate the radiation beam and reduce scatter.
- Avoiding both magnification near the uterus and use of grids results in a decreased dose of radiation.

Fluoroscopy and angiography — During fluoroscopic and angiographic procedures, modifying the exposure time, number of films obtained, beam size, and imaging area can reduce the amount of radiation exposure.

Intravenous pyelography — Renal and pelvic ultrasound are recommended as the initial diagnostic imaging study when an obstructing calculus is suspected. Ultrasound is useful for detecting secondary signs of obstruction, such as hydronephrosis or hydroureter, while avoiding exposure to ionizing radiation. Endovaginal

ultrasound is more sensitive than transabdominal ultrasound for detecting distal ureteral calculi [32]. (See "Maternal adaptations to pregnancy: Renal and urinary tract physiology".)

If after ultrasound examination it is still considered necessary to obtain an intravenous pyelogram (IVP), the radiation dose can be minimized by obtaining a single abdominal radiograph approximately five minutes after intravenous administration of contrast material [33]. This will provide information about the relative excretory function of each kidney, and will demonstrate the site and extent of obstruction of a ureter. The single-shot IVP delivers about 0.5 mGy (50 mrad) to the fetus, a value that is equal to federal guideline for the maximum radiation exposure recommended for pregnant women over a one-month interval.

Computed tomography — The fetal radiation dose from a CT scan is affected by several variables, including the number, location, and thickness of slices. When CT imaging is performed in pregnancy, using a narrow collimation and wide pitch (ie, the patient moves through the scanner at a faster rate) results in a slightly reduced image quality, but provides a large reduction in radiation exposure. Scanning protocols should also be modified. As an example, if performing a CT scan with contrast, the number of acquisitions can be reduced by eliminating the precontrast series. (See "Principles of computed tomography of the chest".)

Fetal radiation exposure during CT scans not involving the abdomen or pelvis is minimal. As an example, the radiation exposure from maternal head CT is approximately 2 mGy (200 mrad) for the mother and less than 0.10 mGY (10 mrad) for the fetus if the abdomen is shielded.

Dental x-rays — The radiation dose to the fetus from maternal dental radiography is minute, 0.0001 mGy (0.01 mrads) for an average study, and is not considered harmful. Although one population based case-control study found an association between antepartum dental radiography of >0.4 mGy (40 mrads) to the maternal thyroid and low birth weight (less than 2500 g) [34], this association is not consistent with findings from multiple other studies and is not biologically plausible [17]. Further investigation is needed before any change is made to the recommendations for dental imaging in pregnant women. (See 'Summary and recommendations' below.)

Mammography — Mammography during pregnancy is discussed separately. (See "Breast imaging for cancer screening: Mammography and ultrasonography".)

Iodinated contrast materials — Iodinated contrast materials cross the placenta and can produce transient effects on the developing fetal thyroid gland, although clinical sequelae from brief exposures have not been reported. Iodinated contrast materials may be used in pregnancy, when indicated.

Breastfeeding women — Since most iodinated intravenous contrast agents are highly protein bound and rapidly cleared from maternal circulation (half-life <60 minutes), they are present only at very low levels in milk [35-37]. Moreover, contrast agents have low oral bioavailability, so the infant absorbs a minimal amount of iodine. In a study of 10 newborns who received intravenous contrast media for urographic studies, thyroid function tests were checked at the time of the study and 10 and 30 days later [38]. No abnormalities were found, suggesting that even therapeutic doses of contrast media administered directly to infants do not affect infant thyroid function.

In their statement on administration of contrast medium to breastfeeding mothers, the American College of Radiology (ACR) estimates that less than 0.01 percent of the maternal dose of iodinated contrast is absorbed by the breastfeeding infant. The ACR concluded that it is safe for women to breastfeed after receiving contrast media, but mothers should be informed of the theoretical risks of direct toxicity or allergic reaction [39]. In a review of the literature, the Contrast Media Safety Committee of the European Society of Urogenital Radiology (ESUR) concluded that the amount of iodinated contrast media transferred into milk was insufficient to warrant interruption of breastfeeding [40]. Women who are concerned about theoretical adverse effects may pump to remove breast milk before administration of the contrast agent and then express and discard milk for 24 hours after the imaging study, which is also the position taken by most manufacturers in their package inserts.

Nuclear medicine — Nuclear medicine studies (eg, pulmonary ventilation-perfusion, thyroid, bone, and renal scans) use a radioisotope bound to a chemical agent. The effect of these substances on the fetus depends upon placental permeability, fetal distribution, tissue affinity, and the half-life, dose, and type of radiation emitted. Substances that can localize in specific fetal organs and tissues, and thus may be of concern, include iodine-131 or iodine-123 in the thyroid, iron-59 in the liver, gallium-67 in the spleen, and strontium-90 and yttrium-90 in the skeleton. Fetal exposure also results from proximity to radionuclides excreted into the maternal bladder; maternal hydration and frequent voiding can reduce this type of exposure.

Pregnant women may have contact with individuals who have received radioactive materials as part of a diagnostic study; the minimal residual radioactivity does not result in a measurably increased risk to the embryo. Radiation exposure from close contact is higher after some types of therapeutic radiation (eg, radioiodine therapy of thyroid cancer, brachytherapy implants for prostate cancer) [41,42]. A period of restricted contact may be prudent, depending upon the type of therapy and degree of exposure.

Ventilation-perfusion and helical CT — A ventilation-perfusion (V-P) scan for suspected pulmonary embolus is among the most common nuclear medicine studies obtained in pregnant women. The procedure involves perfusion with Tc 99m macroaggregates of albumin and ventilation with radiolabeled xenon gas or 99m Tc DTPA aerosol. Helical CT is another commonly used test for diagnosis of suspected pulmonary embolus and is also associated with a low radiation dose to the fetus. One study estimated that in the third trimester, fetal radiation exposure from chest radiography, helical CT, V-P scanning, and pulmonary arteriography (with a brachial approach) was 0.01, 0.13, 0.37, and 0.50 mGy, respectively [43]. The mean radiation dose was lower earlier in gestation. (See "Deep vein thrombosis in pregnancy: Epidemiology, pathogenesis, and diagnosis".)

Thyroid scan — By the 10^{th} to 12^{th} week of gestation, radioiodine isotopes are readily absorbed by the fetal thyroid. Although there are no reports of adverse fetal effects from diagnostic doses of radioactive iodine, it should **not** be administered to pregnant women because induction of thyroid cancer in the offspring is a concern [26]. If a diagnostic scan of the thyroid is required, the preferred agent is Technetium Tc 99m (avoid I-131) [22].

Positron emission tomography — There is minimal information regarding positron emission tomography (PET) in pregnancy. This technique involves injection of a radioisotope, fludeoxyglucose F 18. Animal reproduction studies have not been conducted with fludeoxyglucose F 18 Injection and it is not known whether fludeoxyglucose F 18 Injection can cause fetal harm when administered to a pregnant woman, or can affect reproduction capacity. The radiation dose to the uterus is 3.70 to 7.40 mGy, for the usual dose range of isotope injected [44]. As discussed above, this is a low fetal dose and not associated with adverse effects on development or growth.

Because of the lack of safety data in human pregnancy, magnetic resonance imaging (MRI) or CT are generally preferred to PET as they usually provide similar information, but the decision needs to be made on a patient specific basis.

Breastfeeding women — Breastfeeding should be suspended for the period of time that radioactivity is present in milk; this will depend upon the half-life of the specific agent. The agent with the shortest half-life should be used. Before receiving the agent, the mother should express milk and store it in a freezer for later use. After the study, she should continue to express milk to maintain production and prevent engorgement, but discard the milk until the radioactive compound has been cleared. Radiology departments can also screen milk samples for residual radioactivity before the mother resumes nursing [45].

The Committee on Drugs of the American Academy of Pediatrics (AAP) advises interruption of breastfeeding for a minimum of three weeks after the mother has received I^{131}, I^{125}, N^{22}, and Ga^{67} [46]. Because the lactating breast has a greater I^{131} affinity than does the nonlactating breast, women should cease breastfeeding at least

four weeks before whole-body procedures with I^{131} and should discontinue breastfeeding thereafter to reduce the radiation dose to maternal breast tissue.

Ultrasound — No biologic effects have been documented from diagnostic ultrasound in the pregnant patient, despite intensive use over several decades. The potential for deleterious consequences from heat and cavitation exists since ultrasound uses sound waves that interact with biological tissues. B-mode and M-mode imaging operate at acoustic outputs that do not produce harmful temperature rises. However, Doppler ultrasound does have this potential; therefore, guidelines for Doppler use in pregnancy have been formulated. The use of ultrasound in pregnancy is discussed in detail separately:

- (See "Ultrasound examination in obstetrics and gynecology".)
- (See "Basic principles and safety of diagnostic ultrasound in obstetrics and gynecology".)
- (See "Doppler ultrasound of the umbilical artery for fetal surveillance".)

A limitation of ultrasound is that it does not show soft tissue detail as well as MRI or computed tomography.

Magnetic resonance imaging — MRI uses electromagnetic radio waves, rather than ionizing radiation, to generate detailed computer images. At the cellular level, possible direct biologic effects of MRI consist of (1) induction of local electric fields and currents from the static and time varying magnetic fields, and (2) radiofrequency radiation resulting in heating of tissue. Other potential dangers include trauma from projection of metal objects into the magnetic field (eg, small metal fragments can be projected into the eyes), interference with the operation of electronic devices (eg, cardiac pacemakers) or position of metallic implants, burns from heating of conductive materials in implants, and acoustic damage from high intensity noise.

Despite these concerns, there are no reported harmful effects from MRI of the pregnant woman or fetus [47-50]. In the largest of these studies (MRI: n = 1737 deliveries; no MRI: n = 1,418,451 deliveries), first-trimester MRI was not associated with significantly increased risks for stillbirth, neonatal death, congenital anomaly, neoplasm, or vision or hearing loss in children followed up to age four years, when adjustments were made for differences between exposure groups [50]. However, safety studies have been performed predominantly at or below 1.5 Tesla magnetic field strengths. There may be an increased risk of tissue heating at higher field strengths.

In some cases, MRI is the preferred diagnostic modality because it provides better images than ultrasonography, while avoiding the ionizing radiation of computed tomography. As an example, first trimester MRI is a reasonable option in a pregnant women with suspected appendicitis in whom the appendix cannot be visualized by ultrasound examination. An expert panel on MR safety opined that MRI should be performed at any stage of pregnancy when the information requested from the MRI study cannot be acquired by means of nonionizing means, the data are needed to potentially affect the care of the patient or fetus during the pregnancy, and it is not prudent to wait until the patient is no longer pregnant to obtain this data [51].

Gadolinium — Gadolinium, the contrast agent most commonly used for MRI because of its magnetic properties, crosses the placenta and is excreted by the fetus into the amniotic fluid. It is then swallowed so it can be reabsorbed into the fetal circulation. Given the potentially long half-life in the fetus and few data from human pregnancy, it is not recommended for use in the pregnant patient unless the potential benefit justifies the potential risk to the fetus (ie, “if it significantly improves diagnostic performance and is expected to improve fetal or maternal outcome” [22]) [52].

Human data from gadolinium exposed pregnancies are limited but concerning [50,53-56]. The largest human study comparing gadolinium MRI during pregnancy (n = 397) with no MRI (n = 1,418,451) reported gadolinium exposure at any time during pregnancy was associated with an increased risk for rheumatological, inflammatory, or infiltrative skin conditions (adjusted hazard ratio [HR] 1.36, 95% CI 1.09-1.69) and for stillbirths and neonatal

deaths (adjusted relative risk 3.70, 95% CI 1.55-8.85, 7 versus 9844 events) but not for nephrogenic systemic fibrosis (NSF) or congenital anomalies [50].

NSF is a rare disorder that usually occurs in adults and could be misdiagnosed as a connective tissue or skin disease in young children. It has been hypothesized that persistence of gadolinium in the fetus may increase the risk of NSF in children exposed in utero. The adjusted HR for NSF in this study was 1.00, but the confidence interval was wide (95% CI 0.33-3.02) given the small number of cases (≤5) and the challenge of making the diagnosis in a young child. For this reason, and because of the increased risk for the broader outcome of any rheumatological, inflammatory, or infiltrative skin condition, an increased risk of NSF could not be conclusively excluded, particularly with first-trimester exposure. (See "Nephrogenic systemic fibrosis/nephrogenic fibrosing dermopathy in advanced renal failure".)

This study involved a previous generation of gadolinium-based contrast agents. The newer generation is more stable and may have a lower potential for fetal toxicity, but no data are available. Therefore, gadolinium should generally be avoided in the pregnant patient unless its use significantly improves diagnostic performance and is likely to improve patient outcome.

Breastfeeding women — Gadolinium-based contrast agents are present at very low levels in human milk and not absorbed well by the infant gut; no adverse effects have been reported in infants exposed through lactation [57-59].

In their statement on administration of contrast medium to breastfeeding mothers, the American College of Radiology (ACR) estimates that less than 0.0004 percent of gadolinium-based contrast is absorbed by the breastfeeding infant. The ACR concluded that it is safe for women to breastfeed after receiving contrast media, but mothers should be informed of the theoretical risks of direct toxicity or allergic reaction [60,61]. The American College of Obstetricians and Gynecologists (ACOG) also concluded that breastfeeding should not be interrupted after gadolinium administration [22]. Women who are concerned about theoretical adverse effects may pump to remove breast milk before administration of the contrast agent and then express and discard milk for 24 hours after the imaging study, which is also the position taken by most manufacturers in their package inserts.

By comparison, the Contrast Media Safety Committee of the European Society of Urogenital Radiology (ESUR) concluded that breastfeeding should be avoided for 24 hours after injection of gadolinium-based contrast medium if agents with a high risk for NSF are used (eg, gadodiamide, gadopentetate dimeglumine, gadoversetamide) [62]. Women who receive contrast agents with intermediate risk for NSF (gadofosveset, gadobenate dimeglumine, gadoxetate disodium) may wish to consider the procedure described above (pumping before the procedure, and expressing and discarding breast milk for 24 hours after the procedure).

SUMMARY AND RECOMMENDATIONS

- Ideally, semi-elective radiologic procedures are scheduled during the first 10 days (follicular phase) of the menstrual cycle. All women of childbearing potential should be asked if they could be pregnant at the time of a radiologic examination. If any doubt exists, a pregnancy test should be obtained prior to the diagnostic procedure. The perceived risk of radiation exposure is much greater than the actual risk, but a full explanation of these risks to the woman and her family is best given prior to, rather than after, the exposure. (See 'Introduction' above.)

- During pregnancy, ultrasound examination and magnetic resonance (MR) imaging are generally preferred to imaging modalities that involve ionizing radiation. (See 'Ultrasound' above and 'Magnetic resonance imaging' above.)

  However, concern about the possible effects of ionizing radiation should not prevent medically indicated diagnostic procedures using the best available modality for the clinical situation. When procedures requiring

ionizing radiation are necessary, various techniques can be employed to minimize the radiation dose. (See 'Effects of ionizing radiation on the fetus' above and 'Issues by type of diagnostic imaging procedure' above.)

- Radiation risks should be discussed with the pregnant patient, including an explanation of the background population risk for miscarriage, congenital anomalies, genetic disease, and growth restriction (approximately 20, 4, 10, and 10 percent, respectively), as well as the risk of developmental disorders. Consultation with a radiologist should be obtained to plan the optimum study using the least amount of radiation or to reconstruct the amount of radiation exposure from examinations performed prior to knowledge of the pregnancy. (See 'Effects of ionizing radiation on the fetus' above and 'Fetal exposure from common procedures' above.)

- At doses less than 0.05 Gy, there is no evidence of an increased risk of fetal anomalies, intellectual disability, growth restriction, or pregnancy loss from ionizing radiation. There may be a small increased risk of childhood cancer, 1 in 1500 to 2000 versus the 1 in 3000 background rate. (See 'Exposure less than 0.05 Gy (5 rads)' above.)

- During the first 14 days after fertilization, intact survival or death are the most likely outcomes of radiation exposure above 0.05 Gy (5 rads). A conservative estimate of the threshold for intrauterine death is more than 0.1 Gy (10 rads). (See 'First 14 days after conception' above.)

- After the first 14 days, radiation exposure over 0.5 Gy may be associated with an increased risk of congenital malformations, growth restriction, and intellectual disability. (See 'After the first 14 days' above.)

- Gadolinium should generally be avoided in the pregnant patient, unless its use significantly improves diagnostic performance and is likely to improve patient outcome. It appears to have adverse effects on offspring. Gadolinium-based contrast agents are present at very low levels in human milk and not absorbed well by the infant gut; no adverse effects have been reported in infants exposed through lactation. (See 'Gadolinium' above.)

- Although there are no reports of adverse fetal effects from diagnostic doses of radioactive iodine, it should **not** be administered to pregnant women because induction of thyroid cancer in the offspring is a concern. If a diagnostic scan of the thyroid is required, the preferred agents are Technetium Tc 99m or I-123 (but not I-131). (See 'Thyroid scan' above.)

- Magnetic resonance imaging can be performed at any stage of pregnancy when the information requested from the study cannot be acquired by nonionizing procedures and the data are needed to care for the patient or fetus during the pregnancy. (See 'Magnetic resonance imaging' above.)

- For women undergoing nuclear medicine scans with radioisotopes, breastfeeding should be suspended for the period of time that radioactivity is present in milk; this will depend upon the half-life of the specific agent. (See 'Breastfeeding women' above.) It is safe for women to breastfeed after receiving iodinated contrast media. (See 'Breastfeeding women' above.)

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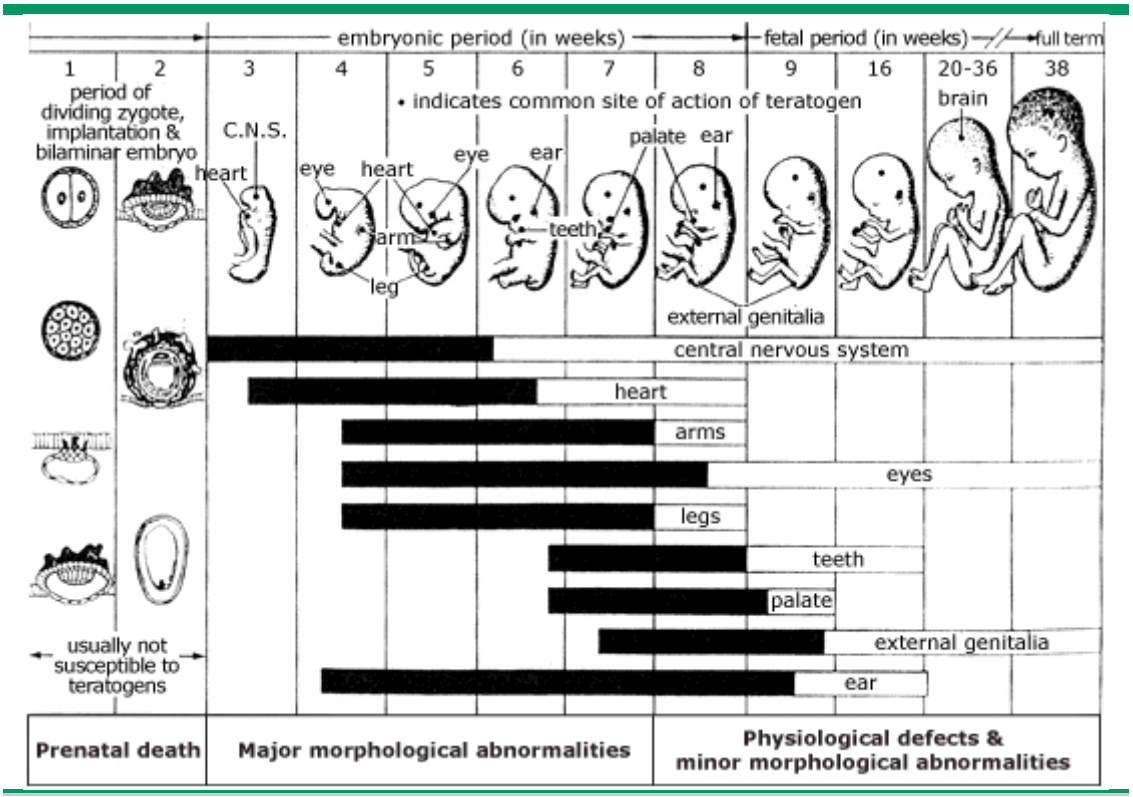
Topic 4791 Version 24.0

GRAPHICS

The developing fetus



The black bars represent the critical period during which development may be disrupted by a teratogen resulting in a major structural malformation. Cell differentiation occurs over a longer period (white bars); exposure during this period can result in minor structural malformations, growth restriction, or functional deficiency. Note, embryonic age is counted from fertilization, whereas menstrual age (ie, gestational age) is counted from the first day of the last menstrual period. Thus, an embryonic age of six weeks corresponds to a menstrual age (gestational age) of eight weeks. Embryonic weeks 1 to 8 are considered the embryonic period of development and are followed by the fetal period of development.

Graphic 56642 Version 3.0

Estimated average fetal radiation exposure from selected imaging studies performed on the mother during pregnancy

Procedure	Fetal dose (mrad) for an average study
Chest radiograph (PA and lateral)	<1
Abdominal plain film	200 to 300
Intravenous pyelogram	400 to 900
Barium enema	700 to 1600
Cervical spine radiograph	<1
Dorsal spine radiograph	<1
Lumbar spine radiograph	400 to 600
Lumbosacral area	200 to 600
Upper GI series	50 to 400
Hip and femur radiograph	100 to 400
Dental radiograph	0.01
Mammography	Negligible
Cerebral angiography	<10
CT of the chest	30
CT of the abdomen	250
Perfusion lung scan with 99Tc	6 to 12
Ventilation lung scan	1 to 19
Pulmonary angiography via femoral route	221 to 374
Pulmonary angiography via brachial route	<50

PA: posterior-anterior; GI: gastrointestinal; CT: computed tomography; 99Tc: techniticum-99.

Data from:

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Graphic 75594 Version 6.0

Risk of childhood leukemia after in-utero exposure to radiation compared to other risk groups

Group	Approximate risk	Increase in risk above baseline
Identical twin of leukemic twin	1/3	1000
Irradiation-treated polycythemia	1/6	500
Bloom syndrome	1/8	375
Hiroshima survivors who were within 1000 meters of the hypocenter	1/60	50
Down's syndrome	1/95	30
Irradiation-treated ankylosing spondylitis	1/270	10
Siblings of leukemic children	1/720	4
Children exposed to in-utero pelvimetry	1/2000	1.5
US white children <15 years old	1/2800	1

Data from: Miller, RW. Epidemiologic conclusions from radiation toxicity studies. In: Late Effects of Radiation, Fry, RJM,Grahn, D, Griem, ML, et al (Eds). Taylor and Francis, London, 1970.

Graphic 67090 Version 1.0

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