Chapter-19

GESTATIONAL RADIATION RISKS AND PROTECTION

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19.1. INTRODUCTION

Pregnant women may be exposed to both non-ionizing and ionizing radiation due to necessary medical procedures, occupational exposure, or therapeutic interventions—sometimes even before they are aware of their pregnancy. Non-ionizing radiation includes modalities such as microwaves, ultrasound, radiofrequency waves, and other forms of electromagnetic radiation. Exposure to non-ionizing radiation is generally considered safe during pregnancy. For instance, ultrasonography is widely used and poses no significant risk to fetal development. In contrast, ionizing radiation—comprising high-energy particles and electromagnetic waves such as X-rays and gamma rays—has sufficient energy to remove tightly bound electrons from atoms, resulting in ionization. This process can cause biological damage if not adequately controlled. Ionizing radiation can harm cellular structures either directly, by breaking chemical bonds in DNA, proteins, and other critical biomolecules, or indirectly, by generating free radicals that subsequently damage cellular components [1] [2]. The biological effects of ionizing radiation are broadly categorized into deterministic and stochastic effects. Deterministic effects, also known as non-stochastic or tissue reactions, occur only after a specific threshold dose is exceeded. Once this threshold is surpassed, the severity of damage increases with the dose. These effects include tissue damage such as skin erythema, cataracts, and, in severe cases, developmental abnormalities in the fetus. Stochastic effects, on the other hand, are probabilistic in nature. They do not have a threshold dose and can occur at any level of exposure. These effects include carcinogenesis and heritable genetic mutations. Unlike deterministic effects, the severity of stochastic effects does not increase with dose; rather, the probability of occurrence rises. Exposure to ionizing radiation during pregnancy may lead to teratogenic (birth defects), mutagenic (genetic mutations), or carcinogenic (cancer-causing) effects depending on the dose and the developmental stage of the fetus at the time of exposure [3].

The embryo and fetus are particularly sensitive to radiation during certain critical periods of development, such as organogenesis and neurodevelopment. Every year, thousands of pregnant women are exposed to ionizing radiation. Unfortunately, a lack of understanding about radiation risks often leads to undue anxiety, and in some cases, unwarranted termination of pregnancy. Therefore, it is crucial to communicate accurate information about the actual risks involved. The primary goal of radiation protection during pregnancy is to limit fetal exposure to the lowest possible level—commonly referred to as the ALARA principle (As Low As Reasonably Achievable). Achieving this requires a collaborative effort between employers and healthcare providers to assess radiation risks thoroughly [4]. Pregnant employees working in radiological environments should be given appropriate work assignments and shielding to minimize accidental exposure or radionuclide ingestion. Careful planning and adherence to radiological safety protocols are essential to ensuring both maternal and fetal health during pregnancy.

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19.2. PRENATAL STAGES AND DEVELOPMENT

Prenatal development refers to the progressive stages a human being undergoes from the moment of conception to birth. This intricate process is marked by dynamic physiological and anatomical changes, and it is commonly divided into three distinct stages: the pre-embryonic, embryonic, and fetal stages. These stages correspond to specific developmental milestones and are further aligned with the three trimesters of pregnancy. The pre-embryonic stage, also known as the germinal stage, spans the first two weeks after fertilization. It begins when a sperm cell successfully fertilizes an ovum, resulting in the formation of a single-celled zygote. The zygote undergoes a series of rapid cell divisions called cleavage, eventually forming a multi-cellular structure known as the blastocyst. Around days 6 to 10 post-fertilization, the blastocyst implants itself into the lining of the uterus, marking the successful initiation of pregnancy [5]. Following implantation, the embryonic stage occurs between the third and eighth weeks of gestation. This is a critical phase characterized by rapid cellular differentiation and organogenesis—the formation of the primary organ systems. During this stage, the three germ layers (ectoderm, mesoderm, and endoderm) develop and give rise to various tissues and organs. The neural tube, which later becomes the brain and spinal cord, begins to form, along with the heart, limbs, and other essential structures. This period is considered highly sensitive to teratogens—external agents like drugs, infections, or radiation that can cause congenital abnormalities [6].

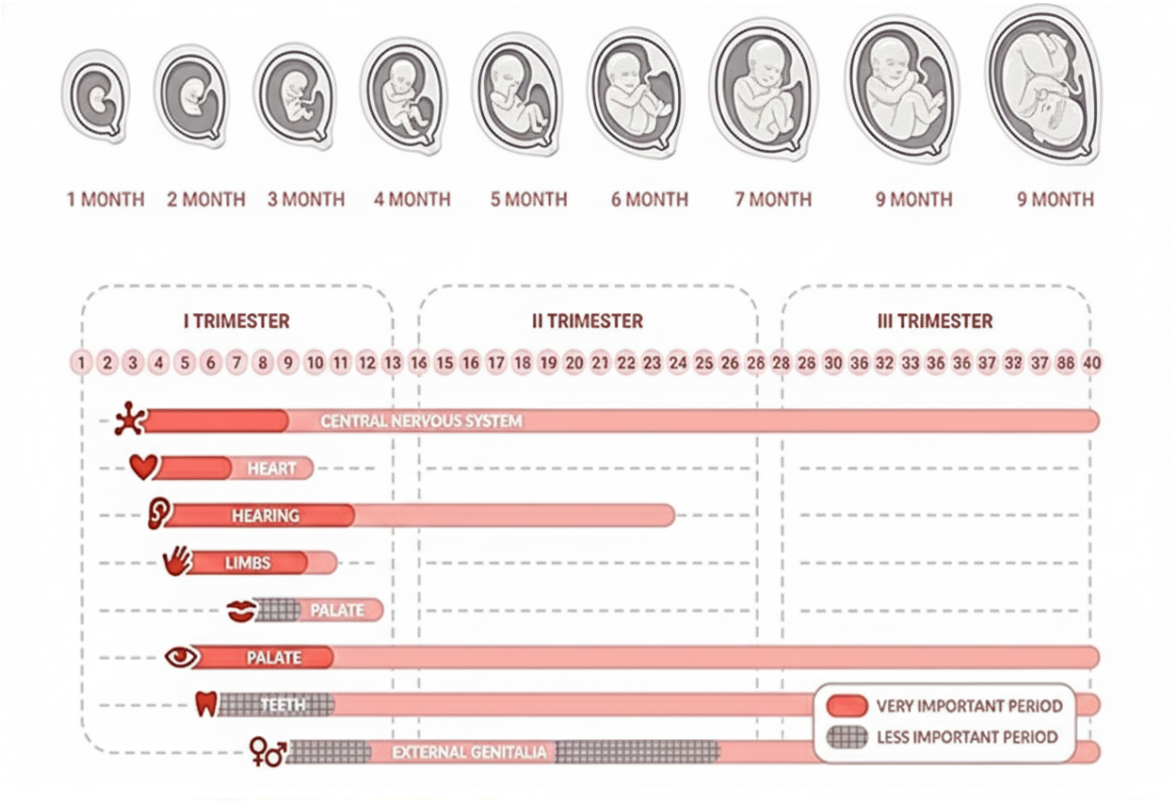

Fig: 19.1. Embryonic development Stages

The fetal stage, extending from the ninth week of gestation to birth (approximately the 40th week), is primarily a period of growth and functional maturation. Although the basic structures of major organs are established by the end of the embryonic phase, they continue to develop and refine their function throughout the fetal stage. The fetus gains weight rapidly, the skeletal system ossifies, and organ systems such as the respiratory and central nervous systems become increasingly sophisticated [7]. By the end of this stage, the fetus is typically capable of independent survival outside the womb with appropriate medical support. In clinical and practical terms, these developmental phases are often grouped into three trimesters. The first trimester, encompassing weeks 1 through

12, includes the entire pre-embryonic and embryonic stages and the beginning of the fetal period. It is during this trimester that the foundations of all body systems are laid, making it a crucial time for prenatal care and risk mitigation. The second trimester, from weeks 13 to 27, is marked by continued growth and the beginnings of fetal movement, which can often be felt by the mother (quickening). Ultrasound examinations during this period can typically determine the fetus's sex and assess structural development. The third trimester, from week 28 to birth, involves further growth, fat accumulation, and the final preparation of the body systems—especially the lungs and brain—for life outside the uterus [8].

Table: 19.1. First Trimester (Week 1 to Week 12)

Week 1-4	Week 5-8	Week 9-12
The fertilized egg (zygote) has undergone several cell divisions and has become a blastocyst. It implants into the uterine lining, and the placenta starts to form	The embryo's major organ systems begin to form, and the heart starts beating. The brain, spinal cord, eyes, ears, and limbs begin to take shape	The fetus has all its essential organs, and its external features become more distinct.

Table: 19.2. Second Trimester (Week 13 to Week 27)

Week 13-16	Week 17-20	Week 21-24	Week 25-27
The fetus continues to grow and develop. Its bones harden, and the skin becomes less transparent	The fetus's hearing develops, and gender may be identifiable during this stage through ultrasound imaging. The baby's skin is covered in a fine hair called lanugo	The fetus's lungs continue to develop, and it begins to practice breathing movements by inhaling and exhaling amniotic fluid. The baby's eyes open and close, and it can sense light	The fetus's nervous system develops further, and it starts to gain more body fat, giving it a more plump appearance. The fetus's brain continues to mature.

Table: 19.3. Third Trimester (Week 28 to birth)

Week 28-31	Week 32-35	Week 36-40
The fetus's organs continue to mature, and it gains more weight.	The fetus's bones are fully formed but still relatively soft and flexible. The baby's skin becomes less wrinkled as more fat accumulates under the skin.	The fetus is considered full-term from week 37 onwards. The baby's brain and lungs are fully developed, and it is ready for birth. Labor typically begins around the 40th week of pregnancy.

19.3. RADIATION EFFECTS ON THE EMBRYO AND FETUS

The biological response of the developing embryo and fetus to ionizing radiation is highly dependent on the stage of gestation at the time of exposure, the radiation dose, and the inherent sensitivity of developing tissues. The severity and nature of radiation-induced damage can vary from negligible to severe, ranging from miscarriage to congenital anomalies and increased cancer risk later in life [9].

- **During the preimplantation stage** (0–2 weeks' post-conception), the embryo consists of rapidly dividing undifferentiated cells. Exposure to high doses of radiation (>50–100 mGy) during this stage is most likely to result in spontaneous abortion or embryonic demise due to the "all-or-none" phenomenon, where the embryo either survives without lasting damage or fails to implant. However, if implantation is successful, subsequent development typically proceeds normally, regardless of the radiation dose.
- **In the organogenesis stage** (2–8 weeks), the embryo undergoes critical cellular differentiation and organ formation, making it highly susceptible to teratogenic effects. Radiation exposure during this period can

lead to intrauterine growth restriction (IUGR), structural malformations, and central nervous system (CNS) damage. The biological mechanisms behind these effects primarily include direct cell death and DNA damage that surpass the embryo's capacity for repair. Notable clinical manifestations include microcephaly, mental retardation, and anomalies of major organs.

- **Radiation effects during the fetal stage** (9 weeks to birth) are generally less severe than during earlier periods, but the risk of neurodevelopmental deficits and carcinogenesis persists. Between weeks 8 and 15, when neurogenesis and neuronal migration are most active, the central nervous system is especially vulnerable. Radiation doses exceeding 100 mGy during this window can result in irreversible cognitive impairments, mental retardation, and reduced head circumference [10].

The biological effects of prenatal radiation exposure can be categorized into three major types**:** spontaneous abortion, teratogenesis, and carcinogenesis.

- **Spontaneous abortion** is primarily a concern during the preimplantation phase. While natural pregnancy loss occurs in approximately 50% of all conceptions, radiation exposure above 50–100 mGy during the first two weeks of gestation may increase this likelihood. However, if implantation occurs, radiation is unlikely to cause harm.
- **Teratogenesis** refers to deterministic effects that arise when radiation exceeds a specific threshold dose, overwhelming the fetal repair mechanisms and leading to impaired tissue development or function. The period of greatest risk for teratogenesis is between 2 and 20 weeks of gestation, particularly weeks 8 to 15, when rapid brain development occurs. Radiation doses above 100 mGy during this stage have been associated with mental retardation, microcephaly, and IUGR.
- **Carcinogenesis**, unlike teratogenesis, results from stochastic effects—random mutations in DNA that can occur at any dose level without a threshold. These mutations may lead to the development of malignancies later in childhood. The risk is greatest in the early stages of gestation, with the relative risk of childhood cancer estimated to be approximately 3.19 in the first trimester, compared to 1.29 and 1.30 in the second and third trimesters, respectively. A fetal radiation dose of 50 mGy is associated with a twofold increase in the risk of fatal childhood cancer relative to unexposed populations.

19.3.1. Effects by Trimester

Radiation exposure during pregnancy is a subject of critical concern in medical, occupational, and public health contexts. As the developing embryo and fetus are particularly sensitive to ionizing radiation, understanding the timing, type, and dose of exposure is essential to prevent adverse biological effects. Radiological procedures, though vital in diagnosing and treating various conditions, can pose potential risks to pregnant women and their unborn children if not managed appropriately [11]. The nature and severity of radiation-induced effects largely depend on the stage of gestation at which exposure occurs, the radiation dose received, and whether the exposure is internal or external. These effects are typically categorized as deterministic (threshold-based and dose-dependent) or stochastic (probabilistic and potentially occurring at any dose). The embryo and fetus exhibit varying levels of radiosensitivity throughout prenatal development, with the greatest susceptibility occurring during the first trimester, particularly during organogenesis and neural development. This section explores the biological impacts of radiation on the embryo and fetus, categorized by trimester. It highlights key developmental milestones, associated risks of malformations, functional impairments, and carcinogenic outcomes, and outlines essential principles for radiation protection during pregnancy [12]. The goal is to promote awareness and guide safe practices in radiological procedures involving women of reproductive age, thereby minimizing fetal radiation exposure while maintaining diagnostic efficacy.

A. First Trimester: The first trimester represents the most vulnerable phase of fetal development, particularly in relation to the central nervous system (CNS) and organogenesis. Radiation exposure exceeding 50 milligray (mGy) during this period is associated with a heightened risk of severe congenital abnormalities or fetal demise. During the initial 12 hours' post-fertilization and throughout the blastogenesis phase (weeks 0–2), radiation may result in either implantation failure or normal development due to the "all-or-none" response. However, between weeks 2 and 7, when organogenesis occurs, radiation exposure significantly increases the

likelihood of structural anomalies and developmental malformations.

B. Second Trimester: This stage is marked by continued growth and maturation of fetal organs, with the CNS remaining especially radiosensitive. Between gestational weeks 8 and 25, neuronal development and migration are at their peak, rendering the fetus particularly susceptible to radiation-induced damage. Exposure to doses ranging from 100 to 200 mGy during this period can lead to major structural abnormalities such as anencephaly, spina bifida, encephalocele, and iniencephaly. The risk of neurodevelopmental impairment is especially pronounced during this critical window [13].

C. Third Trimester: As fetal development approaches completion, overall radiosensitivity decreases considerably. The likelihood of deterministic effects, such as congenital malformations or prenatal death, is significantly reduced. However, the potential for stochastic effects, including the induction of childhood malignancies, persists. Even at lower radiation doses, there remains a measurable risk of radiation-induced genetic mutations that may contribute to carcinogenesis later in life.

Table: 19.4. Radiation Effects Based on Developmental Stage and Dose

Developmental Stage	Gestational Age	Time After Conception	<50 mGy	50–100 mGy	>100 mGy
Blastogenesis	0–2 weeks	Before conception	None	None	None
	3–4 weeks	1–2 weeks	None	Likely none	Spontaneous abortion might occur
Organogenesis	5–10 weeks	3–8 weeks	None	Potential biological effects not clinically detectable	Congenital malformations may occur; risk increases with dose
Early Fetogenesis	11–17 weeks	9–15 weeks	None	Potential biological effects not clinically detectable	Increased risk of IQ reduction or mental retardation; severity increases with dose
Mid Fetogenesis	18–27 weeks	16–25 weeks	None	None	IQ loss unlikely at typical diagnostic doses
Late Fetogenesis	>27 weeks	>25 weeks	None	None	None at average diagnostic dose levels

19.3.2. Oncogenic Effects of Ionizing Radiation During Gestation

The oncogenic (cancer-inducing) effects of ionizing radiation exposure during gestation have been a subject of ongoing study and debate. While the lifetime risk of developing cancer following in utero irradiation is generally considered to be lower than the risk associated with postnatal exposure, it still represents a significant concern, particularly at higher doses or during certain stages of fetal development. Currently, there is limited definitive data indicating which specific stages of pregnancy may be most susceptible to the oncogenic effects of radiation. However, animal studies suggest that the later stages of fetal development may be more vulnerable to radiation-induced carcinogenesis. Epidemiological studies have shown that in utero exposure to radiation doses of 0.01 to 0.02 Gy (10 to 20 mGy or 1 to 2 rad) can increase the risk of childhood cancers, particularly leukemia, by a factor of 1.5 to 2. For example, exposure to 10 mGy (0.01 Gy or 1 rad) in the neonatal period has been associated with a 0.3% to 0.7% risk of developing childhood malignancies, compared to a baseline risk of 0.2% to 0.3% in unexposed populations.

However, it is important to note that the carcinogenic potential of low-level radiation remains controversial. Some studies have found that non-exposed siblings of irradiated children also exhibit a higher incidence of leukemia, suggesting that genetic or environmental factors may play a role alongside radiation exposure. Furthermore,

children exposed in utero during the Hiroshima and Nagasaki atomic bombings demonstrated only a minimal increase in cancer risk, further complicating the assessment of low-dose radiation effects during gestation [14].

19.4. PROTRACTION AND FRACTIONATION OF RADIATION EXPOSURE

Protraction and fractionation are two fundamental concepts in radiobiology that describe how the delivery of ionizing radiation over time can influence its biological effects, especially in sensitive populations such as pregnant women and developing fetuses. These principles play a critical role in assessing the potential risks associated with diagnostic and therapeutic radiation exposure during pregnancy [15].

- **Protraction** refers to the continuous or extended exposure to low-dose ionizing radiation over a prolonged period. Unlike acute or single-dose exposures, protracted exposures allow the body more time to repair cellular damage, thereby reducing the severity of radiation-induced effects. Common examples of protracted radiation exposure include cosmic radiation encountered during frequent or long-duration air travel, certain occupational exposures in the medical or nuclear industries, and internal contamination from radionuclides that have long biological or physical half-lives. In such cases, the gradual accumulation of radiation dose gives fetal tissues the opportunity to activate repair mechanisms, lowering the risk of acute tissue damage or developmental abnormalities.
- **Fractionation** refers to the division of the total radiation dose into multiple smaller doses administered intermittently over a defined time period. This is often observed in clinical settings, such as during the course of radiation therapy, where treatment is delivered in daily fractions over several weeks. Diagnostic imaging procedures, such as multiple X-rays or CT scans performed over hours or days, also represent a form of fractionated exposure. Fractionation allows normal tissues, including those of the developing embryo or fetus, to undergo partial recovery between radiation sessions. This reduces the likelihood of cumulative cellular injury and helps to preserve normal developmental processes, especially during critical periods of fetal growth.

These two exposure patterns protraction and fractionation are particularly significant when evaluating radiation risks during pregnancy. For instance, in scenarios where a pregnant patient receives radiation therapy for cancer located outside the abdominal or pelvic region, such as in breast cancer treatment, the embryo or fetus may still be subjected to incidental radiation doses. In such cases, even though the fetal dose might be low—ranging from 0.01 to 0.30 Gy per session the biological effects cannot be ignored, especially when considering repeated exposure over time. The distribution of these low doses across multiple sessions, rather than being delivered all at once, can influence the extent of biological damage and must be carefully considered in risk assessments. Assessing the reproductive and developmental risks under such circumstances requires a nuanced approach that takes into account not only the cumulative radiation dose but also the timing of exposure relative to the stage of fetal development. The sensitivity of fetal tissues to radiation varies across gestation, with certain periods particularly during organogenesis and neurodevelopment being more vulnerable to radiation-induced injury. Therefore, understanding the modifying effects of protraction and fractionation is essential for accurately evaluating potential hazards and for guiding clinical decisions that aim to protect maternal and fetal health.

19.4.1. All-or-None Phenomenon

The "all-or-none" phenomenon is a foundational concept in the field of teratology, referring to the embryo's unique response to harmful exposures during the earliest stage of prenatal development—specifically, the pre-implantation and early blastogenesis period, which spans from conception to approximately the second week of gestation. According to this principle, exposure to teratogenic agents or harmful environmental factors during this critical window results in one of two possible outcomes: complete embryonic recovery with no lasting effects ("none") or embryonic lethality leading to spontaneous abortion ("all"). This binary response is largely attributed to the totipotency of embryonic cells during the initial stages of development. At this point, the embryonic cells have not yet begun to differentiate and retain the capacity to fully compensate for cellular loss by proliferating and replacing any damaged cells. As a result, low-level or sub-threshold exposure to radiation, drugs, or toxins during this phase typically does not result in malformations or permanent damage. In such cases, the pregnancy

is likely to proceed normally, and the developing embryo shows no signs of teratogenic injury—this constitutes the "none" outcome. Conversely, if the exposure is of a sufficiently high dose or intensity, it may damage all or most of the embryonic cells. Since cellular compensation is no longer possible in this scenario, the damage is irreparable, leading to embryonic demise and, ultimately, a failed implantation or early miscarriage—this is the "all" outcome. Importantly, because organogenesis has not yet commenced during this phase, structural malformations are not typically observed as a result of teratogenic exposure during this period. The all-or-none phenomenon holds significant clinical value in the context of genetic counseling, especially for women who may have been inadvertently exposed to potentially harmful substances (such as medications, alcohol, or diagnostic radiation) before confirming their pregnancy. Understanding this principle provides reassurance in many cases, as early exposures that fall below the threshold for embryonic death are unlikely to result in congenital anomalies. Nevertheless, careful evaluation of the timing, dosage, and nature of the exposure is crucial in determining the appropriate clinical response and follow-up.

19.4.2. Fetal Dose Estimation

Accurate estimation of fetal radiation dose is a critical consideration in the medical management of pregnant patients undergoing radiologic procedures. The period from conception to the first missed menstrual period—typically from day 14 to day 28 of the menstrual cycle—is referred to as the “all-or-none” phase of embryonic development. During this stage, the embryo is either unaffected by low-dose radiation or undergoes spontaneous abortion if the damage is severe. Therefore, if a radiologic examination is performed during this early phase, detailed fetal dose estimation is generally not warranted unless exposure is suspected to be high. However, beyond this initial two-week post-conception window, more careful evaluation is required. Pregnant patients may undergo necessary imaging or radiation-based procedures when the clinical benefit outweighs potential fetal risk. This is particularly relevant in emergent situations where the pregnancy is unknown or unavoidable exposure occurs. In such cases, it is considered best practice to involve a qualified medical physicist to perform a precise fetal dose assessment and guide patient counseling.

Radiologists and radiologic technologists are trained to optimize imaging protocols to minimize exposure in pregnant patients. In computed tomography (CT), for example, dose indexes such as the Volume CT Dose Index (CTDIvol) and Dose Length Product (DLP) are displayed in real-time when scan parameters are entered. These serve as indirect indicators of maternal exposure, and by extension, potential fetal exposure. Adherence to the ALARA (As Low As Reasonably Achievable) principle is essential, with careful consideration of scan technique, exposure parameters, and the anatomical positioning of the fetus in relation to the primary beam. While rough estimation methods are available—such as multiplying the effective milliampere-seconds (mAs) per pitch or using CTDIvol with conversion factors (e.g., 10.8 mGy/100 mAs)—these approaches provide only approximations and should not replace comprehensive dose calculations. The gold standard for fetal dose estimation involves using the patient’s specific geometry and scan parameters in a Monte Carlo simulation performed by a medical physicist. These simulations provide high accuracy and are vital in risk-benefit analyses, patient counseling, and medico-legal documentation. Prospective dose monitoring can also be implemented using physical dosimeters. Placing additional unused personnel dosimeters above and below the patient’s pelvic region during imaging can help estimate radiation levels received by the uterus and fetus.

This method not only helps in documenting actual exposure but may also assist clinicians in making informed decisions about further medical management or follow-up care. In the context of occupational radiation exposure, pregnant radiation workers who formally declare their pregnancy are issued a fetal dosimeter in addition to their standard whole-body dosimeter and/or thermoluminescent dosimeter (TLD) ring. The fetal dosimeter is worn at waist level to provide a more accurate representation of radiation exposure to the fetus. When using fluoroscopic or other high-radiation equipment, and wearing protective lead aprons, the fetal dosimeter should be worn beneath the apron at waist level, while the standard dosimeter is worn outside the apron at collar level. This positioning ensures accurate monitoring of both fetal and maternal radiation doses under varying shielding conditions.

19.4.3. Modality-Specific Dose Considerations

In the context of diagnostic radiology, it is generally accepted that if a radiologic examination is medically indicated, the risk to the mother from not conducting the procedure typically outweighs the potential risk to the fetus. Most diagnostic radiological procedures expose the fetus to relatively low levels of radiation, presenting no significant risk of fetal death, congenital malformation, or neurodevelopmental impairment. When the fetus is positioned within the primary x-ray beam, tailored imaging strategies should be employed to minimize fetal dose. If the uterus lies outside the field of view, the fetus is exposed only to scattered radiation, which results in minimal dose. However, when the uterus is included in the primary beam, the conceptus receives a higher dose of radiation, which is influenced by several factors: maternal body thickness (which determines the x-ray beam's path length), the projection angle (anteroposterior, posteroanterior, or lateral), the fetal depth from the skin surface, and the selected imaging parameters.

Fetal dose variability for a given examination can span a tenfold range depending on fetal positioning and technical factors. Generally, since fetal doses during standard diagnostic radiology procedures are well below 50 mGy, routine pregnancy testing is not required. However, in high-dose scenarios—such as fluoroscopic procedures involving the abdomen or pelvis (e.g., embolization)—a pregnancy test may be advisable depending on the patient's history and reliability. Clinical decision-making begins with determining whether the conceptus is within the primary x-ray field. If it is not, fetal risk is negligible, and the focus should be on optimizing diagnostic quality while minimizing exposure—using fewer images, precise collimation, and appropriate technique. In cases where the fetus is within the primary beam, the procedure's radiation burden must be assessed. Low-dose procedures, such as a single abdominal radiograph, may not require elaborate precautions, while high-dose examinations like fluoroscopy warrant detailed evaluation. Alternative imaging modalities that do not involve ionizing radiation (e.g., ultrasound or MRI) should be considered. When no alternative exists and the procedure cannot be deferred, a comprehensive analysis must include the gestational age, estimated fetal dose, clinical indication, and risks of delaying the examination. Radiation safety principles dictate that any unavoidable irradiation of the fetus should be performed with the utmost effort to minimize exposure.

Specific procedures such as chest radiography and pelvimetry deserve special consideration. The World Health Organization (1992) advises against routine chest radiography during pregnancy unless the regional prevalence of asymptomatic thoracic disease is high. Nevertheless, medically indicated chest, skull, or extremity imaging (excluding hips) is considered safe when performed with appropriate shielding and beam collimation. The most effective dose-reduction strategies include collimating the beam to a restricted region of interest, increasing the tube voltage (kVp), omitting the anti-scatter grid when feasible, and limiting the number of exposures. Fluoroscopic procedures involving the pelvis and abdomen—such as barium enemas—can deliver fetal doses ranging from 3 to 7 mGy with proper technique. Double contrast studies, due to prolonged fluoroscopy times, may double this dose. Failure to recognize a pregnancy before fluoroscopy may lead to prolonged exposure times and significantly increased fetal dose, potentially exceeding 50 mGy, especially with fluoroscopy times over seven minutes. For high-dose procedures, especially when the fetus is in the primary beam, documentation of technical factors is crucial for retrospective fetal dose assessment. Important variables include the use of a grid, kVp settings, dose rate, total fluoroscopy time, dose-area product, and beam geometry. For example, in pregnant patients with suspected distal ureteric stones, a diagnostic approach using a preliminary radiograph followed by a delayed image 10 minutes post-contrast may suffice instead of full intravenous urography, thereby reducing fetal exposure. Computed Tomography (CT) generally imparts higher radiation doses than conventional radiography. Fetal exposure during CT depends on factors such as proximity of the uterus to the scan region, patient thickness, fetal depth, and scan parameters. When the uterus is included in the scan range, fetal doses commonly range from 10 to 40 mGy. However, the tightly collimated x-ray beam and precise scan planning using scout images allow for targeted imaging that can avoid unnecessary exposure. For example, scanning only the kidneys rather than the entire abdomen and pelvis can significantly limit fetal radiation dose.

Routine fetal dose estimation is not necessary in diagnostic radiology unless the fetus is expected to be within the primary beam. Estimating fetal dose from pelvic fluoroscopy is more uncertain than estimation from conventional x-rays or CT due to variable exposure times and beam configurations. Despite the relatively low radiation burden from most diagnostic imaging, pregnant patients and healthcare providers may still express concern about fetal risks. This may lead to unwarranted deferral of necessary imaging or consideration of pregnancy termination. It is important to note that the threshold for radiation-induced malformations is generally accepted to be around 100 mGy; thus, the risk of teratogenesis from routine diagnostic procedures remains exceedingly low. For procedures such as maternal chest x-rays, where the conceptus lies outside the beam, individual fetal dose assessments are typically unnecessary. However, in high-dose examinations involving abdominal or pelvic regions, especially CT or fluoroscopy, it is advisable to engage a qualified expert to estimate the absorbed fetal dose and assess the associated risks. When technical factors such as x-ray energy are known, one can estimate fetal dose using the mean entrance skin exposure per image or by extrapolating from ovarian doses as a surrogate. These methods, although not as precise as Monte Carlo simulations, provide useful approximations when complete scan data is unavailable.

Table: 19.5. Estimated Fetal Radiation Dose from Common Diagnostic Radiologic Examinations

Examination Type	Procedure	Mean Fetal Dose (mGy)	Maximum Fetal Dose (mGy)
Conventional X-ray Examinations	Abdomen	1.4	4.2
	Chest	<0.01	<0.01
	Intravenous Urogram	1.7	10
	Lumbar Spine	1.7	10
	Pelvis	1.1	4.0
	Skull	<0.01	<0.01
	Thoracic Spine	<0.01	<0.01
Fluoroscopic Examinations	Barium Meal (Upper GI)	1.1	5.8
	Barium Enema	6.8	24
Computed Tomography (CT)	Abdomen	8.0	49
	Chest	0.06	0.96
	Head	<0.005	<0.005
	Lumbar Spine	2.4	8.6
	Pelvis	25.0	79.0

19.5. NUCLEAR MEDICINE AND FETAL RADIATION EXPOSURE

Nuclear medicine plays an essential role in modern diagnostic imaging by utilizing radiopharmaceuticals to study physiological processes and detect various pathological conditions. In most developed countries, diagnostic nuclear medicine examinations are predominantly conducted using short-lived radionuclides, particularly technetium-99m (^{99m}Tc). These radionuclides are preferred because of their relatively short physical and biological half-lives, which results in low radiation exposure to the patient, including the fetus in pregnant women. For radiopharmaceuticals that do not cross the placental barrier, fetal radiation exposure arises primarily from the distribution of the radioactive material in the maternal organs and tissues, thereby contributing to fetal dose through external irradiation. However, certain radionuclides have the ability to cross the placenta and may concentrate in specific fetal organs, posing a significant risk to fetal health. For instance, iodine isotopes such as iodine-131 (I-131) and iodine-123 (I-123) readily cross the placenta and accumulate in the fetal thyroid, potentially causing permanent thyroid damage or developmental defects. Similarly, some analogues of essential minerals or metabolites, such as radiostrontium (as a calcium analogue) and radiocaesium (as a potassium analogue), may have limited placental transfer but still present potential risks depending on their retention and uptake in maternal and fetal tissues.

When a nuclear medicine examination is considered for a pregnant patient, it is imperative that the clinical justification for the procedure be thoroughly evaluated. The examination should only be performed when it is essential for diagnosing or treating a medical condition that requires prompt intervention. In such cases, the potential benefit to the mother outweighs the radiation risk to the fetus. Prior to administration, efforts should be made to minimize fetal dose by reducing the administered activity of the radiopharmaceutical while maintaining diagnostic image quality. Additionally, patient history should be meticulously reviewed to determine the possibility of pregnancy, especially in adolescents, where pregnancy status may be uncertain or undisclosed. In order to avoid inadvertent fetal exposures, nuclear medicine departments should display clear advisory notices in multiple locations, particularly at patient registration and waiting areas, reminding patients to inform staff if they are or could be pregnant. The radiation dose to the fetus following nuclear medicine procedures can arise from two primary sources: internal exposure due to transplacental transfer and uptake of radiopharmaceuticals by fetal tissues, and external exposure due to radioactivity retained in maternal organs and body fluids. Certain radiopharmaceuticals, such as radiocolloids, are primarily retained in maternal tissues and do not cross the placenta, acting only as external sources of fetal irradiation. In contrast, radiopharmaceuticals like radioactive iodides cross the placenta freely and can concentrate in fetal tissues, resulting in internal fetal irradiation. The magnitude of the dose also depends on the rate of excretion of the radiopharmaceutical from the maternal body. For agents eliminated rapidly via the renal system, the maternal urinary bladder becomes a significant source of fetal radiation, especially in later stages of pregnancy when the fetus lies in close proximity to the bladder.

To reduce fetal radiation dose in such cases, several strategies can be employed. Maternal hydration and frequent voiding are effective in decreasing bladder residence time of the radionuclide, thereby lowering the dose to the fetus. In situations involving radiopharmaceuticals with gastrointestinal excretion pathways, the use of laxatives may be considered, although their effectiveness in reducing fetal dose is generally limited. Additionally, the total absorbed dose to the fetus can be minimized by employing smaller radiopharmaceutical doses and extending imaging acquisition times to compensate for reduced activity. When appropriate, the sequence of imaging procedures may also be altered to limit exposure. For example, in cases of suspected pulmonary embolism during pregnancy, it is common to perform a ventilation-perfusion (V/Q) lung scan. In standard practice, ventilation imaging precedes perfusion imaging. However, in pregnant patients, performing the perfusion scan first using ^{99m}Tc-macroaggregated albumin (MAA) can help avoid the ventilation scan if perfusion is normal, thereby reducing total radiation exposure. If ventilation imaging is required, using ^{133}Xe gas, which imparts minimal radiation dose to the fetus, is preferable to ^{99m}Tc-DTPA aerosol, which is absorbed and eliminated renally, contributing to fetal dose while in the maternal bladder. Special precautions must be taken when considering therapeutic nuclear medicine procedures, especially those involving high-dose radioiodine therapy (e.g., I-131), which is contraindicated during pregnancy due to its ability to cross the placenta and cause substantial fetal thyroid irradiation. The International Commission on Radiological Protection (ICRP) recommends that women avoid pregnancy until the residual radionuclide activity results in a fetal dose of less than 1 milligray (mGy). This recommendation is particularly relevant for radionuclides with long physical half-lives and extended biological retention, such as iron-59 (^{59}Fe) and selenium-75 (^{75}Se), which are used for metabolic and adrenal imaging, respectively. In such cases, pregnancy should be avoided for at least six to twelve months following the administration of these radiopharmaceuticals. Another area of concern involves radiation exposure to pregnant family members or caregivers who are in close contact with patients undergoing nuclear medicine procedures. Although some patients express concern about transmitting radiation to others, the exposure levels are typically negligible. For most diagnostic nuclear medicine procedures, the total radiation dose to an individual standing at a distance of 0.5 meters from the patient is estimated to range between 0.02 to 0.25 mGy, while at a distance of 1 meter, the dose decreases to approximately 0.05 to 0.10 mGy. These levels are far below thresholds for deterministic effects and do not pose a significant risk to pregnant individuals in the household.

19.5.1. Fetal Radiation Doses from Common Radiopharmaceutical Procedures

Understanding the fetal radiation exposure from various nuclear medicine procedures is essential for risk assessment and the safe management of pregnant patients. The radiation dose received by the fetus varies depending on the radiopharmaceutical used, the administered activity, and the stage of pregnancy—particularly

whether it occurs early or in the third trimester (approximately nine months gestation). One of the most commonly used radiopharmaceuticals, technetium-99m (^{99m}Tc), is involved in multiple diagnostic applications. In a standard bone scan using phosphate compounds with an administered activity of approximately 750 MBq, the estimated fetal dose ranges from 4.6 to 4.7 mGy during early pregnancy and reduces to about 1.8 mGy at nine months gestation. For lung perfusion scans using ^{99m}Tc-labeled macroaggregated albumin (MAA), a typical activity of 200 MBq results in a lower fetal dose, estimated at 0.4 to 0.6 mGy early in pregnancy and around 0.8 mGy at term. When conducting lung ventilation studies using ^{99m}Tc aerosols (such as DTPA), the administered activity is generally 40 MBq, leading to minimal fetal doses ranging from 0.1 to 0.3 mGy early on and approximately 0.1 mGy at nine months. In the case of thyroid scans using ^{99m}Tc-pertechnetate, an activity of 400 MBq can result in fetal doses between 3.2 to 4.4 mGy early in pregnancy, increasing slightly to about 3.7 mGy in late pregnancy. Red blood cell labeling procedures, often performed with 930 MBq of ^{99m}Tc, produce fetal doses ranging from 3.6 to 6.0 mGy in early pregnancy and around 2.5 mGy at nine months. For liver imaging with ^{99m}Tc-labeled colloids at 300 MBq, the fetal dose is relatively low, between 0.5 and 0.6 mGy early in gestation and about 1.1 mGy later in pregnancy. Similarly, renal imaging using ^{99m}Tc-DTPA with an activity of 750 MBq leads to relatively higher fetal doses—estimated between 5.9 to 9.0 mGy early on and about 3.5 mGy by full term.

For procedures involving gallium-67 (^{67}Ga), typically used in abscess or tumor imaging with an activity of 190 MBq, fetal doses are significantly higher, ranging from 14 to 18 mGy in early pregnancy and reaching up to 25 mGy at nine months due to the longer physical half-life and systemic retention of the radionuclide. Iodine-based radiopharmaceuticals also exhibit varying fetal dose profiles. Iodine-123 (^{123}I), when used for thyroid uptake studies at a dose of 30 MBq, results in a relatively low fetal dose of 0.4 to 0.6 mGy in early pregnancy and about 0.3 mGy at term. In contrast, iodine-131 (^{131}I), even at a small administered activity of 0.55 MBq for thyroid uptake studies, contributes around 0.03 to 0.04 mGy early in gestation and 0.15 mGy at nine months. However, when used in higher doses for metastatic thyroid imaging (approximately 40 MBq), ^{131}I can result in fetal doses ranging from 2.0 to 2.9 mGy early in pregnancy and escalating to about 11.0 mGy at full term. These data underscore the importance of carefully evaluating the necessity and timing of nuclear medicine procedures in pregnant patients. They also highlight the variability in fetal dose based on the specific radiopharmaceutical and its pharmacokinetic behavior. Consideration of gestational age, dose minimization strategies, and appropriate substitution of radiopharmaceuticals when feasible are essential for optimizing fetal safety during nuclear medicine imaging.

Table: 19.6. Fetal Dose from Common Radiopharmaceutical Procedures

Radiopharmaceutical	Procedure	Administered Activity	Early Pregnancy Dose	9-Month Dose
^{99m}Tc–Phosphate	Bone scan	750 MBq	4.6–4.7 mGy	1.8 mGy
^{99m}Tc–MAA	Lung perfusion	200 MBq	0.4–0.6 mGy	0.8 mGy
^{99m}Tc–DTPA aerosol	Lung ventilation	40 MBq	0.1–0.3 mGy	0.1 mGy
^{99m}Tc–Pertechnetate	Thyroid scan	400 MBq	3.2–4.4 mGy	3.7 mGy
^{99m}Tc–Labeled RBCs	Red blood cell study	930 MBq	3.6–6.0 mGy	2.5 mGy
^{99m}Tc–Colloid	Liver scan	300 MBq	0.5–0.6 mGy	1.1 mGy
^{99m}Tc–DTPA	Renal scan	750 MBq	5.9–9.0 mGy	3.5 mGy
^{67}Ga	Abscess/tumor imaging	190 MBq	14–18 mGy	25 mGy
^{123}I	Thyroid uptake	30 MBq	0.4–0.6 mGy	0.3 mGy
^{131}I	Thyroid uptake	0.55 MBq	0.03–0.04 mGy	0.15 mGy
^{131}I	Metastases imaging	40 MBq	2.0–2.9 mGy	11.0 mGy

19.6. GUIDELINES FOR IMAGING PREGNANT AND REPRODUCTIVE-AGE WOMEN

Each year, thousands of pregnant women undergo diagnostic imaging procedures involving ionizing radiation. Misconceptions about the potential risks of these examinations often cause undue anxiety among patients and radiologists, occasionally leading to the unnecessary termination of pregnancies. However, several established

guidelines and expert bodies provide clear recommendations on the use of imaging in pregnancy. The International Commission on Radiological Protection (ICRP) Publication 84 states that "prenatal doses from most properly conducted diagnostic procedures present no measurably increased risk of prenatal death, malformation, or impairment of mental development beyond the background incidence of these conditions." Similarly, the American College of Radiology (ACR) asserts that fetal radiation doses below 100 mGy are not a justifiable reason for terminating a pregnancy. The American College of Obstetricians and Gynecologists (ACOG) has issued a policy statement affirming that "X-ray exposure from a single diagnostic procedure does not result in harmful fetal effects." Specifically, exposures less than 5 rad (50 mGy) have not been associated with increased risks of fetal anomalies or pregnancy loss. Furthermore, the ICRP reiterates that fetal doses from correctly performed diagnostic procedures do not significantly elevate the risk of prenatal or postnatal mortality, developmental abnormalities, or intellectual impairment. The lifetime risk of cancer due to in utero exposure is assumed to be comparable to that associated with exposure during early childhood.

19.6.1. Screening for Pregnancy

Screening women of reproductive age for possible pregnancy prior to radiologic procedures involving ionizing radiation is essential to minimize the risk of unintended fetal exposure. Different protocols may apply depending on the anticipated radiation dose of the procedure—for example, an interventional pelvic procedure versus a routine chest radiograph. The actual frequency of unintended radiation exposure in early pregnancy is not well documented; however, studies have shown that up to 1% of women undergoing abdominal radiographs may be unknowingly pregnant during the first trimester, while another study in trauma patients reported an unidentified pregnancy rate of 0.3%.

- **Pregnancy Testing:** When pregnancy test results are available, they should be used judiciously. A positive result necessitates adherence to protocols for known pregnancies, and this information must be promptly communicated to the radiologist, except in emergency situations. Conversely, a negative test should not replace standard verbal or written screening procedures. If a patient fails to meet standard screening criteria—based on menstrual history or potential for pregnancy—the radiologist should be notified, and the date and outcome of any pregnancy testing should be documented. For procedures expected to deliver high fetal doses, pregnancy testing should ideally be conducted within 72 hours before the examination, unless delayed by medical urgency.
- **Patient Interview and Questioning:** Before conducting any imaging examination, all female patients of reproductive age—typically between 12 and 50 years—should be asked about the possibility of pregnancy. This screening may be conducted through standardized forms or direct questioning by the technologist. Employing standardized forms ensures uniformity and provides documentation for the medical record. Guidelines such as the 28-day or 10-day rule can aid in determining appropriate timing for imaging, particularly when early-stage pregnancy is suspected.
- **Patients Who Are Minors:** Special considerations apply to minor patients. In most jurisdictions, minors may consent to pregnancy testing without parental involvement. The Health Insurance Portability and Accountability Act (HIPAA) protects the confidentiality of minors' health information in specific contexts—such as when they are legally authorized to consent to care, when care is provided without parental consent, or when the parent has agreed to a confidential relationship between provider and minor. Radiologic technologists are thus permitted to inquire about pregnancy status directly with the minor in a private setting. If preferred privacy measures are declined, a backup policy may include having the radiologist personally interview the minor before the examination. If responses indicate possible pregnancy, informed consent must be obtained for a pregnancy test—potentially from both the minor and, where legally required, a parent or guardian. The pregnancy test order may be initiated under the radiologist's protocol. If consent is withheld, the radiologist must be informed before proceeding, and the refusal should be thoroughly documented. The pregnancy test may be administered by the referring physician, emergency department, or radiology department. This approach minimizes potential distress and provides a rigorous method of screening prior to high-dose examinations.
- **Proceeding with the Examination**: If the patient reliably answers screening questions and no indication of pregnancy is established, the examination may proceed. If pregnancy is confirmed, the patient must be

informed promptly. Although it is preferable for the referring physician to convey this information, the radiologist must ensure the patient is appropriately counseled if necessary. Together, the patient, radiologist, and referring clinician must determine the most suitable imaging approach to maintain the radiation dose to the conceptus "As Low As Reasonably Achievable" (ALARA). In critical emergencies where pregnancy status cannot be verified, a notation should be made in the patient's medical record indicating that the standard verification protocol was waived due to urgency. The radiologist must document the rationale and the physician who authorized the waiver.

19.6.2. Imaging the Pregnant Patient

Counseling and Informed Consent: Counseling and obtaining informed consent from a pregnant patient prior to radiologic imaging is essential for ensuring she has a realistic and accurate understanding of the potential risks and benefits to both herself and the developing fetus. The goal is to provide balanced information in a reassuring, accessible manner, thereby reducing anxiety and facilitating informed decision-making. It is advisable to use simple, positive language that helps the patient place the risk in context. For instance, rather than stating that there is a chance the child could develop cancer, a more supportive and statistically honest approach would be to emphasize that the risk is minimal and that the probability of the child being healthy remains nearly the same as that of any other child. Radiation dose is a complex and abstract concept, often difficult to grasp for patients and even some clinicians. One effective method of explanation is comparing the dose to natural background radiation received over a year. Some institutions also use comparisons to everyday activities to contextualize risk. To confirm the patient's understanding, providers should ask the patient to acknowledge key points and, if appropriate, explain the information back in her own words.

Preplanning for Imaging: Optimal patient care involves preplanning and the development of tailored imaging protocols for pregnant patients. It is essential to establish written, evidence-based protocols in advance rather than making last-minute, non-standard adjustments during the procedure. If the imaging is expected to require fetal dose estimation, technical details such as radiographic parameters, dose-area product (kerma area product), and cumulative air kerma should be documented. Alternatively, personnel dosimeters may be used to estimate pelvic exposure. The most effective strategy to minimize radiation exposure is early communication with the referring physician to assess the necessity and justification of ionizing imaging. Institutions should also develop pre-established guidelines for imaging common acute conditions during pregnancy, which can expedite patient management while maintaining radiation safety.

Managing Patients Found to Be Pregnant Post-Exposure: If a woman is found to be pregnant after undergoing a radiologic examination involving ionizing radiation, proper counseling must be conducted to provide an objective assessment of potential risks. In most cases, these risks are extremely low and well within accepted thresholds of safety in pregnancy. It is critical to avoid unnecessarily alarming language. Rather than simply stating that the fetus may face a risk of developing cancer, clinicians should reassure the patient that the likelihood of an adverse outcome is very small and that most children in similar situations are born healthy. Accurate risk assessment requires key details, including the gestational age at the time of exposure and a reasonable estimate of the conceptus dose. Often, such exposures occur during early pregnancy, when the embryo or fetus is at its most vulnerable stage. Therefore, establishing the date of conception is fundamental to determining any potential risk.

Patients Becoming Pregnant After Imaging: There is no evidence of heritable genetic effects from diagnostic radiation exposure occurring prior to conception. Thus, patients who become pregnant after receiving radiologic exams do not require additional monitoring or intervention due to the previous exposure. The recommendation for gonadal shielding during imaging procedures is a population-level precaution, intended to safeguard against theoretical cumulative effects in the gene pool, not because of any proven individual risk.

Patients Exposed Within the First Two Weeks Post-Conception: The first 10 to 14 days following conception is considered a "all-or-none" period, where exposure to radiation may result in the loss of the conceptus or no effect at all. However, diagnostic procedures typically deliver doses well below the threshold associated with induced pregnancy loss (50 mGy). Notably, even among women who are not exposed to radiation, spontaneous pregnancy loss occurs in approximately 50% of conceptions during this period, often presenting as a delayed or missed period without the woman knowing she was pregnant. Even higher dose procedures such as fluoroscopy of the pelvis, CT scans, or multiple pelvic X-rays rarely deliver doses that would exceed the 50–100 mGy

threshold considered potentially harmful. In documented cases of such exposures during this early developmental stage, outcomes have overwhelmingly been normal. Therefore, no specific medical intervention is recommended, and the standard advice is for the woman to continue routine prenatal care.

19.6.3. Imaging Considerations: 2–15 Weeks of Pregnancy

Radiologic Procedures Outside the Abdomen and Pelvis: Between 2 and 15 weeks post-conception, the gestational period becomes particularly sensitive to radiation, making dose estimation and management critical. When diagnostic radiologic procedures are performed on areas outside the abdomen and pelvis such as the head, neck, chest, and extremities the conceptus is exposed only to scattered radiation, which results in extremely low radiation doses. Under standard practices involving appropriate beam collimation and patient positioning, direct exposure of the conceptus is effectively avoided. Therefore, in routine cases, the dose delivered is negligible and poses no significant risk to fetal development. Any scenario involving notable exposure would likely result from highly unusual or improperly managed imaging conditions.

Radiologic Procedures of the Abdomen and Pelvis: In contrast, procedures involving the abdomen or pelvis have a greater potential to expose the conceptus to direct radiation. Nevertheless, for typical diagnostic examinations that are well-managed and appropriately planned, the absorbed dose remains well below thresholds known to cause teratogenic effects. While there may be a small increase in the theoretical risk of childhood cancer, this level of risk is not sufficient to justify any medical intervention. Abdominal and pelvic fluoroscopy can result in higher radiation doses compared to standard radiography, but rarely exceed the threshold of 100 mGy associated with developmental abnormalities. CT examinations of the abdomen and pelvis similarly deliver relatively higher doses, typically ranging from 20 to 35 mGy for a single-phase study under optimal conditions. These doses remain below the level of concern and generally do not warrant intervention. However, in instances involving multiple CT scans or more complex fluoroscopic studies, a dose assessment performed by a qualified medical physicist is advisable prior to counseling the patient. For conceptus doses below 100 mGy, no medical intervention is recommended, as these levels are not associated with detectable developmental effects. At doses exceeding 100 mGy, the risk of developmental abnormalities—including growth retardation, microcephaly, and cognitive impairment—begins to increase, although it remains relatively low until exposure surpasses 150 to 200 mGy.

Radiologic Considerations Beyond 15 Weeks Post-Conception: For pregnancies beyond 15 weeks post-conception, the conceptus is more resilient to radiation-induced developmental effects. At this stage, concern for teratogenic effects such as central nervous system defects arises only at doses exceeding 200 mGy—levels far beyond those encountered in conventional diagnostic imaging. For all routine imaging examinations, including abdominal and pelvic CT scans, the primary concern becomes the potential long-term carcinogenic risk rather than structural abnormalities. Even for one of the higher dose procedures, such as CT of the abdomen and pelvis, the delivered dose typically ranges between 20 and 35 mGy. These values fall well below the threshold for developmental damage and do not necessitate any medical intervention. Accordingly, the only measurable risk in this later stage of pregnancy from diagnostic imaging is a minor increase in the lifetime risk of cancer, which remains too small to alter clinical management or require interruption of standard obstetrical care.

19.6.4. Management of Pregnant Staff in Radiology

The management of occupational radiation exposure in pregnant workers is guided by strict regulations to protect the developing fetus from potential harm. The National Council on Radiation Protection and Measurements (NCRP) recommends that the total dose equivalent to the embryo or fetus during the entire pregnancy should not exceed 500 millirem (mrem), as stated in NCRP Report No. 53. Furthermore, NCRP Report No. 91 advises that, once pregnancy is declared, the dose should not exceed 50 mrem in any single month. These limits aim to prevent significant radiation-induced effects on fetal development. Similarly, the U.S. Nuclear Regulatory Commission (NRC), through 10 CFR 20.1208, mandates that the cumulative fetal dose must remain below 500 mrem for declared pregnant radiation workers and that dose distribution throughout the pregnancy should be as uniform as possible to avoid substantial monthly variations. The fetal dose is calculated as the sum of the external deep dose equivalent to the mother and the dose from any incorporated radionuclides affecting either the fetus or the mother. Upon confirmation of pregnancy, a radiation worker should promptly notify her department head or supervisor as

well as the Radiation Safety Officer (RSO). This declaration allows for timely assessment and implementation of appropriate radiation safety measures. The RSO may issue specific recommendations or impose duty modifications to ensure that fetal dose limits are not exceeded. Pregnant employees can continue working in environments where there is a minimal risk of radiation exposure, provided they strictly follow safe radiation practices. However, job assignments with a higher likelihood of significant radiation exposure, either external or internal, should be avoided to protect the fetus from undue risk.

Declared pregnant radiation workers are issued a special fetal dosimeter in addition to their standard dosimeter. The fetal dosimeter must be worn at the waist level, beneath any protective lead apron if one is used. When fluoroscopy or similar procedures are performed, the standard dosimeter should be placed outside the lead apron at the collar level, while the fetal dosimeter remains underneath the apron near the fetus. Proper placement and usage of these dosimeters are essential to accurately monitor exposure and ensure safety. To reduce potential fetal exposure, pregnant staff should avoid handling large quantities—greater than 1 millicurie—of unbound radioiodine (NaI), as the fetal thyroid gland is particularly sensitive to radiation. Prolonged fluoroscopic procedures should be limited whenever possible, and lead protective garments must always be worn. These garments typically attenuate 95–99% of scattered radiation, making the use of multiple layers of shielding unnecessary and potentially burdensome. Many institutions provide specially designed maternity lead aprons that offer increased abdominal protection with a total of up to 1.0 mm lead equivalence.

The biological effects of fetal radiation exposure depend significantly on the absorbed dose. Prenatal exposures below 500 mrem are not associated with observable health effects and are generally considered safe. Exposures between 500 and 5,000 mrem remain below occupational limits and are not linked to developmental abnormalities, although there may be a slight theoretical increase in long-term cancer risk. Doses exceeding 5,000 mrem are extremely rare under standard safety protocols, but such high exposures could potentially lead to more serious outcomes, such as reduced intelligence, growth retardation, or other late-onset effects. According to International Commission on Radiological Protection (ICRP) Publication 84, termination of pregnancy is not justified for fetal doses below 100 milligray (mGy) based solely on radiation risk. For exposures between 100 and 500 mGy, decisions should consider individual clinical and social circumstances, while fetal doses exceeding 500 mGy may result in significant developmental harm depending on the dose level and gestational age.

End of Chapter

REFERENCES

1. Nguyen CP, Goodman LH. Fetal risk in diagnostic radiology. Semin Ultrasound CT MR. 2012;33(1):4-10. doi:10.1053/J.SULT.2011.09.003
2. Tirada N, Dreizin D, Khati NJ, Akin EA, Zeman RK. Imaging pregnant and lactating patients. Radiographics. 2015;35(6):1751-1765. doi:10.1148/RG.2015150031
3. Brent RL. Protection of the gametes embryo/fetus from prenatal radiation exposure. Health Phys. 2015;108(2):242-274. doi:10.1097/HP.0000000000000235
4. Kumar R, Jesus O De. Radiation Effects On The Fetus. Stat Pearls. Published online February 12, 2023. Accessed August 16, 2023. https://www.ncbi.nlm.nih.gov/books/NBK564358/
5. Adam MP. The all-or-none phenomenon revisited. Birth Defects Res A Clin Mol Teratol. 2012;94(8):664-669. doi:10.1002/BDRA.23029
6. Tirada N, Dreizin D, Khati NJ, Akin EA, Zeman RK. Imaging Pregnant and Lactating Patients. Radiographics. 2015;35(6):1751-1765. doi:10.1148/RG.2015150031
7. Sensakovic WF, Royall I, Hough M, Potrebko P, Grekoski V, Vicenti R. Fetal Dosimetry at CT: A Primer. Radiographics. 2020;40(4):1061-1070. doi:10.1148/RG.2020190166
8. https://www.acr.org/-/media/acr/files/practice-parameters/pregnant-pts.pdf
9. McCollough CH, Schueler BA, Atwell TD, et al. Radiation exposure and pregnancy: When should we be concerned? Radiographics.
10. Annals of the ICRP Pregnancy and Medical Radiation. doi:10.1177/ANIB_30_1
11. ACR American College of Radiology. ACR-SPR practice parameter for imaging pregnant or potentially pregnant adolescents and women with ionizing radiation;
12. ACOG Committee on Obstetric Practice. Guidelines for diagnostic imaging during pregnancy (2004) ACOG Committee opinion no. 299, September 2004 (replaces no. 158, September 1995). Obstet Gynecol 104:647651 - Google Search. Accessed August 17, 2023.
13. ICRP International Commission on Radiological Protection. The 2007 recommendations of the International Commission on Radiological Protection;
14. Tomà P, Bartoloni A, Salerno S, et al. Protecting sensitive patient groups from imaging using ionizing radiation: effects during pregnancy, in fetal life and childhood. Radiologia Medica. 2019;124(8):736-744. doi:10.1007/S11547-019-01034-8
15. Mossman KL, Hill LT. Radiation risks in pregnancy. Obstet Gynecol 1982;60:237-242 - Google Search. Accessed August 17, 2023.