# Review Safety of diagnostic imaging in pregnancy. Part 1: X-ray, nuclear medicine investigations, computed tomography and contrast media

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## Key content:

- The safety of diagnostic imaging in pregnancy is a real concern.
- In general, X-rays and computed tomography scans are unlikely to cause deterministic effects in an individual pregnancy.
- Apart from the adverse effect of iodine on the fetal thyroid gland, common nuclear medicine investigation procedures are unlikely to involve teratogenic fetal doses.
- Iodinated agents should be avoided in pregnancy.
- It is recommended that paramagnetic contrast agents used with magnetic resonance imaging are only considered in pregnancy if absolutely necessary.

## Learning objectives:

- To understand the principles, diagnostic value and safety of various diagnostic modalities using ionised radiation, at different stages of pregnancy.
- To choose the most appropriate imaging tool for various medical conditions in pregnancy.
- To be able to counsel pregnant women and provide them with accurate information about the safety of various diagnostic imaging modalities.

## Ethical issues:

- Physicians should carefully weigh the risks and benefits of any radiographic procedure and include the mother in the decision-making process whenever possible.

Keywords angiography / fetal growth restriction / intravenous pyelography / ionising radiation / miscarriage / ventilation–perfusion lung scanning

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# Introduction

The safety of diagnostic imaging during pregnancy is a significant concern for all clinicians. Understanding the principles, diagnostic value and safety of imaging to the fetus and the mother, and of various diagnostic modalities at different stages of pregnancy, is essential to select the most appropriate imaging modality. We discuss the safety and value of the imaging methods available, including conventional X-ray, intravenous pyelography, ventilation–perfusion (V-P) lung scanning, angiography and computed tomography (CT), and the safety of contrast media in diagnostic procedures in pregnancy.

# Ionising radiation and X-rays

Ionising radiation (which can be either particle or electromagnetic), consists of individual particles or photons which carry enough energy to ionise an atom or molecule by completely removing an electron from its orbit. X-ray is a form of electromagnetic radiation with very high frequency and energy; it lies between ultraviolet and gamma radiation on the electromagnetic spectrum and has a very short wavelength: around $10^{-7}$ to $10^{-10}$ m (**Figure 1**). X-rays were accidentally discovered in 1895 by German physicist Wilhelm Roentgen, who was awarded the first Nobel Prize in Physics for his discovery in 1901.

## Units of radiation

Radioactivity is measured in becquerel (Bq) per second; 1 Bq is equal to one disintegration per second. It is also measured in curie (Ci), named after Madam Curie, a Polish scientist who was awarded the Nobel Prize twice: in physics in 1903 and chemistry in 1911. Ionising radiation is measured in rad, gray, sievert and rem. The rad is a unit of radiation dose; it has been superseded by the gray (Gy). Rads are often converted to units of rem or sievert (Sv) by multiplication with quality factors to account for biological damage produced by different forms of radiation. The quality factor for X-rays, gamma and beta radiation is 1 (**Box 1**).

## Effects of ionising radiation

Much of our information regarding the effect of radiation on humans has come from study of the atomic bomb survivors who were irradiated with high doses while *in utero* in Nagasaki and Hiroshima, Japan.[1–3] Ionising radiation can lead to deterministic effects, for which there is a threshold dose below which clinically manifest effects are not observed. The higher the dose is above the threshold, the more severe are the effects.[4,5] Deterministic effects include lethal effect (miscarriage); diminished cell division (fetal growth restriction); mental impairment and microcephaly; and teratogenic effects (fetal malformation). On the other hand, stochastic effects of radiation are those which have their origins in the probability of induction of damage to single cells in tissues, for which there is believed to be no dose threshold. These effects include carcinogenic and mutogenic effects. All these effects are related to the stage of pregnancy at which exposure occurred.

The commonest teratogenic effects of exposure to high dose radiation are central nervous system changes. The risk of microcephaly and severe mental retardation with high exposure begins at 10 weeks of gestation. This risk is greatest at 10–17 weeks, with less risk at 18–27 weeks. There is no proven risk before 10 weeks or after 27 weeks (**Table 1**) even with doses exceeding 500 mGy.[6] Furthermore, a non-threshold, linear, dose-related association between severe mental retardation and radiation has been found following exposure during weeks 10–17 of gestation,[4,7,8] so that even very low doses cause a slight increase in mental retardation incidence. This trend reaches 40% at 100 rad (1000 mGy), although it is not statistically significant at doses generated by diagnostic radiographs.[7] Nevertheless, until more data are available delineating potential fetal risk, it is prudent to delay non-urgent radiographs during the sensitive period of 10–17 weeks of gestation.

The accepted background cumulative dose of ionising radiation during pregnancy is 5 rad (50 mGy), which is much more than the exposure dose of most of the diagnostic radiological examinations.[9] Current evidence suggests that there is no increased risk of major malformations, growth restriction or miscarriage from radiation doses of <5 rad (50 mGy), compared with background risks in non-exposed foetuses, which are 3%, 4%, and 15% respectively.[10,11] There is also evidence that gross congenital malformations would not be increased in a human pregnant population exposed to a dose of <20 rad (200 mGy), which is considered the threshold dose.[12,13] A dose of >250 mGy may be associated with a 0.1% risk of fetal malformation.[14] However, microcephaly, microphthalmia, genital and skeletal malformations, cataracts and small for gestational age have been clearly observed in human embryos and fetuses exposed to >1000 mGy.[4]

**Figure 1**
**Electromagnetic radiation spectrum (wavelengths in metres; non-linear scale)**

| Radio waves | | Microwaves | | Infrared | | Light | Ultraviolet | X-rays | | | Gamma rays | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $10^{3}$ | 10 | 1 | 0.1 | $10^{-2}$ | $10^{-3}$ | $10^{-4}$ | $10^{-5}$ | $10^{-6}$ | $10^{-7}$ | $10^{-8}$ | $10^{-9}$ | $10^{-12}$ | $10^{-16}$ |

**Box 1**
**Measurements of ionising radiation**

| | Radioactivity | Radiation absorbed dose | Radiation effective dose |
|---|---|---|---|
| **Definition** | The activity of the radioactive material refers to the rate of its transformation or its decay | Amount of energy deposited per kg of tissue | Amount of energy deposited per kg of tissue normalised for biological effectiveness |
| **Units** | Becquerel (Bq) per second<br>1 Bq means one disintegration per second | Rad = 1000 mrad | Rem = 1000 mrem |
| | Curie (Ci) = 1000 mCi | Gray (Gy) =1000 mGy = 100cGy | Sievert (Sv) = 1000 mSv |
| | 1 Curie = $3.7 \times 10^{10}$ Bq | Gy = 100 rad | Sv = 100 rem |

For X-rays and gamma and beta radiation, 1 rad = 1 rem

**Table 1**
**Possible effects of acute doses of radiation and estimated threshold doses.[53] Modified with permission from the New Zealand National Radiation Laboratory**

| Gestational age | Possible effect | 1 mGy | 10 mGy | 50 mGy | 500 mGy | Threshold dose (mGy) |
|---|---|---|---|---|---|---|
| Up to 1 week | Miscarriage[a] | Nil | Nil | Nil | Possible | 100[47] |
| 2–6 weeks | Miscarriage | Nil | Nil | Nil | Possible | 250–500[47] |
| | Gross malformations | Nil | Nil | Nil | Possible | 200[47] |
| 10–17 weeks | Mental retardation | Nil | Nil | Nil | 20% | None |
| | IQ score decline | – | – | – | 15 points | Non-threshold |
| | Gross malformations | Nil | Nil | Nil | Possible | 500[47] |
| 18–27 weeks | Mental retardation | Nil | Nil | Nil | 5% | 120[5] |
| | IQ score decline | – | – | – | 4 points | 120[5] |
| Throughout pregnancy | Fetal growth restriction[b] | Nil | Nil | Nil | Possible | 200–250[48] |
| | Childhood cancer[c] | 0.002% | 0.02% | 0.1% | 1% | None |
| | Fatal adult cancer[c] | 0.006% | 0.06% | 0.3% | 3% | None |

[a]There is no threshold at day 1
[b]The most sensitive stage is at 3–10 weeks of gestation
[c]If we accept the controversial concept of the carcinogenic effect of ionising radiation at these small doses

The association of *in utero* diagnostic radiological exposure with subsequent occurrence of malignancy, particularly childhood leukaemia, has been a subject of great controversy over the last 40 years.[15,16] Such malignancy is a stochastic effect which is due to unrepaired or misrepaired DNA damage in a single cell or number of cells. Earlier studies[17–19] and meta-analyses[15,18,20,21] reported that *in utero* radiological exposure was associated with a 40% elevated risk of childhood acute lymphocytic leukaemia. For example, the background rate of leukaemia in children is about 3.6 per 10 000;[22] exposure to 10–20 mGy, falling within the range supplied by some radiographic studies (**Table 2, Table 3, Table 4** and **Table 5**), increases this rate to 5 per 10 000,[1] therefore, although the relative risk is counted as 40%, the absolute risk is only around 1 per 10 000. In other words, the background risk of childhood leukaemia is 40 per $10^6$ per year and the additional risk from 50 mGy exposure is <1–3 per $10^6$ per year.[5] **Table 1** illustrates the estimated excess cancer risk associated with *in utero* exposure to various doses of irradiation. However, the biological plausibility of such an association has been much debated,[16,23] based on the absence of increased childhood leukaemia risks among the Japanese atomic bomb survivors exposed *in utero* to much higher doses of irradiation[24,25] and cohorts of children exposed *in utero* in the UK[26] and the USA.[27] Experimental data do not support an association between fetal irradiation and increased occurrence of leukaemia.[28]

Furthermore, nearly 20 years after the Chernobyl disaster (1986), according to the Chernobyl Forum no evidence of increases in solid cancers and, possibly more significantly, none of the widely expected increases in leukaemia, have been found in the population.[29,30]

Radiation can also induce gene mutation and potentially affect future generations. Radiation merely increases the frequency of mutations occurring naturally in the general population.[7] It is believed that exposure to 10 mGy increases the risk of occurrence of new genetic mutations by 0.1–0.4%,[6] with a 0.012–0.099% risk of developing a genetic disease in future generations.[31] However, the Japanese atomic bomb survivors and inhabitants of areas with high background radiation have shown no significant excess of known genetic disorders.[32]

## Naturally occurring 'background' radiation

During the course of pregnancy, mother and baby inevitably receive a radiation dose from a range of naturally occurring sources such as cosmic rays; radioactive elements in the earth's crust; inhaled radon; radioactive substances in building materials, phosphate fertilisers and crushed rock; and radiation-emitting components of television sets, smoke detectors and other consumer products. Additional sources are encountered by workers in certain workplace environments. Furthermore, air travel can contribute significantly to the cumulative radiation exposure dose during pregnancy; for example, the radiation exposure dose is approximately 0.05 mSv for a 10-hour flight.

The background rate varies considerably with location, being as low as 1.5 mSv per year in some areas and more than 100 mSv per year in others. The average dose received by people in the USA and UK is about 3.6 and 2.2 mSv per year respectively. The estimated average cumulative

natural background radiation during an entire pregnancy is approximately 0.5–1.6 mGy.[33,34] The radiation exposure from one chest X-ray is, therefore, approximately equivalent to the amount of radiation exposure one experiences from the natural surroundings in 10 days.

## Nuclear medicine investigations

Diagnostic nuclear medicine investigations have some similarities to diagnostic X-ray examinations. With nuclear medicine, the patient inhales, ingests or is injected with a small quantity of a radioactive isotope; for example radioisotope technetium-99m ($^{99m}$Tc), which may be tagged to a chemical or biological agent (red blood cells, sulphur colloid or pertechnetate) which targets a particular organ, e.g. the liver, thyroid, bone or heart. The gamma radiation emitted by the radioactive isotope is detected outside the body by the electronic receptors of a gamma camera which displays images or functional data about the organ of interest. The mother and baby will receive a small radiation dose. The fetal absorbed dose depends on the method used to tag the agent; the external irradiation from maternal tissues; the placental transfer and fetal uptake of the radiopharmaceuticals and their concentration in certain organs, e.g. thyroid gland; the renal clearance; and the gestational age. Measurement of radioactive technetium is based on its decay, and the units used are the curie (Ci) or the becquerel (Bq) (**Box 1**, **Table 2**, **Table 3**, **Table 4** and **Table 5**). It is unlikely, however, that any diagnostic nuclear medicine investigation would result in the baby's radiation dose approaching 20 mGy (**Table 5**). Exposure varies with gestational age and is greatest earlier in pregnancy for most studies, except for the uptake, exposure and effect of iodine ($^{131}$I) on the fetal thyroid gland, which is increased by advancing gestational age (**Table 5**).[35] In thyroid scanning at 20 weeks of gestation, the estimated exposure dose to the whole body of the fetus is 3 mGy and the irradiation dose to the thyroid gland, due to $^{131}$I uptake and concentration in the thyroid gland, is 5900 mGy; however, these doses are much smaller at earlier stages of pregnancy (**Table 5**). Because of the risk of fetal hypothyroidism, thyroid ablation and potential mental deficiencies, the current recommendation is that the use of $^{131}$I as a diagnostic or therapeutic agent during pregnancy is generally considered to be contraindicated.[36]

Radiopharmaceuticals other than $^{99m}$Tc, $^{81m}$Kr and $^{51}$Cr should be strongly discouraged; $^{59}$Fe, $^{75}$Se and $^{131}$I are contraindicated. When tracers with renal excretion are used, women should be instructed to drink plenty for a period of 3–4 hours post-injection to reduce the residence time in the urinary bladder.

Clinically suspected pulmonary embolism during pregnancy is studied by V-P lung scanning, which is a form of nuclear medicine investigation. Perfusion is measured with injected technetium macro-aggregated albumin ($^{99m}$Tc MAA), and ventilation is measured with inhaled $^{127}$Xe or $^{133}$Xe. Fetal exposure with either of these is negligible (0.1–3.7 mGy) (**Table 5**).[37,38]

**Table 2**
**Estimated fetal exposure for plain X-rays**

| Examination type | Estimated fetal dose per examination (mGy = mSv) |
|---|---|
| Skull[50] | <0.0005 |
| Dental[52] | 0.001 |
| Cervical spine[52] | 0.02 |
| Upper or lower extremity[52] | 0.01 |
| Chest[50] | 2–7/10[4] |
| Abdominal[52] | 1.4–4.2 |
| Thoracic spine[52] | 0.09 |
| Lumbosacral spine[46] | 1.7–10 |
| Pelvis[46] | 1.1–4 |
| Mammogram[47] | 0.2–0.7 |
| Intravenous pyelogram[40] | 10–40 |
| Retrograde pyelography[49] | 6 |

**Table 3**
**Estimated fetal exposure for fluoroscopic studies**

| Examination type | Estimated fetal dose per examination (mGy = mSv) |
|---|---|
| Upper GI series[40,50] | 0.56–1 |
| Barium swallow[46,48] | 1.1–5.8 |
| Barium enema[48,49] | 6.8–10 |
| Cerebral angiography[50] | <0.1 |
| Cardiac angiography[50] | 0.65 |

GI = gastrointestinal

**Table 4**
**Estimated fetal exposure for computed tomography**

| Examination type | Estimated fetal dose per examination (mGy = mSv) |
|---|---|
| Head[49] | <0.005 |
| Chest[49] | 0.06–0.16 |
| Chest angiography[39] | 0.0035–0.131 |
| Abdomen[48,49] | 8–30 |
| Lumbar spine[49] | 0.9–7.5 |
| Pelvis[51] | 25–79 |
| Pelvimetry[46] | 0.2–0.4 |

## Computed tomography

Tomography is derived from the Greek *tomos*, meaning 'a slice'; it uses X-rays to produce precise cross-sectional images of anatomical structures. The diagnostic potential of computed tomography was first realised in the 1970s by the English physicist Godfrey Hounsfield, who subsequently won the 1979 Nobel Prize in Physiology. Unlike conventional X-rays, CT scans collect X-rays that have passed through the body with an electronic detector mounted on a rotating frame rather than on film. The X-ray source and collector rotate around the patient with the use of a 360° X-ray beam as they emit and absorb X-rays.

Spiral CT, also called helical CT, is a newer version that is continuous in motion and allows for three-dimensional recreation of images. Some facilities have both spiral and conventional CT available. Although spiral CT is more advantageous for many applications, conventional CT is still a superior and precise method for imaging many tissues and structures. The irradiation exposure is dependent on the pitch, which is the degree of stretching or tightening of the spiral. At the current typical pitch range of 1.0–2.0, the estimated radiation exposure

**Table 5**
**Estimated fetal exposure for nuclear medicine studies**

| Study | Estimated activity administered per study | Dose to uterus/embryo (mGy = mSv) |
|---|---|---|
| Brain[50] | 20 mCi $^{99m}$Tc DTPA | 7–8.8 |
| Hepatobiliary[50] | 5 mCi $^{99m}$Tc sulphur colloid | 0.45 |
| | 5 mCi $^{99m}$Tc HIDA | 1.5 |
| Renal[50] | 20 mCi $^{99m}$Tc DTPA | 8.8 |
| V-P lung scanning | | 0.1–0.37 |
| Perfusion portion[39] | 3 mCi $^{99m}$Tc MAA | |
| Ventilation portion[39] | 10 mCi $^{133}$Xe gas | |
| Thyroid scanning[50] | 0.1 mCi $^{131}$I | |
| Whole body (2–6 weeks) | | 0.15 |
| Whole body (12–13 weeks) | | 1.6 |
| Whole body (20 weeks) | | 3 |
| Fetal thyroid (12–13 weeks) | | 1300 |
| Fetal thyroid (20 weeks) | | 5900 |

DTPA = diethylenetriaminepenta-acetic acid; HIDA = hepatobiliary iminodiacetic acid; $^{131}$I = iodine-131; mCi = millicuries; $^{99m}$Tc MAA = technetium macro-aggregated albumin plus; V-P = ventilation-perfusion

Average environmental background radiation (cumulative dose over 9 months): 0.5–1.6[33,34]

The accepted background cumulative dose of ionising radiation during pregnancy is 5 rad (50 mGy), which is much more than the exposure dose of most of the radiological diagnostic examinations.

is similar to or less than that for conventional CT (**Table 4**).

Computed tomography is useful for brain studies, tumours or cysts; enlarged lymph nodes; abnormal collections of fluid, blood or fat; and metastasis of cancer. Hepatic conditions, such as cirrhosis, abscess, fatty liver and metastatic neoplastic diseases (**Figure 2**) can be observed with a CT scan.

Computed tomography in pregnancy is most useful in evaluating cases of severe blunt abdominal trauma; spiral CT is particularly effective at identifying pulmonary thromboemboli, one of the leading causes of maternal mortality in developed countries. In a meta-analysis study comparing V-P scanning and helical CT in cases of suspected pulmonary thromboembolism, Hayashino *et al.*[39] concluded that helical CT had greater discriminatory power than V-P scanning with normal and/or near-normal threshold to exclude pulmonary thromboembolism, while helical CT and V-P scanning with high probability threshold had similar discriminatory power in the diagnosis of pulmonary thromboembolism. However, with V-P scanning, a definitive diagnosis is only obtained in <30% of patients tested, with the remaining 70% needing further testing.[40] Furthermore, in addition to being more accurate, CT demonstrates better inter-observer agreement than V-P scanning, with significantly lower fetal irradiation exposure doses. The estimated fetal ionising radiation exposure dose from V-P scans is approximately 0.1–0.37 mGy and for CT scans around 0.0035–0.131 mGy.[41]

Selective pulmonary angiography remains the reference standard for diagnosis of pulmonary thromboembolism; however, this procedure is invasive and causes morbidity and mortality rates of 4% and 0.2%, respectively, with a fetal exposure dose of about 0.5 mGy.

## Dosimetry and threshold doses

**Table 2, Table 3, Table 4** and **Table 5** show the estimated fetal exposure doses from the most recent surveys of diagnostic radiology practice. Doses for the same procedures vary widely between patients and hospitals. However, the absorbed dose of the embryo or the fetus where the X-ray beam does not directly irradiate them, such as maternal skull or chest X-ray, is extremely low (**Table 2**); therefore, the further the target area from the embryo or fetus, the less the exposure and risk of radiation and vice versa. Based on mean doses, the common procedures giving the greatest fetal exposure are barium enemas, pelvic and abdominal CT and intravenous pyelograms.

**Table 1** shows the risk of possible effect of exposure to acute doses of irradiation and estimates of the threshold dose. In practical terms, the risk of miscarriage from irradiation is limited to the stage of preimplantation and the first 2 weeks after conception. It is an 'all-or-nothing' phenomenon, with an estimated threshold dose of 100 mGy in the first week of pregnancy and 250–500 mGy at 2–6 weeks of gestation. Irradiation during the period of organogenesis, starting from the third week after conception until 12 weeks of gestation, may mainly cause congenital malformations. The threshold doses for the induction of death and gross malformation following fetal irradiation all lie well above the doses in **Table 2, Table 3, Table 4** and **Table 5** and are only approached by the maximum dose (about 80 mGy) noted in the case of pelvic CT procedures. The risk of fetal growth restriction and malignancy due to high dose exposure of irradiation starts from 4 weeks of gestation and lasts throughout pregnancy. The most sensitive stage of pregnancy, for subsequent fetal growth restriction, is at 3–10 weeks and the

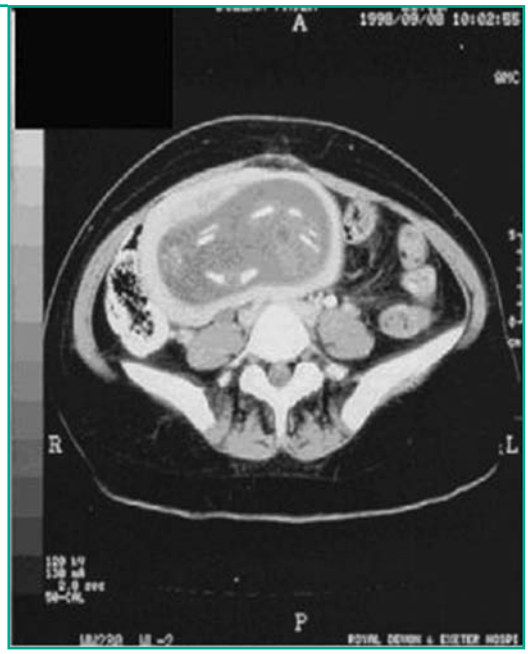


**Figure 2**
**Computed tomography for investigation of advanced intra-abdominal malignancy with hepatic secondaries in a woman at 18 weeks of pregnancy**

estimated threshold dose is 200–250 mGy. The risk of severe mental retardation with high exposure is greatest at 10–17 weeks with less risk at 18–27 weeks. There is no proven risk before 10 or after 27 weeks (**Table 1**).[4] For the induction of mental retardation in offspring, even an assumed no-threshold response in the 10–17 week period of gestation would not have important implications, since for a maximum fetal dose of about 100 mGy the predicted 3-point IQ loss would be undetectable on an individual basis.

In general, therefore, fetal doses are unlikely to cause deterministic effects in an individual pregnancy. All the relevant organisations and committees recommend that women should be counselled that radiological exposure from a single diagnostic procedure is not likely to pose a radiation threat to the fetus, whereas misdiagnosis or delay in diagnosis may cause a major problem to the mother and to the fetus. Concern about possible effects of ionising radiation exposure should not prevent medically indicated radiological procedures from being performed in pregnant women; nevertheless, physicians should carefully weigh the risks and benefits of any radiographic study, particularly between 10 and 17 weeks of gestation, and include the mother in the decision-making process whenever possible.

## Contrast media

Contrast media consist of solutions or suspensions of non-toxic substances that contain a significant proportion of elements of high atomic number, usually iodine. They are usually used in diagnostic procedures such as angiography, intravenous urography, intravenous pyelography and CT scanning.

Computed tomography is exceptionally sensitive to contrast media and will detect slight abnormalities caused by disease following an intravenous injection of contrast medium. This procedure is known as 'enhancing' the scan. About 43% of all CT procedures involve the use of a contrast medium enhancement.

When injected intravenously, most contrast media are rapidly excreted by the kidneys and a series of radiographs taken after the injection will demonstrate the urinary tract. Intravenous urography and intravenous pyelography are the classic examples of radiological investigations that use contrast media and they remain the basic radiological examinations of the urinary tract. The main indication is to assess the morphology of the kidneys. In recent years, for some investigations of the urinary tract, particularly uncomplicated infection, an ultrasound examination and plain abdominal radiograph have replaced intravenous urography, which has classically been used as the initial investigation of the urinary tract. However, the diagnosis of ureteral calculi may pose a real challenge during pregnancy due to the physiological renal changes accompanying pregnancy. Computed tomography is extremely accurate and provides definitive diagnosis, either to demonstrate or exclude it. The fetal irradiation exposure dose from intravenous pyelography is lower in early pregnancy (<10 mGy), which may increase to 30–40 mGy later in pregnancy, whereas the dose from CT scanning is significantly lower in larger women and later in pregnancy (approximately 30 mGy). It is considered, therefore, the method of choice as a secondary mode of investigation, after ultrasound scan, in the third trimester of pregnancy.[42] Although the diagnostic accuracy of magnetic resonance urography for ureteral stones may not be as high as that of excretory urography or CT, it is non-invasive, does not require ionising radiation, does not depend on renal function and in many cases it depicts the level and the cause of ureteral obstruction without requiring contrast material, unlike conventional excretory urography.[43] Therefore, if it is available, it is considered suitable for the evaluation of pregnant women with hydronephrosis.

Radiological contrast media are usually water-soluble solutions, but there is one commonly used variety that is based on a suspension of large insoluble particles. This is the barium sulphate mixture that is used for barium meal and barium enema examinations. All of the other X-ray contrast media are based on the element iodine.

Contrast media are among the safest of all of the pharmaceutical products available today. The incidence of adverse reactions to iodinated contrast media is extremely low; but occasionally they do occur. They include minor reactions such

as flushing, nausea, vomiting, pruritis, mild rash and arm pain; moderate reactions, e.g. more severe urticaria, facial oedema, hypotension and bronchospasm; and severe reactions, e.g. hypotensive shock, laryngeal oedema, convulsions and respiratory and cardiac arrest.

Iodine-based contrast media have not been extensively studied in humans; however, iohexol, iopamidol, iothalamate, ioversol, ioxaglate and metrizamide have been studied in animals and do not appear to be teratogenic.[9] Nevertheless, neonatal hypothyroidism has been associated with some iodinated agents taken during pregnancy, therefore, these agents should be avoided in pregnancy unless essential. Neonatal thyroid function should be checked during the first week if iodinated contrast media have been given during pregnancy.[44]

Paramagnetic contrast agents, such as gadolinium-based contrast media, are used in magnetic resonance imaging (MRI). They cross the placenta and may enter the fetal circulation, to be excreted in the amniotic fluid from the fetal bladder. Intravenous gadolinium is teratogenic in animal studies, albeit at higher doses, two to seven times the recommended human dose. In line with the European Society of Radiology guidelines, and based on the available evidence, gadolinium-based contrast agents appear to be safe in pregnancy;[45] however, it is recommended that they are only considered if absolutely essential and only after discussion of the risks and benefits with the woman and referring clinician.[46]

## Conclusion

Safety of diagnostic imaging in pregnancy is a real concern both among clinicians and their patients. It is very important for clinicians, particularly obstetricians and radiologists, to be familiar with the safety issues of various diagnostic modalities in pregnancy and to tailor the appropriate diagnostic imaging to the patients' presentation and gestational age and to the availability of particular imaging modalities and their individual safety issues. In general, with X-rays and CT scans the fetal doses of irradiation are unlikely to cause deterministic effects in an individual pregnancy. Furthermore, in the case of nuclear medicine investigations, apart from the adverse effect of iodine ($^{131}$I) on the fetal thyroid gland, common procedures are unlikely to involve fetal doses of more than a few milligrays. Concern about possible effects of ionising radiation exposure should not prevent medically indicated radiological procedures from being performed in pregnant women; however, physicians should weigh the risks and benefits of any radiographic study carefully, particularly between 10–17 weeks of gestation, and include the mother in the decision-making process whenever possible. Iodine-based contrast media do not appear to be teratogenic. Nevertheless, neonatal hypothyroidism has been associated with some iodinated agents taken during pregnancy, therefore, these agents should be avoided in pregnancy unless essential and the thyroid function checked during the first neonatal week. The paramagnetic contrast agents used in MRI appear to be safe in pregnancy; however, it is recommended that MRI is considered only if absolutely essential and only then after discussion of the risks and benefits with the woman and referring clinician.

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