Imaging in pregnancy


Published in:
The Obstetrician and Gynaecologist

Document Version:
Peer reviewed version

Queen's University Belfast - Research Portal:
Link to publication record in Queen's University Belfast Research Portal

Publisher rights
© 2019 John Wiley & Sons.
This work is made available online in accordance with the publisher’s policies. Please refer to any applicable terms of use of the publisher.

General rights
Copyright for the publications made accessible via the Queen's University Belfast Research Portal is retained by the author(s) and / or other copyright owners and it is a condition of accessing these publications that users recognise and abide by the legal requirements associated with these rights.

Take down policy
The Research Portal is Queen’s institutional repository that provides access to Queen's research output. Every effort has been made to ensure that content in the Research Portal does not infringe any person’s rights, or applicable UK laws. If you discover content in the Research Portal that you believe breaches copyright or violates any law, please contact openaccess@qub.ac.uk.

Open Access
This research has been made openly available by Queen’s academics and its Open Research team. We would love to hear how access to this research benefits you. – Share your feedback with us: http://go.qub.ac.uk/oa-feedback
Imaging in pregnancy

Key content
- The appropriate use of imaging in pregnancy is necessary for prompt investigation and management of acute and chronic medical symptoms.
- Healthcare professionals should consider carefully which imaging modality and scanned area of interest will yield maximum diagnostic information.
- The use of shielding techniques significantly reduces the dose of ionising radiation exposure to the fetus.
- Theoretical concerns regarding magnetic resonance imaging use in pregnancy have not been demonstrated in human studies.
- Gadolinium contrast should be avoided in pregnancy unless the maternal benefits outweigh fetal and neonatal risks.

Learning objectives
- To review the safety of different imaging modalities in pregnancy.
- To understand the risks and benefits of various imaging techniques in pregnancy.
- To review the investigations required to image common medical symptoms encountered by obstetricians.

Ethical issues
- Do obstetricians adequately counsel women regarding safety of imaging in pregnancy to enable them to give informed consent for the procedure?

Keywords: imaging / obstetric / pregnancy / radiation / safety

Introduction
Imaging studies are important adjuncts for the diagnosis of acute and chronic conditions. It is, however, important to note that reliance on imaging is no substitute for thorough history taking, clinical examination and selective use of appropriate radiological investigations. Debate over the safety of imaging modalities for pregnant women can result in avoidance of useful diagnostic tests in pregnancy and the potential for delayed diagnosis. This review will discuss the benefits and risks of varied imaging techniques in pregnancy and highlight
appropriate techniques to image women presenting with common medical symptoms to healthcare professionals.

**[A head] Ionising radiation**

Ionising radiation, including radiography and computed tomography (CT), is commonly used in the evaluation of medical conditions. Examinations that expose the fetus to ionising radiation may be required during pregnancy to aid clinical diagnosis and decision making. Alternatively, a fetus may be unintentionally exposed to ionising radiation, particularly in early pregnancy. It is estimated that the fetus is exposed to background radiation in the order of 1 mGy during pregnancy.\(^1\) Table 1 summarises the common units used to measure ionising radiation.

Both X-rays and gamma rays are short wavelength electromagnetic waves that can ionise tissues and alter normal cellular structure in two ways: through stochastic and deterministic effects.\(^2\) Stochastic effects, for example, development of carcinogenesis, are theorised to occur at any radiation dose as a result of cellular damage following a germline mutation.\(^3\) There remains no known threshold value at which these effects will not occur. Importantly, stochastic effects are associated with an increased risk of childhood malignancy including leukaemia and lymphoma.\(^4\) Deterministic effects involve the loss of tissue function because of cell death and result from radiation doses above a threshold value. These effects are predictable and involve multicellular injury, including chromosomal anomalies.\(^3\) As a result, major risks include fetal malformation (skeletal, ophthalmic and genital tract anomalies), fetal growth restriction and neurological effects (microcephaly, intellectual or developmental...
disability). These outcomes are dependent on gestational age and the dose used for the diagnostic test (Table 2).

Our understanding of the effects of ionising radiation is based on findings from animal studies, epidemiologic studies of survivors of atomic bombs (Hiroshima and Nagasaki, Japan)\(^5\,6\) and studies of groups of people exposed to radiation for medical reasons. The risk of carcinogenesis as a result of in utero exposure to ionising radiation remains uncertain.\(^4\) Legacy studies of the atomic bomb survivors in Japan did not initially observe an association between in utero exposure and excess cancer mortality or incidence. However, longitudinal data collection has subsequently identified significant associations between in utero exposure and increased cancer risk.\(^6\) A study of 19,536 children born to women either employed in a large nuclear facility in the Southern Urals or living in areas near the Techa river, which was contaminated by waste from the same nuclear facility, demonstrated an increase in haematological malignancies in children whose mothers had been exposed to more than 80 mGy ionising radiation while in utero (n = 58, excess relative risk of 1.27, 95% confidence interval [CI] 0.02–2.56).\(^7\) Importantly, fetal exposure to ionising radiation during diagnostic examinations is at a far lower magnitude than fetal survivors who were exposed in Hiroshima and Nagasaki. Table 3 outlines fetal radiation doses for common radiological investigations. Exact fetal exposure does, however, vary with gestational age, maternal body mass index and image acquisition parameters.\(^8\)

[B head] Radiography

Radiographs are commonly used to investigate a wide range of medical symptoms. The British Thoracic Society\(^9\) recommends chest radiography for all patients – including pregnant women
– complaining of a chronic cough (>8 weeks) or who have atypical symptoms of haemoptysis, breathlessness, fever, chest pain or weight loss. Given the minimal risks to the fetus in pregnancy and potential for delayed diagnosis, clinicians should proceed with chest radiography for the same indications as in the non-pregnant patient. 

[B head] Computed tomography

The use of CT as a diagnostic imaging modality in pregnancy has increased dramatically; in a review of 5270 examinations in more than 3000 women in a 10-year period, Lazarus et al. noted an annual increase of 25% in the use of CT in the decade studied. CT is often essential for the diagnosis and investigation of maternal conditions in pregnancy. Indications for use of CT in pregnancy are wide ranging, including assessing injuries following trauma, diagnosing pulmonary embolism, investigating gastrointestinal complications (appendicitis, small bowel obstruction) and malignancy. Although less common than fetal MRI, there has also been a move to use antenatal CT for the purposes of better defining fetal anomalies before delivery, for example, in cases of skeletal dysplasia.

[B head] Minimising the effects of ionising radiation

The use of ionising radiation in pregnancy should follow the ALARA (as low as reasonably achievable) principle. The International Commission on Radiological Protection recommends that ‘imaging radiation must be applied at levels as low as reasonably achievable, while the degree of medical benefit must counterbalance the well-managed levels of risk’. The use of modern shielding techniques has significantly reduced the dose of ionising radiation exposure to the fetus; for example, the fetal radiation dose received during
mammography is in the order of 0.001–0.01 mGy. The use of lead shielding can further reduce this risk by an additional 50%.

The fetal radiation dose received as the result of CT is dependent on a number of factors: the anatomical region of interest, machine set-up, X-ray tube voltage, tube current and number of image acquisitions. In general, the fetal radiation dose is highest when the fetus is captured directly in the X-ray beam, for example, when using abdominopelvic CT. For head and chest CT, the fetus is exposed to scatter radiation, which confers a low-dose radiation exposure. Radiologists should aim to plan scans in advance, to monitor the length of scanning time and to check the quality of images collected to minimise scanning time. In general, increasing the voltage and decreasing the pitch will increase the radiation dose. In a single-slice CT, pitch is the ratio of table movement per gantry rotation (mm) to collimation (mm). Higher pitch results in more scan artefact and lower-resolution images, but it may be required to image women with a higher body mass index and in those with cardiovascular implanted electronic devices.

The use of intravenous contrast agents may improve the diagnostic accuracy of CT by enhancing soft tissue and vascular structures. The most commonly used intravenous contrast media contains iodine, which carries a small risk of maternal adverse effects including nausea, vomiting, flushing and anaphylactoid reactions. Iodinated contrast medium can cross the placenta and enter the fetal circulation or pass directly into the amniotic fluid, however, animal studies have not revealed any teratogenic effects from its use.
[A head] Other imaging modalities

[B head] Ultrasound

Following pioneering work on soft-tissue ultrasonography in the USA in the late 1940s and early 1950s, ultrasound was further applied to obstetrics by Professor Ian Donald in Glasgow.\textsuperscript{26} Ultrasound quickly became a relied on and widely used imaging technique in pregnancy. Initially, ultrasound imaging was assumed to be safe in pregnancy. It is important to note, however, that early ultrasound machines used relatively low output settings and did not rely on colour flow, power Doppler or three-dimensional or four-dimensional imaging of the fetus.\textsuperscript{27} Effects of potential clinical significance have been demonstrated in laboratory studies but not completely borne out in clinical practice. These effects are as a result of thermal effects on tissue temperature and mechanical effects resulting in tissue cavitation. The fetal central nervous system is the most susceptible tissue to thermal injury; animal studies have demonstrated associations between neural tube defects, arthrogryposis, disorders of muscle tone, miscarriage and fetal growth restriction.\textsuperscript{28} The risk of temperature elevation is lowest in B-mode imaging and is higher with colour Doppler and spectral Doppler applications.\textsuperscript{23} Cavitation refers to the development of gas bubbles in tissues exposed to ultrasonic vibration.\textsuperscript{29} These bubbles can cause inertial (transient) or non-inertial (stable) cavitation effects. Inertial cavitation effects have been shown to cause genetic damage in vitro,\textsuperscript{29} while in vivo studies of non-inertial effects have remained inconclusive.\textsuperscript{30} Overall, it is thought that there are no significant effects of ultrasound unless fetal exposure is prolonged (longer than 60 minutes).\textsuperscript{28}

Concern over the biological effects of diagnostic ultrasound has resulted in the development of safety indices. The two most commonly used indices are the thermal index and the
mechanical index. Sonographers should aim to follow the ALARA principles; in doing so, the thermal index and mechanical index should be kept as low as possible to obtain optimal images.

[B head] Magnetic resonance imaging

MRI enables the visualisation of deep soft tissue structures and does not rely on the use of ionising radiation. MRI is useful for assessing a variety of medical conditions, for example, posterior reversible encephalopathy syndrome, cerebral venous thrombosis, acute appendicitis, Crohn’s disease and suspected morbidly adherent placenta. Antenatal MRI is increasingly used to further evaluate structural fetal anomalies, including cranial lesions (ventriculomegaly, agenesis of the corpus callosum, gyral or sulcation pattern), neural tube defects, congenital pulmonary airway malformations, congenital diaphragmatic hernia and cardiovascular anomalies (teratoma, rhabdomyoma or vascular abnormalities).

Obstetric MRI can be technically challenging to perform and interpret given the movement of the fetus and variable lie and presentation. However, MRI has several advantages over antenatal ultrasound. In comparison with ultrasound, MRI has improved resolution, and cranial imaging allows direct visualisation of both sides of the fetal brain. Additional limitations of sonography, resulting from oligohydramnios, fetal positioning and acoustic shadowing from the ossifying calvaria, can be overcome using fetal MRI. Factors affecting the quality of fetal MRI include fetal movement, and therefore a need for repeated image acquisition, the small size of the fetal anatomical structures under evaluation and the increased distance between the fetus and the receiver coil. Additional maternal complications include claustrophobia and discomfort, particularly at advanced gestations.
Avoidance of prolonged supine positioning, particularly in the third trimester, will reduce the occurrence of significant maternal hypotension precipitated by compression of the inferior vena cava by the gravid uterus.\textsuperscript{36}

MRI is not associated with any radiation exposure but does expose the fetus to a magnetic field more than 10 000 times greater than that of Earth (50 µT).\textsuperscript{8} Theoretical concerns include teratogenesis as a result of fetal exposure to the static magnetic field and potential cell damage secondary to cell migration, proliferation and differentiation; tissue heating and possible disruption of organogenesis owing to exposure to pulsed radiofrequency fields; and acoustic damage given fetal exposure to high-gradient electromagnetic fields used with the fast acquisition sequences required for fetal imaging.\textsuperscript{37} The American College of Radiology\textsuperscript{38} stipulates that MRI can be carried out at any time during pregnancy if the maternal benefits outweigh fetal risks. Concerns regarding the impact of first-trimester MRI on fetal growth, the risk of miscarriage and ophthalmic anomalies have not been borne out in human studies.\textsuperscript{36}

From a practical standpoint, MRI performed during the first trimester is often for maternal indications and not to aid prenatal diagnosis. Strizek et al.\textsuperscript{39} evaluated the effects of in utero exposure to MRI (1.5 T) on fetal growth and neonatal hearing function in a group of newborns at low risk for congenital hearing impairment or congenital deafness (n = 751). Median gestational age at first MRI exposure was 37 weeks of gestation (range 16–41\textsuperscript{6} weeks). There were no neonates with hearing impairment in the exposure group. No significant differences in birthweight percentiles were apparent between cases (50.6%) and controls (48.4%), \( P = 0.22.\textsuperscript{39} \) A further observational study of 72 healthy pregnant women who had 1.5-T fetal MRI using single-shot fast spin echo (SSFSE) sequences in the third trimester reported child outcomes at a mean age of 24.5 ± 6.7 months.\textsuperscript{40} These children demonstrated age-
appropriate scores in the communication, daily living, socialisation and motor skills subdomains of the Vineland Adaptive Behaviour Scale, \( P > 0.05 \). Furthermore, all exposed children passed their newborn hearing tests and had normal hearing at preschool age. MRI study duration and exposure time to radio frequency waves and SSFSE sequences was not associated with adverse functional outcomes or hearing impairment.

[B head] Use of gadolinium contrast

Gadolinium-based contrast agents are useful in enhancing MRI of the central nervous system as they cross the blood–brain barrier. Lesions disrupting this barrier, such as tumours, abscesses or demyelination, are therefore more readily identifiable with the use of contrast.\(^{23}\) However, there remains debate about using contrast-enhancing agents in pregnancy because of the possible risk of teratogenicity in the first trimester during organogenesis.\(^{41}\) It is also thought that gadolinium may cross the placenta in the second and third trimester, where it is then excreted by the fetal kidneys into the amniotic fluid and recirculated. Theoretically, there are concerns that persistent circulation of contrast agent may cause nephrogenic systemic fibrosis in the child.\(^{42}\) In a large retrospective cohort study conducted by Ray et al.\(^{41}\) the long-term safety of MRI was evaluated in 1,424,105 matched maternal–child pairs. MRI was carried out either in the first trimester of pregnancy or with gadolinium at any time during pregnancy. The overall rate of MRI was 3.97 per 1000 pregnancies. Comparing first-trimester MRI \((n = 1737)\) with no MRI \((n = 1,418,451)\), there was no significant difference in stillbirth or neonatal death rate between the exposed and unaffected groups (19 versus 9844, adjusted relative risk \([RR] = 1.68, 95\% \, CI \, 0.97–2.90\) ). No additional risk of congenital anomalies, neoplasm, visual or hearing loss was seen in the first trimester MRI group. Comparing gadolinium MRI \((n = 397)\) with no MRI \((n = 1,418,451)\), the hazard ratio (HR) for nephrogenic
systemic fibrosis-like outcomes was not statistically significant. However, rheumatological, inflammatory and infiltrative skin conditions were more likely in the group exposed to MRI with gadolinium contrast (123 versus 384 180 births, adjusted HR = 1.36, 95% CI 1.09–1.69). In addition, the stillbirth and neonatal death rate was higher in the gadolinium-exposed group (adjusted RR = 3.70, 95% CI 1.55–8.85). Given the available evidence, it is therefore recommended that gadolinium contrast be avoided in pregnancy unless the benefits clearly outweigh the possible risks to the fetus. If gadolinium is used, the American College of Radiology recommends that clinicians seek informed consent from the patient and document that information requested from the MRI cannot be acquired without the use of IV contrast or by using other imaging modalities; that the information needed affects the care of the patient and/or fetus during the pregnancy; and that it is the opinion of the referring physician that it is not prudent to wait to obtain this information until after the delivery.

[B head] Nuclear medicine imaging

Nuclear studies are useful to determine organ function by tagging a chemical agent with a radioisotope (radiotracer). Investigations include pulmonary ventilation/perfusion (V/Q), thyroid, bone and renal scans. In pregnancy, fetal exposure during nuclear medicine studies depends on both the physical and biochemical properties of the radioisotope. Technetium-99m is a commonly used isotope in V/Q scanning to diagnose pulmonary embolism in pregnancy. It is a gamma ray emitter and has a half-life of approximately 6 hours. In general, V/Q scans result in a fetal radiation exposure of <5 mGy. To reduce fetal radiation exposure, a normal chest radiograph can be used as a surrogate marker of ventilation and half-dose perfusion scans could be considered. In contrast, radioactive iodine (iodine-131), for assessment of thyroid pathology, readily crosses the placenta, has a half-life of 8 days, and
may cause fetal hypothyroidism, especially if used after 10–12 weeks of gestation. It is therefore not routinely recommended for use in pregnancy. If a diagnostic scan of the thyroid is essential, technetium-99m is the isotope of choice.\textsuperscript{23,24}

Imaging of malignancy during pregnancy may warrant investigation with a positron emission tomography (PET) scan.\textsuperscript{44} In pregnant women with cancer, the use of PET imaging has been debated because it uses radioactive-labelled tracers, therefore increasing the risk of exposing the fetus to radiation. The most commonly used radiotracer is 2-deoxy-2\{fluorine-18\}-fluoro-D-glucose (\textsuperscript{18}F-FDG). The amount of fetal radiation exposure depends on the weight of the fetus, the type of radiotracer, the administered dose and physiological changes during pregnancy.\textsuperscript{45} Data indicate that the fetus is at highest radiation exposure risk in the first trimester but that the total absorbed dose of radiation is well below the threshold for non-cancer health effects throughout pregnancy.\textsuperscript{46} Studies in the second and third trimester of pregnancy also indicate that the fetal radiation dose from \textsuperscript{18}F-FDG administration is low. When medically indicated in pregnant women, \textsuperscript{18}F-FDG PET scanning should therefore not be withheld for fear of excessive radiation exposure to the fetus.\textsuperscript{47}

\textbf{[A head] Radiological investigation of common medical symptoms in pregnancy}

Venous thromboembolism (VTE) remains one of the leading direct causes of maternal death during pregnancy and in the immediate postpartum period.\textsuperscript{12} In the UK and Ireland, between 2014 and 2016, 39 women died as a direct result of VTE.\textsuperscript{48} Subjective clinical assessment of deep venous thrombosis (DVT) and pulmonary embolism is particularly unreliable in pregnancy and only a minority of women with clinically suspected VTE have the diagnosis confirmed when objective testing is used (2–6%).\textsuperscript{12}
[B head] Calf pain/swelling

First line imaging for suspected DVT is with compression duplex ultrasound, and women should remain on therapeutic anticoagulation until imaging is completed. If the ultrasound is negative and a high level of clinical suspicion remains, anticoagulant treatment should be discontinued but the ultrasound repeated on days 3 and 7.¹²

[B head] Shortness of breath

Shortness of breath is a common presenting complaint in pregnancy with a wide range of differential diagnoses. Women presenting with signs or symptoms of an acute pulmonary embolism should be investigated as a matter of urgency. Initial investigations should include an electrocardiogram and a chest radiograph. In those presenting with a suspected pulmonary embolism but without symptoms and signs of DVT, a V/Q scan or a CT pulmonary angiogram (CTPA) should be performed. A Cochrane review to determine the diagnostic accuracy of CTPA and V/Q scanning for diagnosis of pulmonary embolism demonstrated no significant difference between the imaging techniques. The median frequency of inconclusive results was 5.9% for CTPA and 4.0% for V/Q scanning.¹³

It is important that clinicians and patients are aware of the benefits and limitations of these diagnostic tests. CTPA has potential advantages over V/Q imaging including availability, relatively low fetal radiation exposure and superior identification of other pathology including pneumonia (5–7%) and pulmonary oedema (2–6%). A significant drawback to the use of CTPA in pregnancy, however, is delivery of up to 20 mGy radiation to maternal breast tissue, which is associated with an increased risk of breast cancer. Delivery of 10 mGy radiation to a
woman’s breast before the age of 35 years is expected to increase her lifetime risk of developing breast cancer by 13.6% above that of the general population. In contrast, V/Q scanning has a high negative predictive value for pulmonary embolism and delivers a lower radiation dose to the breast tissue of a pregnant woman. In women with a personal or significant family history of breast cancer, many centres advocate a V/Q scan as the first line investigation. V/Q scanning may carry an increased childhood malignancy risk when compared with CT owing to a slightly higher fetal radiation dose. The International Commission on Radiological Protection estimates an increased risk of fatal childhood cancer up to the age of 15 years following in utero radiation exposure of 0.006% per mGy, which equates to a risk of one in 17 000 per mGy.

[B head] Abdominal pain

Abdominal pain in pregnancy can be attributed to a wide range of underlying conditions, including hepatobiliary, gastrointestinal, genitourinary, infectious, inflammatory, vascular and malignant aetiologies. Perhaps the most common causes of non-obstetric pain in pregnancy are appendicitis and cholecystitis. Ultrasound and MRI (without contrast) are the primary imaging modalities recommended for evaluation of abdominal pain in pregnancy, however, abdominal radiography may also be indicated. Ultrasound is a useful first line investigation to image the appendix, bowel, hepatobiliary tree, renal tract and adnexae. In the setting of active infection or inflammation, particularly inflammatory bowel disease, MRI can also help identify bowel obstruction, fistulas or abscess formation.

[B head] Headache
Headaches remain the most frequent reason for referral to an outpatient neurology clinic. Most headaches are benign but warrant prompt investigation because they can herald intracranial catastrophe. In many cases, headaches are a primary disorder: migraine, tension-type headache and cluster headache. However, clinicians must be alert to causes of secondary headache in pregnancy, including pre-eclampsia, posterior reversible encephalopathy syndrome, reversible cerebral vasoconstriction syndrome and acute arterial hypertension. Other causes of secondary headache in pregnancy include cerebral venous thrombosis, intracranial haemorrhage, subarachnoid haemorrhage, ischaemic stroke, pituitary adenoma and malignancy. Box 1 summarises red flag symptoms associated with headache that require further investigation in pregnancy.

Following detailed history taking and clinical assessment, women with focal neurological deficits or signs of raised intracranial pressure (papilloedema, ocular palsy, hypertension) should be referred for urgent intracranial imaging. Table 4 summarises the intracranial imaging techniques that can be employed to investigate underlying causes of headache in pregnancy. Fetal exposure following CT of the maternal head is estimated at 0.001–0.01 mGy (Table 3).

[B head] Breast mass

Breast cancer remains the leading cause of death in women aged 35–54 years (lifetime risk of one in nine). Women presenting with a breast mass in pregnancy persisting for more than 2 weeks should be referred to a multidisciplinary team. Ultrasound of the affected breast is recommended in addition to tissue biopsy. Samples should be sent for histological examination, and if malignancy is identified, mammography is advised to assess the extent of disease, visualise microcalcifications and assess the contralateral breast. Because of
physiological hyper-vascularisation and the increased density of breast tissue in pregnancy, mammography is often challenging to interpret.\textsuperscript{44} Sensitivity of mammography during pregnancy is thought to be between 78\% and 90\% in women with clinical abnormalities, and both breasts should be evaluated.\textsuperscript{44} To reduce exposure of the fetus to ionising radiation, fetal shielding is recommended. The overall dose of radiation exposure from mammography is thought to be in the order of 0.001–0.01 mGy (Table 3).\textsuperscript{8} Additional imaging may be required to stage the malignancy. Where there is a high index of clinical suspicion of metastases in pregnancy, women should have a chest radiograph and liver ultrasound. Conventionally, MRI with gadolinium contrast is recommended for additional staging of malignancy.\textsuperscript{41} Women should be counselled regarding the real risk of maternal morbidity, and therefore fetal morbidity and mortality, if malignancy in pregnancy is not assessed and treated appropriately, in addition to the potential risks to the neonate with use of gadolinium contrast in pregnancy.\textsuperscript{41} Ultimately, the importance of prompt optimal treatment of breast cancer is the most crucial factor in determining the further management of the woman and her pregnancy.

**Conclusion**

Timely investigation and management of complex medical symptoms in pregnancy is essential to reduce maternal morbidity and mortality. The available literature demonstrates that effects of diagnostic imaging studies on the fetus involving <50 mGy radiation at any gestation are likely to be negligible. MRI remains preferable to studies using ionising radiation, and for MRI examinations requiring contrast, gadolinium can be used if the maternal benefits outweigh fetal risks. Safety of imaging in pregnancy is improved by careful history taking and examination, clear identification of the clinical question to be answered
and the timeframe in which it should be investigated, advice from a senior radiologist regarding the most suitable imaging modality and appropriate counselling of the woman by a competent clinician.

Disclosure of interests

There are no conflicts of interest.

References


   *Green-top Guideline No. 12.* London: RCOG; 2011

   [https://www.rcog.org.uk/en/guidelines-research-services/guidelines/gtg12/].


43. ACR Committee on Drugs and Contrast Media. *ACR Manual on Contrast Media.*


Table 1. Measurements of ionising radiation

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Definition</th>
<th>Traditional units</th>
<th>Internationally accepted units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exposure</td>
<td>Number of ions produced by X-ray or gamma radiation per kilogram of air</td>
<td>Roentgen (R)</td>
<td>Coulomb/kilogram (C/kg) 2.58 x 10^{-4} C/kg</td>
</tr>
<tr>
<td>Dose</td>
<td>Amount of energy deposited per kilogram of tissue</td>
<td>Rad (rad)</td>
<td>Gray (Gy)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1000 mGy = 1 Gy</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1 Gy = 100 rad</td>
</tr>
<tr>
<td>Relative effective</td>
<td>Amount of energy deposited per kilogram of tissue normalised for biological</td>
<td>Roentgen equivalent man (rem)</td>
<td>Sievert (Sv)</td>
</tr>
<tr>
<td>dose</td>
<td>effectiveness</td>
<td></td>
<td>1000 mSv = 1 Sv</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1 Sv = 100 rem</td>
</tr>
</tbody>
</table>

\(^a\)For diagnostic X-rays: 1 rad = 1 rem; 1 Gy = 1 Sv.
Table 2. Summary of deterministic effects by gestational age$^{19,21}$

<table>
<thead>
<tr>
<th>Gestational age (weeks)</th>
<th>Effect of &lt;50 mGy (&lt;5 rad)</th>
<th>Effect of 50–100 mGy (5–10 rad)</th>
<th>Effect of &gt;100 mGy (&gt;10 rad)</th>
<th>Estimated threshold dose$^a$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0–2</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td>50–100 mGy</td>
</tr>
<tr>
<td>3–4</td>
<td>None</td>
<td>Probably none</td>
<td>Possible spontaneous miscarriage</td>
<td></td>
</tr>
<tr>
<td>5–10</td>
<td>None</td>
<td>Uncertain</td>
<td>Possible congenital anomaly (skeletal, ophthalmic, genital tract)</td>
<td>200 mGy</td>
</tr>
<tr>
<td></td>
<td></td>
<td>May be clinically undetectable</td>
<td>Fetal growth restriction</td>
<td>200–250 mGy</td>
</tr>
<tr>
<td>11–17</td>
<td>None</td>
<td>Uncertain</td>
<td>Risk of diminished IQ or mental retardation</td>
<td>60–310 mGy</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Microcephaly</td>
<td>200 mGy</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Severity is dose dependent</td>
<td>25 IQ point loss per 1000 mGy</td>
</tr>
<tr>
<td>18–27</td>
<td>None</td>
<td>None</td>
<td>IQ deficits not detectable at diagnostic doses</td>
<td></td>
</tr>
<tr>
<td>&gt;27</td>
<td>None</td>
<td>None</td>
<td>Not applicable to diagnostic medicine</td>
<td></td>
</tr>
</tbody>
</table>

$^a$Data based on results of animal studies, epidemiological studies of survivors of atomic bombs and groups exposed to medical radiation. IQ = intelligence quotient.
Table 3. Fetal radiation dose for common radiological investigations

<table>
<thead>
<tr>
<th>Type of examination</th>
<th>Fetal radiation dose (mGy)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Very low dose examinations (&lt;0.1m Gy)</strong></td>
<td></td>
</tr>
<tr>
<td>Cervical spine X-ray (AP and lateral views)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Chest X-ray (two views)</td>
<td>0.0005–0.01</td>
</tr>
<tr>
<td>Radiography of extremities</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Mammography (two views)</td>
<td>0.001–0.01</td>
</tr>
<tr>
<td>Head and neck CT</td>
<td>0.001–0.01</td>
</tr>
<tr>
<td><strong>Low to moderate dose examination (0.1–10 mGy)</strong></td>
<td></td>
</tr>
<tr>
<td>Abdominal X-ray</td>
<td>0.1–3.0</td>
</tr>
<tr>
<td>Lumbar spine X-ray</td>
<td>1.0–10</td>
</tr>
<tr>
<td>CT chest or pulmonary angiography</td>
<td>0.01–0.66</td>
</tr>
<tr>
<td>Limited CT pelvimetry</td>
<td>&lt;1</td>
</tr>
<tr>
<td>Low-dose perfusion scintigraphy</td>
<td>0.1–0.5</td>
</tr>
<tr>
<td>Technetium-99m bone scintigraphy</td>
<td>4–5</td>
</tr>
<tr>
<td>Pulmonary digital subtraction angiography</td>
<td>0.5</td>
</tr>
<tr>
<td><strong>Higher dose examinations (10–50 mGy)</strong></td>
<td></td>
</tr>
<tr>
<td>Abdominal CT</td>
<td>1.3–35</td>
</tr>
<tr>
<td>Pelvic CT</td>
<td>10–50</td>
</tr>
<tr>
<td>$^{18}$F-FDG PET/CT whole-body scintigraphy</td>
<td>10–50</td>
</tr>
</tbody>
</table>

$^{18}$F-FDG = 2-deoxy-2[fluorine-18]-fluoro-D-glucose. AP = anterior-posterior. CT = computed tomography. PET = positron emission tomography.
Box 1. Red flag symptoms associated with headache in pregnancy

<table>
<thead>
<tr>
<th>Red flag symptoms</th>
<th>Other considerations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sudden-onset headache reaching maximal intensity in &lt;1 minute</td>
<td>Patient blood pressure</td>
</tr>
<tr>
<td>New onset of severe headache</td>
<td>Past history of neurological conditions</td>
</tr>
<tr>
<td>Significant change in chronic headaches</td>
<td>Pituitary disease</td>
</tr>
<tr>
<td>Headache ± fever, meningism</td>
<td>Immunocompromise (HIV infection, immunosuppression)</td>
</tr>
<tr>
<td>Headaches triggered by cough, valsalva, sneezing or exercise</td>
<td>Malignancy</td>
</tr>
<tr>
<td>Orthostatic headache</td>
<td>Conditions associated with procoaguable state (thrombophilia, antiphospholipid syndrome, etc.)</td>
</tr>
<tr>
<td>New-onset focal neurological deficit, cognitive dysfunction or seizure</td>
<td>Current medication (medication overuse/abuse)</td>
</tr>
<tr>
<td>Head or neck trauma (within last 3 months)</td>
<td>Family history</td>
</tr>
<tr>
<td>Headache with aura including motor weakness (lasting &gt;1 hour)</td>
<td></td>
</tr>
<tr>
<td>Worsening headache (weeks or months)</td>
<td></td>
</tr>
<tr>
<td>Visual disturbances/visual field defects</td>
<td></td>
</tr>
</tbody>
</table>
Table 4. Recommended neurological imaging for suspected intracranial lesions

<table>
<thead>
<tr>
<th>Suspected intracranial lesion</th>
<th>Recommended imaging</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acute cerebrovascular accident (stroke)</td>
<td>CT/MRI and angiography*</td>
</tr>
<tr>
<td>Subarachnoid haemorrhage</td>
<td>Non-contrast enhanced CT</td>
</tr>
<tr>
<td>Central venous thrombosis</td>
<td>MRI and MRV or CT and CTV</td>
</tr>
<tr>
<td>Arterial dissection</td>
<td>Cervical MRI, duplex scanning, MRA ± CTA</td>
</tr>
<tr>
<td>Pituitary tumour</td>
<td>MRI</td>
</tr>
<tr>
<td>Choriocarcinoma</td>
<td>MRI or CT</td>
</tr>
<tr>
<td>Posterior reversible encephalopathy syndrome</td>
<td>MRI</td>
</tr>
<tr>
<td>Idiopathic intracranial hypertension</td>
<td>MRI and MRA</td>
</tr>
</tbody>
</table>

*May require multiple imaging modalities. CT = computed tomography. CTA = computed tomography angiogram. CTV = computed tomography venogram. MRA = magnetic resonance angiogram. MRI = magnetic resonance imaging. MRV = magnetic resonance venogram.