CLINICAL REVIEW

Risks of exposure to radiological imaging and how to minimise them

H E Davies,1 C G Wathen,2 F V Gleeson3 4

Since the 1970s, when computed tomography was introduced into clinical practice, the array of imaging tests that expose patients to radiation has vastly increased. This is a result of improved computed tomography techniques, advances in other techniques such as digital subtraction angiography, and the development of modalities such as positron emission tomography coregistered with computed tomography and single photon emission tomography coregistered with computed tomography. Improvements in non-ionising radiation imaging techniques, such as magnetic resonance imaging with increased field strength (3T) and multichannel technology, and Doppler and colour flow applications in ultrasound, have also occurred.

The demand for imaging has grown for several reasons. The development of picture archiving computer systems, which enable the referring doctor to view images easily, may have led to an increase in requests for diagnostic imaging. The public has become more aware of imaging tests and their potential benefit, especially in screening for cancer and cardiovascular disease, and faster scanners have allowed for imaging in previously unsuitable patients. Enhanced spatial resolution of images has resulted in the detection of previously unseen abnormalities of unknown relevance that often require further investigation and follow-up scanning. The treatment effects for many common diseases are now monitored using repeated imaging. Simultaneously, computed tomography has become more readily available, particularly in acute clinical areas.

Although the risks of cancer from computed tomography scans have been estimated recently,1 4 such risks may be poorly understood by doctors and poorly communicated, especially in the case of young patients and those with benign disease. In one survey of health providers in the United States, only 9% of emergency department doctors and 47% of radiologists were aware of the increased cancer risk associated with computed tomography.5

Here, we examine the risks of exposure to radiation associated with some routine diagnostic imaging investigations and discuss practical ways to minimise such risks. This review is based on evidence from retrospective cross sectional studies, special reports, prospective cohort studies, surveys, observational studies, and current international guidelines.

Why is exposure to radiation from medical imaging increasing?

In the developed world, medical “technology creep” has promoted the use of modern technology while ignoring more conventional imaging tests. For example, two recent reviews of imaging in pulmonary embolic disease in leading medical journals did not mention chest radiography but suggested using computed tomography pulmonary angiography as the initial test.6 7

The past 30 years has seen more than a 20-fold increase in the number of computed tomography scans obtained annually in the US.8 In the United Kingdom, use of computed tomography has doubled in the past decade.9 We predict that computed tomography based screening programmes for the prevention of primary and secondary disease will escalate markedly and further contribute to iatrogenic radiation exposure. As an example, a recent press release in the US stated the benefit of lung cancer screening using computed tomography.9

New approaches to treatment often now require imaging at diagnosis and at intervals during treatment to assess the response. As examples, guidelines from the Fleischner Society advise that a 5 mm pulmonary nodule should be followed up with regular scans for two years,10 and the reclassification of gastrointestinal stromal tumours and their treatment with imatinib mean that computed tomography and positron emission tomography with computed tomography are now used in patient groups previously not scanned.11 12

SUMMARY POINTS

The demand for imaging, especially computed tomography, has increased vastly over the past 20 years

An estimated 30% of computed tomography tests may be unnecessary

Ionising radiation may be associated with cancer and other non-neoplastic sequelae

The risks of iatrogenic radiation exposure are often overlooked and patients are seldom made aware of these risks

The requesting doctor must balance the risks and benefits of any high radiation dose imaging test, adhering to guideline recommendations if possible

Difficult cases should be discussed with a radiologist, ideally at a clinicoradiological or multidisciplinary team meeting

REFERENCES


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10. BMJ.com Previous articles in this series

11. Telehealthcare for long term conditions (BMJ 2011;342:d120)

12. Preventing exacerbations in chronic obstructive pulmonary disease (BMJ 2011;342:c7207)


14. Diagnosis and management of hereditary haemochromatosis (BMJ 2011;342:c7251)

15. bmj.com

16. SOURCES AND SELECTION CRITERIA

We searched PubMed and used our personal reference collections. We also reviewed guidelines from the British Thoracic Society, Royal College of Radiology, and American College of Radiology. In addition, we retrieved national recommendations from the National Institute for Health and Clinical Excellence (NICE).
**CLINICAL REVIEW**

### Table 1 | Average* effective doses of radiation for various diagnostic radiology procedures

<table>
<thead>
<tr>
<th>Procedure†</th>
<th>Average effective dose of radiation (mSv)</th>
<th>Equivalent number of radiographs</th>
<th>Equivalent period of average natural background radiation (days)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Posteroanterior chest radiography</td>
<td>0.02</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Skull radiography</td>
<td>0.1</td>
<td>5</td>
<td>15</td>
</tr>
<tr>
<td>Mammography</td>
<td>0.4</td>
<td>20</td>
<td>61</td>
</tr>
<tr>
<td>Pelvic radiography</td>
<td>0.6</td>
<td>30</td>
<td>91</td>
</tr>
<tr>
<td>Abdominal radiography</td>
<td>0.7</td>
<td>35</td>
<td>106</td>
</tr>
<tr>
<td>Lung perfusion scintigraphy (99m-Tc-MDP)</td>
<td>2.0</td>
<td>100</td>
<td>304</td>
</tr>
<tr>
<td>CT brain</td>
<td>2.0</td>
<td>100</td>
<td>304</td>
</tr>
<tr>
<td>Intravenous urography</td>
<td>3.0</td>
<td>150</td>
<td>456</td>
</tr>
<tr>
<td>Bone isotope scintigraphy (99m-Tc-MDP)</td>
<td>6.3</td>
<td>315</td>
<td>958</td>
</tr>
<tr>
<td>CT chest</td>
<td>7.0</td>
<td>350</td>
<td>1065</td>
</tr>
<tr>
<td>CT abdomen</td>
<td>8.0</td>
<td>400</td>
<td>1217</td>
</tr>
<tr>
<td>Barium enema</td>
<td>8.0</td>
<td>400</td>
<td>1217</td>
</tr>
<tr>
<td>CT pulmonary angiography</td>
<td>15.0</td>
<td>750</td>
<td>2281</td>
</tr>
<tr>
<td>CT coronary angiography</td>
<td>16.0</td>
<td>800</td>
<td>2433</td>
</tr>
</tbody>
</table>

*Exact doses vary according to the imaging technique used. As an example, for CT of the chest, whether volumetric 0.675 mm or 2.5 mm settings are used and whether overlapping or contiguous image acquisition is used.

CT=computed tomography; 99m-Tc-MDP=technetium-99m-methyl methacrylate; 99m-Tc-MDP=technetium-99m-methylene diphosphonate.

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### What levels of radiation accompany routinely performed procedures?

Table 1 shows representative mean effective doses of radiation associated with various procedures.

The term “effective dose” is used in radiation protection and indicates the radiation effect of a specific imaging modality in terms of an estimated equivalent whole body radiation dose. This allows the level of exposure associated with different techniques to be compared. This biological effect is measured in millisieverts (mSv), which are the product of the “absorbed dose” (in grays; Gy) and a dimensionless weighting factor (often known as the quality factor or Q); Q varies according to the body part irradiated, the radiation type, and the regimen delivered.

The “organ specific dose” reflects the calculated radiation delivered to any selected organ (table 2) and is the preferred measure for estimating radiation risk.

### How much radiation exposure is usual?

Natural background radiation emanates from two primary sources—cosmic radiation and terrestrial or environmental radionuclides, which vary according to the latitude and altitude of the location. Little can be done to influence natural radiation levels. Radon gas is one of the main contributors; it emits α radiation, which can build up within the home (particularly if well insulated). The average person receives an effective dose of about 2.4 mSv each year, but this varies between populations. About 10% of people worldwide are exposed to annual effective doses greater than 3 mSv.

Global radiation doses to the public have increased by 20% since the start of the 20th century, mainly because of the expansion of diagnostic imaging techniques. Indeed medical radiation accounts for around 15% of the total exposure in the UK’s population.

### What are the known consequences of radiation exposure?

Most information about the adverse effects of radiation has been extrapolated from data collected from atomic bomb survivors at Hiroshima and Nagasaki, populations living near nuclear disasters such as Chernobyl, or people with medical or occupational exposures. Whether such projections accurately assess the effects on people exposed to lower clinical radiation doses is unknown, but biological experiments suggest that all radiation exposure may cause harm.

#### Cancer

Epidemiological data have shown that ionising radiation causes cancer in humans. The risk of adverse sequelae increases with higher doses of radiation and for tissues with a high sensitivity to ionising radiation, such as the breast and thyroid. In 2004, x ray related radiation was estimated to be responsible for 0.6% of all cancers diagnosed in the UK, and recent estimates indicate that one in 270 women aged 40 years who undergo computed tomographic coronary angiography will develop cancer as a result. These figures may seem alarming, but they must be viewed in the context of the absolute excess risk associated with medical radiation compared with the lifetime risk of disease.

#### Non-neoplastic effects

Radiation can cause genetic mutations, intellectual or developmental disabilities in the children of mothers exposed to radiation during pregnancy, and an increased incidence of cardiovascular disease. Direct effects include skin injury, the development of cataracts, and hair loss; these most commonly occur after radiotherapy, although diagnostic computed tomographic perfusion examinations have been implicated as the cause of hair loss in patients in the US, with litigation ensuing.

#### Understanding the size of increased risks

The recent Biologic Effects of Ionizing Radiation (BEIR) VII report on the effects of ionising radiation predicted a lifetime attributable risk from a 10 mSv effective dose of one radiation induced cancer per 1000 patients. This lifetime risk model estimates that a single 100 mSv exposure would cause one in 100 people to develop a solid cancer or leukaemia, compared with a lifetime risk of about 42 in 100 from unrelated causes. This suggests that the excess number of cases (inclusive of non-fatal cases) of solid tumours in the UK population is 800 a year (95% confidence interval 400 to 1600) in men and 1300 a year (690 to 2500) in women; excess deaths in the UK a year from exposure to 100 mSv would be 410 (200 to 830) and 610 (300 to 1200) for men and women, respectively.
Although these numbers seem small compared with the estimated one in three absolute lifetime risk per person of developing cancer in the UK,\(^{20}\) they are worrying for the following reasons. The risk arises from an iatrogenic cause; large numbers of people are exposed; children may be exposed; and risks may be underestimated, particularly in those who have repeated tests, such as young patients with suspected renal colic who have repeated abdominal computed tomograms.

**Who is most at risk?**

**Pregnant women**
The use of diagnostic imaging in pregnant women should be carefully considered because of potential teratogenic and oncogenic effects of radiation on the fetus. The minimum dose at which adverse sequelae may occur has not been firmly established. However, the International Commission on Radiological Protection (ICRP) regards radiation doses greater than 100 mGy as potentially teratogenic, with a risk of fetal growth retardation, cognitive impairment, and damage to the central nervous system.\(^{21,22}\)

The absolute risk of future malignancy remains low. For example, if chest radiography, ventilation-perfusion scanning, and computed tomographic pulmonary angiography are performed in a pregnant patient with suspected pulmonary emboli, the fetus is exposed to a total radiation dose of about 4 mGy. The ICRP states that fetal exposure to 10 mGy increases the probability of cancer before 20 years of age from 0.03% to 0.04% and suggests that this is not a clinically important increase in risk.\(^{21}\)

However, risks to the mother must also be considered. There is a concerning lack of evidence about the safety of computed tomographic pulmonary angiography during pregnancy, because pregnant patients have been excluded from the large prospective trials performed to date.\(^{22}\) Although this test exposes the fetus to less radiation than when ventilation perfusion scintigraphy is used,\(^{21}\) it exposes the maternal breast to about 150 times more radiation than does ventilation perfusion scintigraphy.\(^{21}\) During pregnancy, breast tissue is more susceptible than normal to radiation damage. Protective shields may reduce radiation exposure by more than 50%,\(^{21,23}\) but these are not always used in UK radiology departments. Alternative imaging modalities, such as half dose perfusion scans, should be performed wherever possible in pregnant women.

**Children**
Computed tomography is now performed more often than previously in children because technological advances have eliminated the need for anaesthesia to prevent movement artefacts in all except the very young. National surveys have estimated that in the US 6-11% of all computed tomography studies are currently performed in children.\(^{24,25}\)

The risks from exposure to radiation are greater for children than for adults because paediatric tissues are more radiosensitive and because children have a longer life expectancy during which radiation related effects may develop.

**How to reduce the risk?**
National guidelines have been developed to help doctors and to optimise the use of radiology services.\(^{26,27}\) However, to reduce the numbers of unnecessary scans, this advice needs to be integrated into clinical practice. Some strategies that may help to cut exposure to radiation by reducing the number of imaging tests are as follows.

**Calculate before you order**
Several online tools are available to enable doctors (and patients) to calculate the estimated effective radiation dose from specific investigations and the equivalent period of background exposure (www.doseinfo-radar.com/RADAR-DoseRiskCalc.html; www.xrayrisk.com/calculate/calculator.php). An iPhone application is available to calculate and record accumulating radiation exposure from radiological examinations (Radiation Passport, Tidal Pool Software). Calculating single and accumulated exposure to ionising radiation may lead to more considered decisions being made about the need for imaging, particularly for patients who need repeated tests.

**Reduce unnecessary computed tomography examinations**
Estimates from cohort studies suggest that about 30% of computed tomography scans are unnecessary.\(^{7}\) Adherence to local or national radiological guidelines, such as the American College of Radiology’s appropriateness criteria and the Royal College of Radiologists’ publications, should reduce the number of unnecessary tests.\(^{27,28}\) One example is the use of brain computed tomography for patients admitted after an acute head injury. Recommendations from the National Institute for Health and Clinical Excellence and the Scottish Intercollegiate Guidelines Network set clear parameters on which patients require an urgent scan.\(^{29,30}\) Recommendations for certain patients, such as those presenting 24 hours after the injury, are unclear however, and for these patients discussion with radiology colleagues is prudent. Similarly, the measurement of the clinical probability score and D-dimer in patients with suspected pulmonary emboli may reduce the number of unnecessary computed tomographic pulmonary angiography scans performed.\(^{31}\)

**Use other imaging techniques if possible**
Magnetic resonance imaging and ultrasound procedures do not deliver radiation to the patient and should be used instead of radiological imaging wherever possible.

**Standardise operating procedures for radiological examinations**
Implementation of standard operating procedures for radiological tests at a local and national level could negate discrepancies in the radiation doses given for the same test at different sites.

**Use technological advances to increase safety**
New computed tomography scanners that can detect signal at lower radiation doses could enable the delivery of lower doses of radiation. Low dose computed tomography protocols should be used as standard to follow up pulmonary nodules and renal calculi.

**What should patients be told?**
Although patients are routinely told about the potential adverse events of interventional diagnostic procedures...
and their informed consent required, patients undergoing radiological imaging studies do not usually receive similar information and neither are they asked for consent. These tests are usually performed in the patients’ best interests, but in certain circumstances an awareness of the radiation risk and knowledge of alternative options might affect the patient’s decision and alter the course of their management. In our experience, some pregnant mothers choose to undergo computed tomographic pulmonary angiography when pregnant rather than a half dose perfusion scan because they wish to reduce the radiation exposure to their fetus even when reassured that the perfusion scan is safe.

We believe that the risks associated with some diagnostic radiation exposures, particularly from procedures involving much higher doses than conventional radiography, should be discussed with patients or their guardians before the examination. Table 3 outlines the risks associated with some commonly performed procedures that may be communicated to patients.

Current legislation does not give dose limits for common medical imaging exposures, although radiology departmental policies in the UK usually adhere to an “as low as reasonably practicable” policy. The position of the doctor in recommending a screening computed tomography scan is not clear and has recently been reviewed by the Department of Health’s committee on medical aspects of radiation in the environment.26

Patients should be provided with the information needed to understand the potential benefits and risks of the intervention and assign subjective weight to these factors, in order to make an informed choice (box). Provision of these data is often overlooked.

It is important to ensure meticulous documentation to outline the indication for the test, and to discuss the choice with the patient or their representative and with colleagues. Wherever possible, to promote good practice, such decisions should be discussed in clinicoradiological or multidisciplinary meetings.

### Considerations before any radiological examination

**Review the circumstances of each case individually**

**Assess whether the patient needs the test? Why is it needed? Will the result change management?**

**Consider whether a non-radiological alternative exists**

**Explain to the patient, his or her family, or the carer what the test involves and the associated radiation exposure; this may be most clearly shown in terms of equivalent numbers of chest radiographs (see table 1)**

**Outline the risks versus the benefits of the test** (see table 2)

**Agree an alternative management plan if the patient declines the examination**

### Conclusion

Over recent years increasing numbers of imaging studies have been performed, and this trend looks set to continue on a global scale. As technological progress creates more sensitive faster scanners, and worldwide access improves, greater numbers of patients will be exposed to radiation and contribute to an increasing public health problem.

Communication between the doctor and radiologist is crucial in deciding whether computed tomography is appropriate. To ensure that only justifiable tests are performed, imaging requests should either be discussed with a radiologist or agreed protocols should be adhered to. It is the responsibility of the clinician to assess the benefits and risks of any proposed test, to incorporate recommendations from existing guidelines, and to provide patients with the information needed to ensure an informed decision is made before high radiation dose imaging tests are performed.

### Provenance and peer review

Not commissioned; externally peer reviewed.


ANSWERS TO ENDGAMES, p 605. For long answers go to the Education channel on bmj.com

PICTURE QUIZ Atypical diabetic retinopathy

1. All layers of the retina contain widespread multiple haemorrhages. Some haemorrhages look round and have a white centre. These are indicative of Roth spots (figure). There are also some cotton wool spots but no features of retinal abscess or necrosis. 2. Roth spots have been seen but no features of retinal abscess or necrosis; anoxia (after prolonged filtration surgery); intracranial decompression (such as glaucoma filtration surgery); intracranial haemorrhage; and neonatal birth trauma. Because the patient was well and asymptomatic, with no features of infection, the most likely differential diagnoses are leukaemia, anaemia, hypertension, and diabetic retinopathy. 3. Ascertain the patient’s medical history and any history of past trauma. History taking should aim to identify features of systemic sepsis, malignancy, or the chronic disorders mentioned above. Carry out a full systemic examination, bearing in mind the differential diagnoses. 4. A full blood count to look for anaemia, leucocytosis, and thrombocytopenia; a peripheral blood film if the full blood count suggests leukaemia; inflammatory markers (erythrocyte sedimentation rate and C reactive protein), which may be raised in infective endocarditis; blood cultures in suspected infective endocarditis or septicemia; urine dipstick to look for haematuria and proteinuria (infective endocarditis can cause glomerulonephritis), leucocytes and nitrates (urinary tract infections), and glucose (diabetes); random blood glucose to look for diabetes; echocardiography to identify vegetations and valvular dysfunction in infective endocarditis; other investigations for systemic infections (such as cerebrospinal fluid cultures for bacterial meningitis, abdominal ultrasound for liver abscess, etc.).

STATISTICAL QUESTION

Sampling methods II

Answer c best describes the sampling method used.

ON EXAMINATION QUIZ

Total hip replacement

Option E is the correct answer.

CASE REPORT

A young woman with rigors and abdominal pain

1. The fever and rigors suggest infection, and viral illnesses should be considered in the absence of objective evidence of a bacterial infection. The development of a rash in response to penicillin suggests infectious mononucleosis as a result of Epstein-Barr virus (EBV) infection. Other possibilities include false negative urinary in the presence of urinary tract infection or pyelonephritis; gastroenteritis; pelvic inflammatory disease; and inflammatory conditions, such as Crohn’s disease.

2. The most commonly performed investigation is a “monospot” test for heterophile antibodies, which identifies IgM antibodies to EBV viral capsid antigen. This test may be negative in the incubation period and early stages of the illness. Other tests available include assays for other antibodies to viral capsid antigen and polymerase chain reaction (PCR) for EBV DNA, which may be useful in immunocompromised hosts.

3. Patients should be given supportive treatment, with analgesia and fluid replacement if needed. Trials of antivirals and corticosteroids have shown little benefit in uncomplicated infectious mononucleosis, although steroids may be useful for treating complications, such as airway obstruction. Splenic rupture requires urgent surgery.

4. Life threatening but infrequent complications include splenic rupture and upper airway obstruction secondary to swollen pharyngeal tissues. Transient hepatitis may also occur. Other rare documented complications include Guillain-Barré syndrome, myelitis, haemolytic anaemia, and thrombocytopenia. Another rare complication is haemophagocytic syndrome (haemophagocytic lymphohistiocytosis) for which acute EBV infection is the most commonly identified infectious trigger. The disease is associated with chronic fatigue syndrome, which may prevent the patient returning to work or studies.