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CORE TRAINING FOR DOCTORS

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Explaining radiation risks to patients

Introduction

Technological advances in radiological imaging have improved diagnosis and treatment in modern medicine. This has included several ionizing radiation modalities, which are now becoming increasingly available and more rapid in acquisition. The demand for modalities such as computed tomography is also linked with an increased public awareness both of the potential benefit and also perceptions about quantities of radiation involved.

This article gives practical advice to doctors about radiation. It will improve understanding and therefore aid communication regarding radiation risk.

Radiation exposure

Radiation originating for medical examinations and tests is the greatest manmade source of radiation exposure, representing around 20% of the average radiation exposure to the population of the world (World Health Organization, 2013). The unit used to measure the biological effect is the sievert (Sv). One sievert is equal to one joule per kg.

The average person is constantly exposed to natural background radiation. This originates from cosmic radiation or environmental radionuclides, and the largest component is made up of radon gas. An effective dose of approximately 2.7 mSv annually is quoted for the average person in the UK but there will be variability with location and populations (Public Health England, 2013).

X-rays form a large proportion of the different types of ionizing radiation used in medicine. Other types include gamma rays, alpha particles and beta particles used in clinical oncology and nuclear medicine.

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Biological effect of radiaton

Ionizing radiation causes damage by depositing energy into tissue. This happens in two ways, either by direct damage of covalent bonds or indirectly by production of free radicals. The overall amount of energy is relatively small, but the energy is deposited over a very small area and in diagnostic radiology this is high enough to break molecular bonds and cause free radical formation. The most potentially serious effects of ionizing radiation are caused by damage to DNA molecules. If not repaired DNA damage can lead to cell death, cancer and inherited genetic defects.

Different tissues of the body have different sensitivities to radiation. Those that are more rapidly turning over cells have a higher chance of incurring radiation-induced damage. Owing to these differences the same dose applied to different parts of the body inherently will have different potential to cause harm. For example, a computed tomography scan of the head has a far lower risk of causing radiation-induced cancer or inherited effect than a computed tomography scan of the thorax or pelvis with radiosensitive organs such as the breast and gonads respectively.

Estimation of radiation risk

The information collected regarding the adverse effects of radiation has relied heavily on extrapolated data from the atomic bomb and survivors. The doses involved with Hiroshima and Nagasaki, however, in general far exceed any medical exposures and very little accurate data exist for the types of low dose exposures that patients receive in radiology departments. Radiation protection principles for medical and occupational exposures are essentially based on estimates using extrapolated data. There are several models that have been described to estimate the risks of low dose ionizing radiation.

The dominant model in use has been described by the Biological Effects of Radiation (BEIR) subcommittee of the US National Institute of Science (BEIR VII) (National Research Council et al, 2006). They describe a 'linear and non-threshold' model in which the biological risks of radiation (primarily cancer) are directly proportional to dose, with no minimum threshold value. Low dose radiation is defined by the BEIR VII as an effective dose less than 100 mSv (National Research Council et al, 2006). Most doses in diagnostic radiology are far lower than this and there is therefore significant uncertainty about the excess cancer risk induced by these very low doses of radiation. At low doses the body's repair mechanisms should provide some additional protection against radiation damage.

Radiation protection and radiation risk reduction

Radiation protection relies on the premise that any dose, regardless of quantity, can result in detrimental health effects. Using the principle of 'do no harm', current practice aims to keeps doses 'as low as reasonably achievable' (ALARA).

Radiation protection is one of the primary roles of a radiologist, but all doctors have a role in radiation protection. It is the job of the 'referrer', usually a doctor, to provide accurate and relevant information for every radiological investigation. According to the Ionising Radiation (Medical Exposure) Regulations (Department of Health, 2000) every investigation involving ionizing radiation requires 'justification' by a suitably trained 'practitioner' who should have appropriate knowledge of the potential benefits and risks of the type of exposure.

In the UK radiologists or clinical oncologists usually act as 'practitioners' depending on the radiological test or intervention. Radiologists are allowed to delegate this responsibility under set guidelines to 'operators', i.e. radiographers, because of the sheer number of imaging procedures that are performed. For example, plain radiographs are often protocolled in this way. Owing to the higher radiation doses involved in computed tomography, interventional radiological and nuclear medicine studies these all require justification by a radiologist or nuclear medicine specialist.

While guidelines for clinical scenarios may reduce unnecessary scans, radiologists are suitably placed to offer advice on alternative lower dose or even non-ionizing modalities. Patients most at risk of exposure to large cumulative doses are those who frequently present with the same clinical condition, e.g. inflammatory bowel disease. Instead of serial computed tomography scans, magnetic resonance imaging could be used for imaging these patients, which would significantly reduce their cumulative dose over several admissions.

Explaining radiation to patients

It has been demonstrated that there is a general lack of understanding regarding the potential risks of radiation. A study in America has shown that a substantial portion of doctors across specialties did not perceive that there is an increased risk of cancer from a diagnostic computed tomography scan. The same study also showed that there is a lack of understanding regarding the dose quantities involved with computed tomography scans when compared to chest radiographs (Lee et al, 2004). It is important for every health professional to have a concept of and be able to explain the risks associated with ionizing radiation.

Good explanation of risk is especially important in the case of children and pregnant women but the importance of risk *vs* benefit should always be considered. Studies have shown that the chances of developing a radiation-induced cancer are higher the younger the age at which the exposure occurred (National Research Council et al, 2006). This is why it is especially important to reduce radiation exposure in these vulnerable groups to a minimum. Use of modalities such as magnetic resonance imaging and ultrasound is advisable where possible. The use of low dose computed tomography protocols is also prudent.

There is increasing evidence that radiation exposure in childhood causes an excess risk of cancer over and above that seen in an adult population (Brenner et al, 2001). A recent large Australian cohort study adds to this evidence, not only demonstrating an increased risk of cancer with increasing computed tomography dose but also an increased risk the younger the age at radiation exposure (Mathews et al, 2013). This again highlights the need for very careful justification of the use of X-ray and in particular computed tomography in children and young adults.

When explaining risks to patients it is important to emphasize that the effective doses used in most diagnostic imaging studies are low and therefore the relative risk to their health is also low. *Table 1* compares the radiation doses where more immediate effects can occur to some common radiation exposures and background radiation (Public Health England, 2013).

The fact that doses are relatively low does not reduce the need for careful justification as there remains a small increased risk of not only cancer but also inherited effects. The risks of ionizing radiation are postulated to increase linearly with dose and therefore, with increasing use of computed tomography, cumulative doses can quickly start to add up, significantly increasing a patient's risk in the following years. It is estimated that 42 out of 100 individuals will be diagnosed with a cancer (solid or leukaemia) in their lifetime. This

Table 1. Comparison of different effective doses

Source of exposure	Effective dose (mSv)
Chest X-ray	0.02
Transatlantic flight	0.07
Average background radiation dose in UK	2.7
Whole body computed tomography	10
Annual exposure limit for nuclear power employees	20
Dose at which changes in blood cells can be seen	100
Acute radiation effects, e.g. nausea and reduction in white blood cell count	1000
Dose of radiation that would kill around half of those receiving it in a month	5000

From Public Health England (2013)

is the average person's baseline risk. The BEIR VII report estimates that a dose of 10 mSv will lead to an excess cancer risk above baseline of 0.01% (National Research Council et al, 2006).

To put this into context we could take an average staging computed tomography scan of the chest, abdomen and pelvis, the dose of which is approximately equal to 10 mSv (Public Health England, 2013). Applying the BEIR VII estimate would mean that, on average, one extra cancer above baseline would be expected if 10 000 patients underwent this procedure. This is a small but not insignificant risk, especially as the number of computed tomography scans which are being performed in the UK is rising year on year. In 2008 it is estimated that in the UK 3.4 million computed tomography examinations were carried out compared to 1.4 million back in 1997. There is therefore the potential for a significant number of radiation-induced cancers in the future (Hart et al, 2010).

Comparison of dose to background levels of radiation can also help to put dose levels into context. The average annual radiation dose in the UK is around 2.7 mSv (Public Health England, 2013). This is made up of a number of different sources. The largest source of radiation comes from radon gas. Average radon exposure equates to around 1.3 mSv a year, although in Cornwall this is estimated to be as high as 7.8 mSv (Public Health England, 2013). *Table 2* shows the average effective doses of some of the most commonly performed radiological examinations and equivalent number of chest radiographs.

The use of ionizing radiation in pregnant women should be very carefully considered because of the potential teratogenic and oncogenic effects on the fetus. A threshold dose above which adverse outcomes occur has not been accurately determined, but doses greater than 100 mGy have been postulated to be teratogenic (International Commission on Radiological Protection, 2000). Other detrimental effects include fetal growth retardation, cognitive impairment and CNS damage (Hart et al, 2010). The risk of teratogenesis is highest in the 3–8th week of gestation as this is the period where organogenesis occurs.

The International Commission on Radiological Protection (2000) has stated that a fetal exposure of around 10 mGy increases the probability of cancer before 20 years of age from between 0.03 to 0.04%. This is not felt to be a clinically important risk.

The investigation of pulmonary emboli is one of the most common reasons for exposure of higher doses of radiation during pregnancy. The incidence of pulmonary emboli is estimated at between 5 and 12 events per 10 000 pregnancies (Bourjeily et al, 2010). With just over 900 000 conceptions in 2011 in England and Wales this potentially equates to up to around 1000 diagnoses of pulmonary emboli per year (Office of National Statistics, 2013). However, this figure is likely to be a far smaller number than those who will be investigated for pulmonary emboli during pregnancy.

As with every test in medicine a risk–benefit analysis must be undertaken. It is important to note that pulmonary embolism is an important and preventable cause of death during pregnancy and the postpartum period. The most recent data from the Confidential Enquiry into Maternal and Child Death shows a mortality rate from pulmonary emboli of 0.79 per 100 000 pregnancies between 2006 and 2008. This represents 16 deaths directly caused by pulmonary emboli, equating to approximately 6% of the total number of maternal deaths (261) in that 3-year period (Centre for Maternal and Child Enquiries, 2011).

Guidelines from the Royal College of Obstetrics and Gynaecology (2007) recommend a chest X-ray and bilateral lower limb compression ultrasound as part of the initial work up of suspected pulmonary embolus. If no deep venous thrombosis is detected and there remains a strong clinical suspicion of pulmonary emboli, either a ventilation–perfusion scan or computed tomography pulmonary angiogram are recommended. There is debate about which is the most appropriate test to use during pregnancy. There has to be a balance between making an accurate diagnosis and keeping the risks to the mother and fetus to a minimum. The average fetal exposure for both procedures is approximately 4 mGy although

Table 2. Examples of plain radiograph, computed tomography and nuclear medicine effective doses and comparison with equivalent number of plain chest radiographs

Type of exposure	Average adult effective dose (mSv)	Equivalent no of chest X-rays
Chest X-ray	0.02	1
Cervical spine X-ray	0.2	10
Lung ventilation (^{99m}Tc-DTPA)	0.2	10
Pelvis X-ray	0.6	30
Abdominal X-ray	0.7	35
Thoracic spine X-ray	1.0	50
Lumbar spine X-ray	1.5	75
Lung perfusion scintigraphy (^{99m}Tc-MMA)	2.0	100
Computed tomography brain	2.0	100
Low dose computed tomography kidneys, ureters, bladder	2.8	140
Computed tomography pelvis	6.0	300
Bone isotope scintigraphy (^{99m}Tc-MDP)	6.3	315
Computed tomography thorax	7.0	350
Computed tomography abdomen	8.0	400
Computed tomography pulmonary angiogram	15.0	750

DTPA = diethylenetriamine pentaacetic acid; MMA = macroaggregated albumin; MDP = methylene-diphosphonate.
From Liu et al (2000), Mettler et al (2008), Public Health England (2013)

this is thought to be slightly less in a computed tomography pulmonary angiogram (Bourjeily et al, 2010). However, it is important to note that there is an approximately 150-fold increase in the maternal breast dose with computed tomography pulmonary angiogram compared to a ventilation–perfusion scan (Bourjeily et al, 2010).

Neither test is perfect, however. There will be a proportion of false positives and false negatives as well as non-diagnostic scans with both techniques. Using data from the PIOPED study for ventilation–perfusion scans, almost all patients with pulmonary emboli had abnormal scans of high, intermediate or low probability, but so did most without pulmonary emboli (sensitivity 98%, specificity 10%) (PIOPED Investigators, 1990).

The type of scan used is often dependent on individual institution, its local guidelines and the availability of ventilation–perfusion scanning. A normal chest radiograph is required before performing a ventilation–perfusion scan. If an abnormality is found on the initial chest radiograph and pulmonary embolism is still suspected a computed tomography pulmonary angiogram is recommended. In an unstable patient computed tomography pulmonary angiogram should be performed, as it is not only quicker but may provide an alternative diagnosis, for example an aortic dissection (Bourjeily et al, 2010).

Conclusions

Medical imaging modalities that use ionizing radiation are an invaluable resource in diagnostic medicine. Technological advances in computed tomography most especially have meant that lower doses than ever are possible. The rapid acquisition of images has also meant that more patients can have scans than ever before. The benefits of accurate and timely diagnosis are extremely important factors to explain why the field of medical imaging is growing exponentially. This does not negate the fact that careful justification of all investigations using radiation is extremely important because of the small but cumulative risks associated with radiation exposure. BJHM

Conflict of interest: none.

TOP TIPS

- When asked to explain radiation risk to patients, always balance the risk with benefit of diagnosis.
- As a ‘referrer’ for an examination, it is important to provide both accurate and relevant information to allow for ‘justification’ for an examination.
- Always consider the use of non-ionizing radiation wherever possible, particularly if patients need repeated examinations.
- The use of less ionizing basic examinations, where appropriate, should be encouraged initially rather than more complex cross-sectional imaging.

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KEY POINTS

- The increase in use of ionizing radiation modalities requires all doctors to have a working knowledge of effects.
- In communicating with patients a balanced view of risk against benefit should always be emphasized.
- Certain scenarios require extra justification (for example children and pregnant women) and non-ionizing modalities should be used wherever possible.
- Doses to patients should always be kept as low as reasonably achievable.