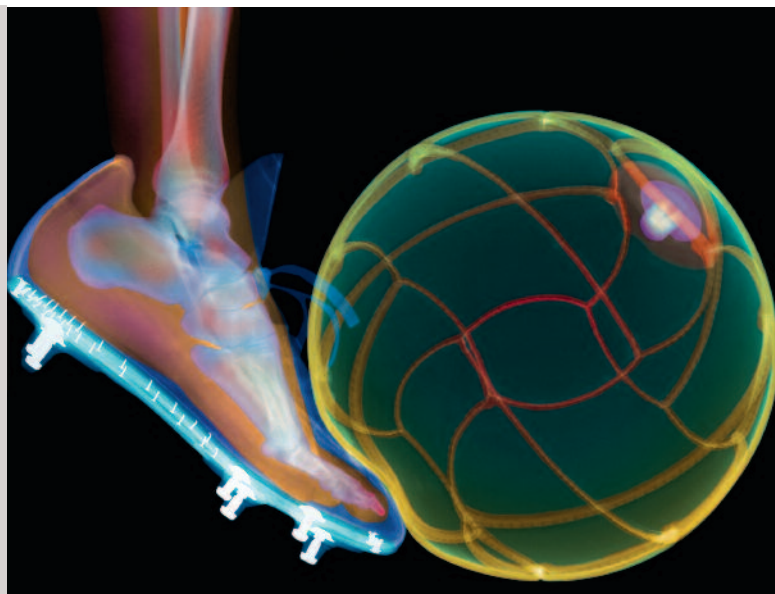


# Diagnostic imaging: radiation exposure and safety considerations

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Despite the overall health benefits to patients from advances in medical imaging, the small and theoretical risk of a detriment to health from exposure to diagnostic ionising radiation should be appreciated.

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Doctors have a number of investigations available to them to help diagnose suspected injuries in sports medicine. Many of these involve ionising radiation (conventional radiography, CT scanning, bone scanning), whereas others do not (MRI, ultrasound). One of the dictums of medical practice is *Primum non nocere* (First, do no harm). Exposure to diagnostic ionising radiation, like other medical tests and procedures, is associated with a risk to the patient. In this case, there is a potential risk, albeit small, of a radiation-induced cancer and/or a genetic disorder in one's offspring.

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The use of ionising radiation in medicine is the single largest man-made source of population radiation exposure.<sup>1-3</sup> Exposure to diagnostic ionising radiation continues to rise significantly, year after year. This is due to the increasing availability and use of medical imaging procedures in modern healthcare systems as well as the development of some high-dose techniques. For example, Americans were exposed to more than six times as much ionising radiation from diagnostic medical procedures in 2006 than they were in the early 1980s.<sup>4</sup>

It must be appreciated that radiation is constantly present in our environment. Sources of this 'background radiation' include cosmic rays from the universe, and naturally occurring radioactive substances in the food and water we eat and drink and the air we breathe, and in the ground and soils.

## HOW ARE DOSES OF DIAGNOSTIC IONISING RADIATION MEASURED?

The more common sports medicine tests associated with ionising radiation involve x-ray radiation (from conventional radiography or CT scanning) or gamma radiation (emitted by radiopharmaceuticals, most commonly technetium-99m [<sup>99m</sup>Tc] in bone scanning) in nuclear medicine imaging. X-rays and gamma rays ionise atoms and molecules in human tissues through the deposition of energy. DNA strand breakages from this ionisation process may be the first step in a series of events that lead to a biological effect (cancer) and/or genetic effect.<sup>5</sup>

Biological exposure to ionising radiation is expressed in terms of the 'effective dose', which takes into account the amount of radiation absorbed by each irradiated organ and its relative

## EFFECTIVE DOSES AND RISK ESTIMATES FOR SOME COMMON INVESTIGATIONS IN SPORTS MEDICINE\*

The effective doses and risk estimates shown in the tables below were calculated for a theoretical male patient (20 to 29 years of age, 80 kg), and are based on the machines and imaging protocols in use at a particular radiology practice in Sydney in 2003.<sup>10</sup> It should be appreciated that the effective dose can vary significantly between radiological practices because of differences in machinery and imaging protocols.<sup>1-4,7,12</sup> Effective doses and risk estimates were estimated using mathematical modelling developed by the National Radiological Protection Board (NRPB) and International Commission on Radiological Protection (ICRP).<sup>5,6,10,11</sup>

The risk estimate is defined as the risk incurred by this theoretical patient that he will develop a fatal cancer earlier in life than he would otherwise have developed had he not been exposed to a particular effective dose of ionising radiation.

**TABLE 1. CONVENTIONAL RADIOGRAPHY**

Examination	Effective dose per examination series (mSv)	Risk estimate (fatal cancer)
Chest	0.067	1 in 250,000
Ribs	0.720	1 in 23,000
Sternum	1.270	1 in 13,000
Face/nose/orbit	0.030	1 in 550,000
Cervical spine	0.034	1 in 480,000
	0.063 (with oblique views)	1 in 260,000
Thoracic spine	0.730	1 in 22,000
Lumbar spine	1.630	1 in 10,000
	1.960 (with oblique views)	1 in 8000
Pelvis	0.860	1 in 19,000
Shoulder	0.040	1 in 410,000
Elbow/forearm	0.003	1 in 5,460,000
Hand/wrist	0.003	1 in 5,460,000
Knee	0.020	1 in 820,000
Leg	0.004	1 in 410,000
Foot and ankle	0.004	1 in 410,000

**TABLE 2. CT SCANNING PROCEDURES**

Examination	Effective dose per examination (mSv)	Risk estimate (fatal cancer)
Brain	2.3	1 in 7000
Facial bones	1.0	1 in 16,000
Chest	4.1	1 in 4000
Abdomen	7.6	1 in 2200
Pelvis	4.5	1 in 3600
Cervical spine	4.4	1 in 3700
Thoracolumbar spine	11.7	1 in 1400
Lumbar spine	5.2	1 in 3200
Leg length	1.0	1 in 16,000
Shoulder	2.0	1 in 8200
Elbow	0.5	1 in 33,000
Wrist	0.5	1 in 33,000
Knee	0.5	1 in 33,000
Foot and ankle	0.5	1 in 33,000

### BONE SCANNING

For a bone scan, the effective dose for the same theoretical patient was calculated to be 4.6 mSv (based on 800 MBq of <sup>99m</sup>Tc radioisotope injected intravenously).<sup>12</sup> This effective dose confers a risk estimate of inducing a fatal cancer of one in 3500.<sup>10,12</sup>

\* Effective doses and risk estimates are based on the methodology briefly described above. For a more thorough explanation, the reader is referred to reference 10. Methodology is based on practice in 2003 – the transferability of data to 2012 is discussed in the text (see page 74).

Acknowledgement: Tables 1 and 2 reproduced from reference 10 with permission of Wolters Kluwer Health. Cross TM, Smart RC, Thomson JEM. Exposure to diagnostic ionizing radiation in sports medicine: assessing and monitoring the risk. *Clinical Journal of Sport Medicine* 2003; 13(3): 164-170.

radiosensitivity.<sup>6</sup> The unit of effective dose is the sievert (Sv), often expressed in millisieverts (mSv). As a general rule, the more radio-sensitive tissues are located in the trunk region (gonads, lung, breast, gut, bone marrow and thyroid), and therefore conventional radiography and CT scanning in the trunk region deliver a much greater effective dose than these tests done of the extremities.<sup>6</sup>

The effective dose associated with most diagnostic imaging modalities is in the range of 0.03 to 20 mSv.<sup>7</sup> This dose range may be compared with the annual dose of background radiation, which is about 1.5 mSv in Australia,<sup>8</sup> or with the doses received by the survivors of the two atomic bombs of 1945, which were in the range of 5 mSv to more than 2000 mSv.<sup>9</sup>



Figure. A patient being aligned for a CT scan.

The box on page 73 shows the effective dose for various common investigations performed in sports medicine, which have been estimated for a theoretical patient: Athlete X. Athlete X is an 80 kg male athlete, aged between 20 and 29 years, who plays a contact sport. Such a patient is common in sports medicine practice. Effective dose estimates are shown for conventional radiography (Table 1), CT scans (Table 2) and bone scanning.<sup>10</sup>

Analysis of the effective doses received by Athlete X in Tables 1 and 2 demonstrates some important points:

- CT scanning (particularly in the trunk region) and bone scanning have a significantly higher effective dose than conventional radiography. Although CT scans account for only 11% of the radiological examinations in the USA, CT delivers about 67% of the medical effective dose.<sup>13</sup>
- CT scanning and conventional radiography of the extremities (distant from radiosensitive tissues) are associated with significantly lower effective dose values than investigations in the trunk region.

For a bone scan, the effective dose depends on the activity of the radiopharmaceutical injected intravenously and is independent of the anatomical region studied in the bone scan.

These estimates of effective dose for radiography, CT and bone scans are roughly transferable to adult female patients and paediatric patients, provided that appropriate technical

adjustments are made by the radiographer/nuclear medicine technician performing the test.

It should be appreciated that the methodology discussed in the box is based on practices in 2003. Overall the doses are transferable to 2012, but there have been advances in CT technology that have resulted in reductions in ionising radiation doses and most bone scans performed in 2012 are CT-SPECT studies, which carry a higher effective dose than bone scans performed in 2003.

### WHAT IS THE RISK OF RADIATION-INDUCED INJURY?

At the very low levels of radiation used in diagnostic procedures, radiation-induced injury is expressed in terms of the probability of biological and/or genetic effects.<sup>14</sup> Since the first excess cancers were observed following the atomic bombs of 1945, scientists have worked to establish the relation between dose of radiation and the risk of that exposure.<sup>9,15,16</sup> The ICRP has reviewed the research and concluded that all radiation exposure, even at an extremely low level, carries a risk.<sup>6,11</sup>

Using accepted mathematical modelling, risk estimates for Athlete X have been calculated for common sports medicine investigations (see the box on page 73).<sup>10</sup> The term 'risk estimate' is defined as the risk incurred by the theoretical patient (Athlete X) that he will develop a fatal cancer earlier in life than he would otherwise have developed had he not been exposed to that particular dose of ionising radiation.<sup>10</sup>

These risk estimates are roughly transferable to adult female patients. However, for paediatric patients, the risk estimates are higher than for adults. This is because young people's tissues are more radiosensitive and also because their longer expected life ahead means that they carry the risk for a longer period of time. The ICRP estimates the relative risk to be 1.8 times higher for a child exposed to a particular effective dose of ionising radiation than for a 30-year-old adult.<sup>9</sup>

The risk estimates discussed in the box should be put in perspective by considering the high cancer burden in Australia. According to the Australian Institute of Health and Welfare, cancer accounted for 29% of all deaths in 2007.<sup>17</sup> Therefore, in a random sample of 2200 people it is to be expected that 638 individuals will die of cancer. A CT scan of the abdomen, associated with a risk of fatal cancer of one in 2200, will theoretically increase that number from 638 to 639 cancer deaths.

### UNCERTAINTIES IN THE ESTIMATION OF RISK

Risk estimates are derived from epidemiological studies of survivors of the two atomic bombs of 1945. Complex mathematical modelling by the ICRP has estimated and extrapolated the risk estimates to the very low levels of ionising radiation associated with the diagnostic tests stated above, but some uncertainties remain in this process.<sup>6,9,11,15</sup> Indeed, a lot of

scientists argue many of the DNA breakages caused by very low levels of radiation are repairable and therefore a 'threshold' level of ionising radiation exists, below which there is no risk.<sup>18</sup>

There are no convincing studies in the medical literature that have proven or disproven that individuals exposed to diagnostic radiation from conventional radiography, CT scans or bone scans have developed early fatal cancers or have an increased incidence of birth defects in their offspring.<sup>11</sup> No statistically significant increase in genetic effects have been observed in the children of the atomic bomb survivors of 1945.<sup>19</sup> It is extremely difficult to accurately demonstrate causality between low-dose radiation and the risk of inheritable disease. This is because the natural incidence of genetic anomalies in children is high (one in 44 births). The ICRP estimates that 1 mSv of radiation exposure may confer an increased risk of a genetic anomaly in one in 77,000 births.<sup>11</sup>

### CUMULATIVE EFFECTIVE DOSE AND CUMULATIVE RISK

It should be appreciated that radiation-induced effects are believed by the ICRP to be cumulative – that is, the dose and risk associated with each new exposure can be added to the dose and risk from any previous exposure(s).<sup>11</sup> The cumulative effective dose and cumulative risk for an individual may become quite significant. Such an individual may be an elite athlete who has a long career and suffers many injuries over a period of years, or a patient with a chronic disease such as rheumatoid arthritis or a chronic respiratory disease.<sup>10</sup>

### DOSE REDUCTION STRATEGIES

The ICRP promotes two important dose reduction strategies for minimising patients' exposure to ionising radiation:<sup>6,11</sup>

- justification
- optimisation.

It is ethically right to restrict the use of diagnostic tests that involve ionising radiation to those who will benefit from them. It is incumbent on the treating doctor to balance expected benefits and possible risks for every investigation that is ordered in each patient's particular case. It should be stated clearly that if the result of performing an investigation on a patient will benefit his or her overall health (in the short and longer term) despite the possible theoretical risk of the radiation exposure discussed, then the investigation is justified.<sup>6,11</sup> For example, a whole body bone scan is justified to investigate a patient presenting with multiple joint symptoms suggestive of an inflammatory polyarthropathy or spondyloarthropathy. A CT scan of the lumbar spine is not justified to investigate non-specific mechanical low back pain.

When a patient presents to a radiology practice for an x-ray, CT scan or bone scan, the aim should be to minimise the radiation exposure (as much as is reasonably achievable) without

### FURTHER RESOURCES

The Royal Australian and New Zealand College of Radiologists provides information for health professionals and the general public about various aspects of radiology, including radiation risk.

This is available online – see [www.insideradiology.com.au](http://www.insideradiology.com.au)

compromising the quality of the diagnostic images. This is the principal of optimisation.<sup>6,11</sup> Closer communication (either written or spoken) between the referring doctor and the radiologist/radiographer may result in more limited imaging protocols being adopted and a reduction in the effective dose.<sup>1,2,11,20</sup>

The principles of justification and optimisation are particularly relevant to paediatric patients.<sup>1-4,9-17,21</sup>

Whenever possible, diagnostic imaging procedures that do not use diagnostic radiation (MRI and ultrasound) should be used if they can yield the same (or superior) information. MRI is decreasing in cost and becoming increasingly available to many patients.

### CONCLUSION

The significant overall health benefits to our patients from advances in medical imaging cannot be overstated. However, the small and theoretical risk of a detriment to their health from single or multiple exposures to diagnostic ionising radiation should also be appreciated.

Doctors who care for patients who require sports medicine diagnostic procedures involving ionising radiation (and indeed other interventions that involve exposure to such radiation) should have a working knowledge of the effective doses and risk estimates associated with the more common tests. The concepts of justification and optimisation should be appreciated, particularly when caring for paediatric patients. Investigations that do not involve ionising radiation should be considered whenever possible and affordable. MT

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### REFERENCES

References are included in the pdf version of this article available at [www.medicinetoday.com.au](http://www.medicinetoday.com.au).

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