*Clinical Journal of Sport Medicine,* 13:164–170

# Exposure to Diagnostic Ionizing Radiation in Sports Medicine: Assessing and Monitoring the Risk

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**Objective:** To understand the estimation of both the effective dose and the risk estimate associated with diagnostic ionizing radiation in sports medicine and to appreciate strategies by which this radiation exposure may be minimized.

**Design:** Observational study.

**Setting:** Sports medicine practice.

**Patients:** A theoretical patient, athlete X (male, aged 20–29 years, 80 kg), was used to illustrate how the effective dose and the corresponding risk estimate are calculated for various common sports medicine investigations. Doses and risk estimates for female and pediatric athletes also are discussed.

**Main Outcome Measures:** The effective dose and corresponding risk estimate associated with common sports medicine investigations.

**Results:** Computed tomography and radiographic examinations of the extremities have significantly lower effective doses than investigations about the trunk region. Bone scanning and computed tomography have a significantly higher effective dose than radiography. The risk estimates associated with the low doses used in diagnostic ionizing radiation procedures are extrapolated from epidemiologic studies on exposures to high doses of radiation, and several uncertainties exist in this estimation. Notwithstanding this, the responsible clinician should be aware of both the effective doses and the risk estimates that are associated with the more common investigations. The principles of justification and optimization for these investigations will help guide clinicians to reduce radiation exposure without compromising the management of their patients.

**Conclusions:** Certain investigations have a greater effective dose and risk estimate than others. Elite athletes may potentially undergo numerous investigations in their career. An athlete radiation record may be useful to better manage this exposure.

**Key Words:** athlete radiation record—athlete X—effective dose—justification—optimization—risk estimate

*Clin J Sport Med* 2003;13:164–170.

## INTRODUCTION

Physicians have a number of diagnostic investigations available to help them better define suspected injuries in the athlete patient. Many of these investigations (radiography, computed tomography [CT], and nuclear medicine) involve exposure to ionizing radiation, whereas others do not (ultrasound, magnetic resonance imaging [MRI]).

By far the greatest manmade exposure to ionizing radiation in the general population is from medical diagnostic procedures involving the use of radiation.[1,2] The elite sportsperson nowadays can have a career spanning many years, and the investigation of any injuries he or she sustains may involve numerous exposures to ionizing radiation. Elite sportspersons (particularly those playing collision sports) may require more investigations than the average active person not only because they train and play more and are therefore more likely to suffer an injury but also because the nature of their career does not allow a wait and see approach but, rather, requires an early accurate diagnosis so that treatment can be optimized for an expeditious and safe return to play. Elite sportspersons may therefore be considered to be a population in the general community at risk for increased exposure to diagnostic ionizing radiation.

No discussion exists in the literature that deals with the issue of radiation exposure from diagnostic ionizing radiation in sports medicine. The estimation of the dose of radiation associated with the more common sports medicine investigations, and the estimation of the associated risk to the athlete patient from the radiation, is particularly pertinent to the elite or professional athlete who is more likely to undergo more of these investigations.

The objectives of this paper are to understand (1) radiation dosimetry for the more commonly ordered sports medicine investigations, (2) the estimation of risk (both carcinogenic and genetic) to the athlete patient incurred by exposure to certain levels of ionizing radiation, and (3) how exposure to ionizing radiation may be minimized in our athlete patients and also to propose a model to better monitor that exposure.

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Received for publication May 2002; accepted January 2003.

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### An Introduction to Radiation Dosimetry

The more common sports medicine investigations associated with ionizing radiation involve ionizing radiation in the form of x-rays, from conventional radiography (x-ray) or CT, or gamma rays from radiopharmaceuticals (most commonly $^{99m}$Tc in bone scanning) in nuclear medicine.

X-rays and gamma rays ionize atoms and molecules in human tissues through the deposition of energy.[3] (This ionization is the first step in a series of events that may lead to a biologic and/or genetic effect.) The absorbed dose is a measure of energy deposited per unit mass and is measured in units of gray (Gy) or milligray (mGy). One gray is equivalent to an energy deposition of 1 J/kg. The outdated unit of absorbed dose is the rad, which equals 0.01 Gy.[1]

In order to better quantify the risks from ionizing radiation, the effective dose has been defined by the International Commission on Radiological Protection (ICRP).[1] The effective dose takes into account the absorbed dose received by each irradiated organ and the organ's relative radiosensitivity.[1] The unit of effective dose is the sievert (Sv). The more radiosensitive tissues are the gonads, bone marrow, lung, breast, and gut. As a general rule, the more radiosensitive tissues are located in the trunk, and, therefore, investigations (radiography and CT) in the trunk region carry a much greater effective dose than investigations of the extremities. It should be noted that effective dose is an estimate of the whole body dose that would be required to produce the same detriment as the partial body dose that was actually delivered in the localized radiologic procedure.[1] Effective dose is useful because it allows comparison of radiologic dose with other types of radiation exposure, such as background radiation.

In a bone scan, a radiopharmaceutical is injected intravenously and is subsequently distributed throughout the body. The effective dose in this case is determined by the activity (measured in becquerels [Bq]) of the radiopharmaceutical injected, the pharmacokinetics of the radiopharmaceutical, and certain patient-specific factors, such as age, weight, sex, and pathophysiology.[4,5]

The effective dose associated with most diagnostic imaging modalities is in the range of 0.03 to 20 mSv.[6] This may be compared with the annual dose from natural background radiation (mainly in the form of cosmic rays) in Australia of about 1.5 mSv[7] or with the doses received by the survivors of the 2 atomic bombs of 1945, which were in the range of 5 mSv to greater than 2 Sv.[8]

## MATERIALS AND METHODS

### Estimating Effective Doses for Common Sports Medicine Investigations

In order to best achieve our stated objectives, we chose the paradigm of using a theoretical patient, athlete X. Athlete X is to be considered a male athlete aged 20 to 29 years involved in a collision sport. Such a patient is common in sports medicine practice. To make the estimation of effective dose for athlete X even more transferable to common sports medicine practice, we estimated effective doses for athlete X if he were to attend a certain busy metropolitan radiology practice in Sydney, Australia (this radiology practice will not be specifically identified), using the machines and imaging protocols in use at that practice.

We collaborated to determine what were the more commonly ordered investigations in sports medicine associated with exposure to ionizing radiation (including radiographs, CT scans, and bone scans). An estimate of the effective dose for each imaging modality was made after considering certain variables.

#### *Patient Population*

We chose the paradigm that the treating physician was the team physician for a male team involved in a collision sport (players aged 20–29 years). The theoretical athlete described is referred to as athlete X.

#### *Plain Film Radiology*

Radiation doses from plain film radiology are affected by the exposure factors used (milliampere seconds, kilo voltage), the size of the patient, distance of the x-ray tube, "speed" of the image receptor, and the image preferences of individual practitioners. The technique factors for athlete X were based on those that would be used for such a patient at the radiology practice mentioned previously. Entrance surface doses were calculated using these exposure factors with the computer code XCOMP5R.[9] Organ and effective doses were evaluated from these entrance surface doses using the Monte Carlo methods developed by the National Radiological Protection Board.[10,11] Monte Carlo techniques involve a computer simulation of the interaction of the x-rays with the human body, which takes into account patient, machine, and technique factors and which enables the radiation dose to each organ of the body to be calculated. The organ doses are then combined to calculate the effective dose.

#### *Computed Tomography*

In addition to the technique factors for plain film radiology, the absorbed dose in CT is affected by variables specific to axial imaging (the number of slices imaged, the slice width, and the couch increment). The radiographer and/or radiologist select these variables for each patient based on the indication for the test and also the patient's size/weight and sex. Radiation doses from CT scans were estimated on the bases of typical technique factors used at the radiology practice with a Sytec 2000i machine (General Electric Medical Systems, Milwaukee, WI). The organ doses and effective doses were calculated using the methods developed by the National Radiological Protection Board.[12]

#### *Nuclear Medicine*

The most commonly used activity of $^{99m}$Tc-HDP for bone scans in Australia was taken from the 1998 National Survey.[13] The effective dose was calculated using data from ICRP Publication 80.[4] The reader is referred to this document for more details. Using this methodology, the effective dose from a bone scan for athlete X is calculated to be 4.6 mSv if 800 MBq of $^{99m}$Tc-HDP (the standard activity for an 80-kg man) is injected intravenously. Although the standard activity injected would be increased for a heavier athlete or decreased for a lighter athlete, there is minimal change in the estimate of effective dose.

### Estimating Risk Associated With Ionizing Radiation

What is the risk of radiation-induced injury and how is it estimated? At the levels of radiation used in diagnostic procedures, radiation-induced injury is expressed in terms of the probability of biologic (eg, carcinogenesis) and/or genetic effects (eg, chromosomal aberrations).[1] For a comprehensive discussion of the medical effects of ionizing radiation, the reader is referred to the text by Mettler and Upton.[14]

The ICRP[1] refers to the "detriment" from low-dose radiation, which includes (1) the risk of induction of a fatal cancer, (2) the risk of induction of a nonfatal cancer, and (3) the risk of induction of a genetic disease. Since the first excess cancers were observed following the explosion of the atomic bombs in Japan, scientists and epidemiologists have worked hard to establish the relation between dose and the risk of detriment.[8,15,16] The data are generally consistent, with a linear response for doses greater than 100 mSv. However, the sample size of the study was not large enough to show whether a risk, albeit small, persisted down to very low doses. In fact, there are no studies on humans that have had the resolving power to determine what the dose–risk relationship is at the low-dose levels used in medical diagnostic radiology. Several models have been proposed that are based on biologic knowledge (breaking of DNA strands), animal studies, and statistical processes. Some models propose that at low doses the body can repair the DNA, and that there is a threshold dose below which there is no risk. The most conservative approach is to propose that the risk is strictly related to the number of DNA breaks, and that the risk at low doses can be obtained by a linear extrapolation of the high-dose data (linear no-threshold hypothesis).

An alternative proposition that multiple breaks of a DNA strand are needed to result in detriment leads to a model in which the risk is proportional to the square of the dose (linear–quadratic dose response model). This model gives the risks at low doses that are less than those obtained by a simple linear extrapolation of the high-dose data.

The ICRP[1] reviewed the published data and recommended a "linear no-threshold hypothesis" for the relationship between risk and dose. For high doses, the gradient of the relationship (nominal probability coefficient) was determined by fitting a line through the high-dose data (>200 mSv). At low doses, which are relevant to occupational exposure and diagnostic medical exposures, the ICRP recognized the validity of biologic arguments and animal studies and recommended a gradient (nominal probability coefficient) that is half that obtained for high doses. Radiation protection and regulatory bodies throughout the world have accepted these recommendations.

The nominal probability coefficients for each of the radiation-induced effects are given in Table 1. Table 2 shows risk estimates for 1 aspect of the "detriment"—that is, the risk of inducing a fatal cancer. Note that the probability coefficients and risk estimates correspond to an exposure of 1 Sv (1000 mSv).

## RESULTS

Using the methodology described, Tables 3 and 4 report the estimated effective dose and risk estimates for some of the more common sports medicine radiographic and CT procedures, respectively, for athlete X. The risk estimates are derived from the nominal probability coefficients defined by the ICRP.[1] The risk estimates in Tables 3 and 4 refer specifically to the risk of induction of a fatal cancer in athlete X for the corresponding effective dose for each imaging modality.

The effective dose in bone scanning, as described previously, depends on the activity of the radiopharmaceutical injected intravenously and is independent of the anatomic region studied. The effective dose for athlete X was calculated to be 4.6 mSv (risk of induced fatal cancer, 1 in 3500).

## DISCUSSION

Analysis of the effective doses received by athlete X demonstrates several significant principles: (1) bone scanning and CT (particularly in the trunk region) have a significantly higher effective dose than x-ray; and (2) CT and radiographic examinations of the extremities (distant from radiosensitive tissues) are associated with significantly lower effective dose values than investigations in the trunk region.

In our estimations of the effective dose and risk for the aforementioned investigations, we have chosen athlete X to serve as a broad guide for physicians to help them estimate radiation doses and risk when ordering the more

**TABLE 1.** *Nominal Probability Coefficients for Stochastic Radiation Effects (Those for Which the Probability of the Effect Occurring Is a Function of the Radiation Dose Received)[1] for Low Doses and/or Dose Rates*

| Exposed Population | Probability of the Effect per Sievert | | | |
|---|---|---|---|---|
| | Fatal Cancer | Nonfatal Cancer | Severe Hereditary Effects | Total |
| Adult workers | 1 in 25 ($4 \times 10^{-2}$) | 1 in 125 ($0.8 \times 10^{-2}$) | 1 in 125 $0.8 \times 10^{-2}$) | 1 in 18 ($5.6 \times 10^{-2}$) |
| Whole population | 1 in 20 ($5 \times 10^{-2}$) | 1 in 100 ($1 \times 10^{-2}$) | 1 in 77 ($1.3 \times 10^{-2}$) | 1 in 13.5 ($7.3 \times 10^{-2}$) |

Adult worker population age range, 25 to 64 years (mean, 45 years).

**TABLE 2.** *Estimates of Radiation-Induced Fatal Cancer Risks According to Sex and Age at Exposure for Low Doses and/or Dose Rates (Derived from Estimates in the United Kingdom Population)*[1,7]

| Age at Exposure, y | Probability of a Fatal Cancer per Sievert | |
|---|---|---|
| | Male | Female |
| 0–9 | 1 in 10 | 1 in 8 |
| 10–19 | 1 in 11 | 1 in 9 |
| 20–29 | 1 in 16 | 1 in 14 |
| 30–39 | 1 in 23 | 1 in 22 |
| 40–49 | 1 in 24 | 1 in 24 |
| 50–59 | 1 in 24 | 1 in 26 |
| 60–69 | 1 in 30 | 1 in 34 |
| 70–79 | 1 in 59 | 1 in 62 |
| 80+ | 1 in 125 | 1 in 143 |
| Population weighted average | 1 in 17 | 1 in 17 |

common sports medicine investigations. How do we estimate doses and risk for the younger athlete or the female athlete?

For pediatric patients, the risk estimates (Table 2) are higher than for adults.[17] The reason for this is that young patients' tissues are more radiosensitive and their longer life expectancy means that they carry the risk for a longer period of time. The most recent report on atomic bomb survivors estimates the increase in lifetime risk per sievert for solid cancers for children to be 1.8 times higher than that for individuals exposed at age 30.[8] There may also be an increase in the effective dose for children if technique factors are not appropriately adjusted. For example, Ware et al[18] found that for children younger than 10 years undergoing abdominal CT, the increase in effective dose may be as much as 50%, and the increase in risk may be even greater. The markedly increased effective dose from CT in the pediatric population also was noted by Brenner et al.[19] These considerations are particularly important to those physicians caring for pediatric athletes (eg, gymnasts, ballerinas, and so on).

**TABLE 3.** *Effective Dose and Risk Estimate (Odds) for Some Common Sports Medicine Radiographic Procedures (Male Aged 20 to 29 Years, 80 kg)*

| 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 4.** *Effective Dose and Risk Estimates for Some Common Sports Medicine Computed Tomography Scanning Procedures (Male Aged 20 to 29 Years, 80 kg)*

| 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 |

For adult women, the tissue weighting factors are the same as for men for all tissues, except the breast. The lower body weight of most female athletes, when compared with their male colleagues, would result in higher effective doses for most procedures, unless the technical factors are scaled for different body sizes. Special consideration of pregnancy in female patients is of paramount concern, as the fetus is particularly sensitive to ionizing radiation.[20]

### Uncertainties in the Estimation of Risk

We have described how risk coefficients have been derived from epidemiologic studies of survivors of the 2 atomic bombs of 1945, and it is worthwhile at this point to discuss some of the uncertainties in this process. There is still considerable uncertainty regarding the methods and validity of extrapolating risks from studies on high-dose exposure.[1,21–23] We must also consider the alternate hypothesis that there is no risk up to a certain dose and that the risk increases above this threshold.[24] Several recent studies have investigated the cancer risk in patients who have undergone diagnostic x-ray procedures.[25–27] These studies on low-dose exposure are more transferable to the imaging modalities we have considered. However, the evidence to show causality between irradiation and induction of cancer in these studies is largely unconvincing. For example, the study by Boice et al[25] demonstrates a trend in the induction of multiple myeloma from multiple x-ray procedures, but this has not been substantiated by other studies.[28,29] Additional studies involving very large numbers of patients are required to detect and quantify the possible low levels of risk at these low doses.

For radiation protection purposes, the model and risk factors given by the ICRP[1] generally have been accepted. However, even within this model, a recent survey of these sources of uncertainty puts the 95% confidence limits on the overall risk coefficient at between 1.5 ×

$10^{-2}$ and $8.2 \times 10^{-2}$ fatal cancers per sievert (1 in 66 to 1 in 12 per sievert) in a population of all ages.[23]

It is equally difficult to accurately demonstrate causality between low-dose radiation and risk of serious hereditary disease. The ICRP estimates that 80% of the radiation-induced effects are due to dominant and X-linked mutations. Of these, 15% occur in the first 2 generations. The recessive mutations induced produce little effect in the first few generations descended from the irradiated individual but make a contribution to the pool of genetic damage in subsequent generations.[1] The ICRP[1] estimated a probability of severe hereditary effects in the first 2 generations of 1.0% per sievert (1 in 100) compared with the prevalence of naturally occurring genetic disorders of 1.6% (1.6 in 100).[1] This risk estimate was based on animal experiments, as no statistically significant genetic effects have been observed in the children of the atomic bomb survivors.[30]

### What Level of Exposure Is Considered Acceptable?

One of the dictums of medical practice is the Hippocratic aphorism *Primum non nocere* (First do no harm). Diagnostic radiation, like other medical practices, is associated with a risk to the patient. In this case, there is a risk of a radiation-induced cancer and/or genetic disorder. The physician ordering the test is responsible for assessing the potential benefit to the overall health of the patient from performing the test versus the potential risks. This benefit–risk equation will then assist the physician in the selection of the most appropriate management approach for the patient.

The ICRP has recommendations for the maximum level of radiation exposure per year, excluding medical exposures. This value is 1 mSv per year for the general population and 20 mSv per year for radiation workers (radiographers, radiologists, and so forth), although the value must be kept as low as reasonably achievable.[1] Radiation workers wear personal radiation monitors that record their exposure to radiation in the workplace, and this typically is assessed at 3 monthly intervals.

Medical exposures are specifically excluded from these dose limits, as the patient is expected to receive diagnostic information from the study, the benefits of which are required to markedly outweigh any detriment from the radiation exposure. This point deserves particular attention, as it refers to the benefit side of the risk–benefit equation when considering a particular investigation. The ICRP essentially has not mandated maximum exposure levels for medical exposures on the basis that if an investigation is clinically justified it will benefit the "overall health" of the individual to a far greater degree than any possible health risk from the radiation exposure. This is the principle of justification (as discussed later), which is emphasized by the ICRP.[1]

### Cumulative Effective Dose

It should be appreciated that radiation-induced effects are believed to be cumulative. In other words, the risk associated with each radiation exposure is added to the risk from any previous exposure. This concept may be defined as the *cumulative effective dose* for an individual. The cumulative effective dose for an elite athlete may, in some circumstances, become relatively significant, particularly if the athlete has a long career and is troubled by numerous injuries. Such athletes may include gymnasts and professional football players. For example, using the methodology described, the cumulative effective dose for a 28-year-old male gymnast who retires after an 18-year career may amount to 140 mSv. This equates to a risk estimate of inducing a fatal cancer of 1 in 117, assuming the linear no-threshold hypothesis. Another common sports medicine scenario may involve a 20-year-old male professional football player who has undergone numerous investigations (radiographs, CT scans, bone scans) over a 2-year period for various injuries, amounting to a cumulative effective dose of 30 mSv. This exposure equates to a risk estimate of 1 in 550, once again assuming a linear no-threshold hypothesis.

From the 2 aforementioned hypothetical scenarios, it can be appreciated that the cumulative effective dose is an important consideration. This is especially the case if the athlete is young when he or she starts his or her career. Some athletes have long careers and may be injured on multiple occasions. A gymnast or a professional football player may be such a higher-risk athlete that he or she accrues a higher cumulative effective dose. These athletes in particular require vigilance on the part of their treating physician as to what investigation is indicated if at all.

Are there any strategies the physician can consider in an effort to minimize the effective dose from an investigation and therefore help to minimize the cumulative effective dose?

## Minimizing the Exposure in Sports Diagnostic Radiology

The ICRP[1] discusses 2 very important principles, or, rather, dose-reduction strategies, in the minimization of radiation exposure to patients: (1) justification and (2) optimization. The principal concern in radiologic protection is the reduction of unnecessary exposures by requiring adequate clinical justification and optimization for every investigation.

The principle of *justification* refers to the clinical justification for an investigation and requires judgment from both the referring practitioner and the imaging specialist. It is ethically desirable to restrict the use of diagnostic radiation to only those who will benefit from it. Balancing the expected benefits and the possible risks for every investigation in each patient's case is the physician's responsibility. In this report, we have attempted to inform physicians about the risk side of the equation. The evaluation of the health benefit from ordering an investigation is the treating physician's interpretation of each patient's particular condition and is essentially subjective. The complex issues of patient consent in this area are complicated by the decided lack of objectivity in quantifying the benefit and also, as we have described, the uncertainties in estimating the risk; these issues are beyond the scope of this discussion. However, as in other areas of clinical practice, informed consent may become an issue in diagnostic radiology.

It should be reiterated that if the result of performing an investigation on an athlete will benefit his or her overall health (both in the short and the long term), despite the possible radiation risk associated with the investigation, the investigation is justified. For example, if an occult stress fracture of the lumbar spine is suspected clinically in athlete X, a bone scan may well be indicated, most likely followed by a CT scan (limited, reverse gantry). The benefit of diagnosing or excluding such an injury in a contact sportsman clearly outweighs the estimate of risk associated with the radiation exposure.

*Optimization* refers to minimizing aspects of dosimetry that are related to machine and technique factor variables. The aim is to reduce the irradiation of the patient to as low as possible without compromising the quality of the diagnostic images. Several codes of practice[31–33] and protocols have been published in recent years with the aim of reducing the variation in radiation exposure for the same procedures that had been observed between centers.

Several authors[34,35] have commented on how closer communication (either written or spoken) between the referring physician and the radiologist may result in more limited imaging protocols being adopted (eg, fewer slices on CT) for the particular patient, with a resultant reduction in effective dose. This approach is particularly relevant to pediatric patients (eg, a 10-year-old gymnast).[36,37] It should be noted that although CT scans account for only 11% of radiologic examinations in the United States, CT delivers about 67% of the medical effective dose.[38]

Optimization should ensure that practitioners are knowledgeable about typical patient doses that are received in each type of radiologic examination and about the factors that affect these doses. By understanding the factors that affect patient doses and by maintaining close communication with the radiologist, practitioners can help keep doses as low as possible while still obtaining quality diagnostic images.

### Role of Magnetic Resonance Imaging and Ultrasound

Whenever possible, diagnostic procedures that do not use ionizing radiation (MRI and ultrasound) should be used if they can yield the same or, in many instances, enhanced information. Over the last 10 to 15 years, the superior value of MRI in the precise diagnosis of certain sports medicine conditions has been realized. However, despite the unequivocal evidence for the benefits of MRI, in many countries it remains underused, largely because of its high cost for many individuals or sporting organizations.[39]

### Athlete Radiation Record

Throughout the course of their careers, the higher-risk athletes described previously may be managed by numerous physicians who may be unaware of what investigations have been performed in the past. The athlete may have lost or forgotten information regarding previous investigations. It is therefore reasonable to expect that some investigations may be inadvertently repeated, and that the current physician may be unaware of multiple past investigations, many of which may have been associated with ionizing radiation.

Having identified elite athletes as potentially a high-risk group in the community for exposure to ionizing radiation, in addition to implementing the dose-reduction strategies already mentioned, it would be prudent to monitor their exposure on a yearly basis by means of a record or log book maintained by their treating physician (usually a sports physician). This athlete radiation record, like a medication record or immunization record, could easily be added to the front of the patient's medical file.

The errors in the estimation of an effective dose for each investigation will undoubtedly cause concern; however, it should be emphasized that this record cannot purport to be a precise assessment but, rather, should be used as a guide. The effective dose for each common sports medicine investigation calculated for athlete X could be used as a guide, recognizing that the doses relate to male athletes aged 20 to 29 years with the technique/machine factors described.

Elite athletes may have careers spanning many years and may have many consultations with numerous physicians. An athlete radiation record located in the front of the medical notes will serve to inform the treating physician what tests have been done and the associated estimated effective dose from each test and therefore will enable the physician to better monitor and manage the athlete's cumulative effective dose.

## CONCLUSIONS

Elite athletes are a population in the community that may undergo numerous diagnostic medical investigations for the injuries possibly sustained. Many of these investigations are associated with ionizing radiation, whereas others are not. The physician caring for these athletes should not only have a working knowledge of the radiation dosimetry associated with the more common investigations but also should appreciate the risk associated with this exposure. In addition, the physician should appreciate the concepts of optimization and justification, particularly when caring for the pediatric athlete. Investigations that do not involve ionizing radiation should be considered when indicated.

We propose that elite athletes have a record (athlete radiation record) of their radiologic investigations in their medical notes and that it be transferred between treating physicians and/or institutions so that their exposure to ionizing radiation may be monitored and better managed.

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